National Nuclear Security Administration

Electrical Systems and Safety Oversight

Qualification Standard

Reference Guide

DECEMBER 2009

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Acronyms

A (or amp)	ampere
AC	alternating current
AHJ	authority having jurisdiction
ANSI	American National Standards Institute
AOO	anticipated operational occurrence
AOP	abnormal operating procedure
ASTM	American Society for Testing and Materials
AWG	American wire gauge
C	capacitance
cal	calorie
CAP	corrective action program
CAT	category
CD	critical decision
CEMF	counter-electromotive force
CFR	Code of Federal Regulations
CM	configuration management
cm	centimeter
CSI	current source inverter
CSO	cognizant secretarial office
CT	current transformer
DBE	design basis event
DC	direct current
DIS	design information summary
DMG	directives management group
DNFSB	Defense Nuclear Facilities Safety Board
DOE	United States Department of Energy
DOE-HDBK	DOE handbook
DOE-STD	DOE standard
DR	design reconstitution
DSA	documented safety analysis
E&CF	events and causal factor
EMI	electromagnetic interference
EMF	electromotive force
EOP	emergency operating procedure
EPG	emergency procedure guideline
ESD	electrostatic discharge
ES&H	environment, safety, and health
ft	foot or feet
FAQS	Functional Area Qualification Standard
FR	facility representative
G-GC	ground-check conductor (cable type)
GFCI	ground-fault circuit interrupter

Acronyms

GFPE	ground-fault protection for equipment
GOCO	government-owned, contractor-operated
H	Henry
HELB	high energy line break
hp	horsepower
HVAC	heating, ventilating, and air conditioning
Hz	hertz
I&C	instrumentation and control
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
in.	inch or inches
ISA	Instrumentation, Systems, and Automation Society
ISMS	integrated safety management system
J	joule
kA	kiloampere
kHz	kilohertz
kN	kilonewton
kV	kilovolt
kVA	kilovolt-ampere
kW	kilowatt
KSA	knowledge, skill or ability
L	inductance
LBD	licensing basis documentation
LOCA	loss of coolant accident
LOTO	lockout/tagout
LPS	lightning protection system
LPSO	lead Program Secretarial Office
LVPCB	low-voltage power circuit breaker
m	meter
MCA	material condition and aging
MCCs	motor control centers
MCL	maximum contaminant level
MHz	megahertz
mm	millimeter
MORT	management oversight risk tree
MOV	motor-operated valve
MV	medium voltage
MVA	megavolt-ampere
MW	megawatt electrical
MWt	megawatt thermal
N	newton
NEC	National Electrical Code

Acronyms

NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
nm	nanometer
NM	nonmetallic (cable type)
NMC	nonmetallic, corrosion-resistant (cable type)
NNSA	National Nuclear Security Administration
NPH	natural phenomena hazard
NRTL	nationally recognized testing laboratory
OSH	occupational safety and health
OSH Act	Occupational Safety and Health Act
OSHA	Occupational Safety and Health Administration
P	usable (true) power
PC	performance category
PCB	polychlorinated biphenyl
PM	preventive maintenance
PPE	personal protective equipment
PSO	program secretarial office
PT	potential transformer
PWM	pulsewidth modulation
pu	per unit
QA	quality assurance
QAP	quality assurance program
QC	quality control
R	resistance
R-C-L	resistance-capacitance-inductance
RCM	reliability-centered maintenance
RF	radio frequency
RFI	radio frequency interference
RMS	root-mean-square
rpm or RPM	revolutions per minute
s or sec	second or seconds (time)
S	apparent power
SAR	safety analysis report
SC	safety class
SER	safety evaluation report
SFC	single-failure criterion
SQA	software quality assurance
SSC	structure, system, and component
SS	safety significant
SSO	safety system oversight
TQP	technical qualification program

Acronyms

TSRs	technical safety requirements
TYSP	ten-year site plan
UL	Underwriters Laboratories
UPS	uninterruptible power supply
USQ	unreviewed safety question
V	voltage or the unit volt
VA	volt-ampere
VAM	valve actuator motor
VAR	volt-ampere-reactive
VFD	variable-frequency drive
VRLA	valve-regulated lead-acid (battery)
VSI	voltage source inverter
W	watt
X	reactance
X_C	capacitive reactance
X_L	inductive reactance
X/R	ratio of reactance to resistance in a transformer
Z	total reactive impedance
Ω	ohm
Σ	summation
θ	phase angle
ω	angular velocity

PURPOSE

The purpose of this reference guide is to provide a document that contains the information required for a Department of Energy (DOE)/National Nuclear Security Administration (NNSA) technical employee to successfully complete the Electrical Systems and Safety Oversight Functional Area Qualification Standard (FAQS). Information essential to meeting the qualification requirements is provided; however, some competency statements require extensive knowledge or skill development. Reproducing all the required information for those statements in this document is not practical. In those instances, the candidate is directed to additional resources.

SCOPE

This reference guide addresses the competency statements in the August 2007 edition of DOE-STD-1170-2007, *Electrical Systems and Safety Oversight Functional Area Qualification Standard*. The qualification standard contains 51 competency statements within 7 sections.

Please direct your questions or comments related to this document to the NNSA Learning and Career Development Department.

PREFACE

Competency statements and supporting knowledge, skill or ability (KSA) statements from the qualification standard are shown in contrasting bold type, while the corresponding information associated with each statement is provided below it.

A comprehensive list of acronyms and abbreviations is found at the beginning of this document. It is recommended that the candidate review the list prior to proceeding with the competencies, as the acronyms and abbreviations may not be further defined within the text unless special emphasis is required.

The competencies and supporting KSA statements are taken directly from the FAQS. Most corrections to spelling, punctuation, and grammar have been made without remark, and all document-related titles, which variously appear in roman or italic type or set within quotation marks, have been changed to plain text, also mostly without remark. Capitalized terms are found as such in the qualification standard and remain so in this reference guide. When they are needed for clarification, explanations are enclosed in brackets.

Every effort has been made to provide the most current information and references available as of December 2009. However, the candidate is advised to verify the applicability of the information provided. It is recognized that some personnel may oversee facilities that utilize predecessor documents to those identified. In those cases, such documents should be included in local qualification standards via the Technical Qualification Program (TQP).

In the cases where information about an FAQS topic in a competency or KSA statement is not available in the newest edition of a standard (consensus or industry), an older version is referenced. These references are noted in the text and in the bibliography.

Unless noted otherwise, a specific reference in a competency statement to a regulation, directive, or other industry or consensus standard is the source of the discussion text. Some of the directives referred to have been archived.

In DOE-STD-1170-2007, the letters E and V represent volts and voltage. This reference guide uses only the letter V.

Much of the text in this reference guide is taken directly from the four volumes of the electrical science guides in the DOE Fundamentals Handbooks series. While efforts were made to ensure the accuracy of the content of the manuals, the QC process has continued, and inaccuracies are occasionally identified.

GENERAL TECHNICAL COMPETENCIES

I. KNOWLEDGE OF ELECTRICAL THEORY & EQUIPMENT

1. Electrical personnel shall demonstrate a working level knowledge of electrical and circuit theory, theorems, terminology, laws, and analysis.

a. Explain the basic law of electrostatics.

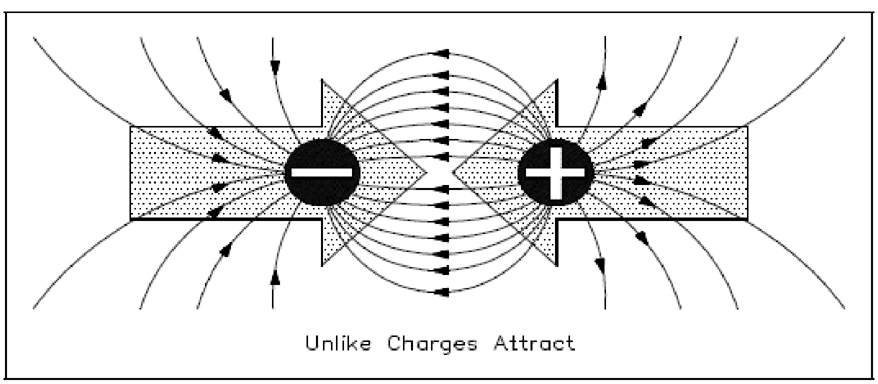
The following is taken from DOE-HDBK-1011/1-92

The First Law of Electrostatics

The first law of electrostatics (sometimes referred to as the law of electrical charges) states that a negative charge of the electron is equal to, but opposite, the positive charge of the proton. These charges are referred to as *electrostatic charges*.

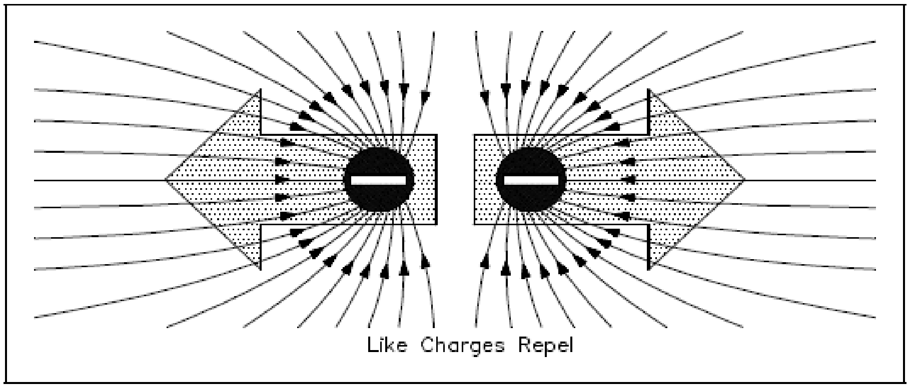
In nature unlike charges (such as electrons and protons) attract each other, and like charges repel each other. Some atoms can lose electrons and others can gain electrons; thus, it is possible to transfer electrons from one object to another. When this occurs, the equal distribution of negative and positive charges no longer exists. One object will contain an excess of electrons and become negatively charged, and the other will become deficient in electrons and become positively charged. These objects, which can contain billions of atoms, will then follow the same law of electrostatics as the electron and the proton. The electrons that can move around within an object are said to be *free electrons*. The greater the number of these free electrons an object contains, the greater its negative electric charge. Thus, the electric charge can be used as a measure of electrons.

Charged objects repel or attract each other because of the way magnetic fields act together. This force is present with every charged object. When two objects of opposite charge are brought near one another, the electrostatic field is concentrated in the area between them, as shown in figure 1. The direction of the small arrows shows the direction of the force as it would act upon an electron if it were released into the electric field.



Source: DOE-HDBK-1011/1-92

Figure 1. Electrostatic field between two charges of opposite polarity



Source: DOE-HDBK-1011/1-92

Figure 2. Electrostatic field between two charges of like polarity

When two objects of like charge are brought near one another, the lines of force repel each other, as shown in figure 2.

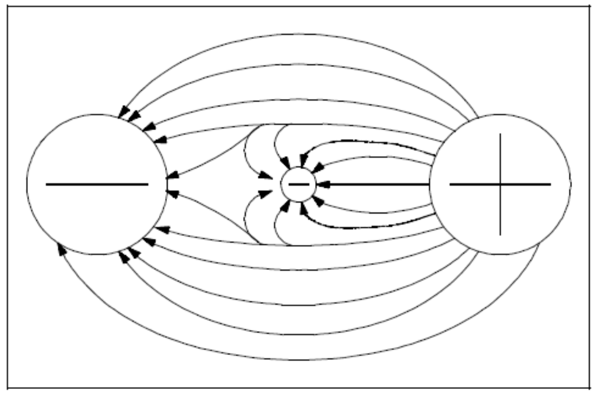
The strength of the attraction or of the repulsion force depends upon two factors: (1) the amount of charge on each object, and (2) the distance between the objects. The greater the charge on the objects, the greater is the electrostatic field. The greater the distance between the objects, the weaker is the electrostatic field between them, and vice versa. This leads us to the law of electrostatic attraction, commonly referred to as *Coulomb's law of electrostatic charges*, which states that the force of electrostatic attraction, or repulsion, is directly proportional to the product of the two charges and inversely proportional to the square of the distance between them, as shown in this equation:

$$F = K \frac{(+q_1)(-q_2)}{d^2}$$

where
d = distance between two particles (meters [m])
F = force of electrostatic attraction or repulsion (newtons [N])
K = constant of proportionality ($\text{coulomb}^2/\text{N-m}^2$)
q_1 = charge of first particle (coulombs)
q_2 = charge of second particle (coulombs)

If q_1 and q_2 are both either positively or negatively charged, the force is repulsive. If q_1 and q_2 are opposite polarity, or charge, the force is attractive.

"Potential difference" is the term used to describe how large the electrostatic force is between two charged objects. If a charged body is placed between two objects with a potential difference, the charged body will try to move in one direction, depending upon the polarity of the object. If an electron is placed between a negatively charged body and a positively charged body, the action due to the potential difference is to push the electron toward the positively charged object. The electron, being negatively charged, will be repelled from the negatively charged object and attracted by the positively charged object, as shown in figure 3.



Source: DOE-HDBK-1011/1-92

Figure 3. Potential difference between two charged objects

Due to the force of the electrostatic field, these electrical charges have the ability to do work by moving another charged particle by attraction and/or repulsion. This ability to do work is called *potential*; therefore, if one charge is different from another, there is a potential difference between them. The sum of the potential differences of all charged particles in the electrostatic field is referred to as *electromotive force* (EMF).

The basic unit of measure of potential difference is the volt, also referred to as *voltage* (V).

b. Define the following terms and their relationship in energized circuits:

- **Resistance**
- **Capacitance**
- **Inductance**
- **Reactance**

Information on resistance, capacitance and inductance is taken from DOE-HDBK-1011/1-92; information on reactance is taken from DOE-HDBK-1011/3-92.

Resistance

Resistance is defined as the opposition to current flow. The amount of opposition to current flow produced by a material depends upon the amount of available free electrons it contains and the types of obstacles the electrons encounter as they attempt to move through the material. Resistance is measured in ohms and is represented by the symbol R in equations. One *ohm* is defined as that amount of resistance that will limit the current in a conductor to one ampere (A or amp) when the potential difference applied to the conductor is one volt. The shorthand notation for ohm is the Greek letter capital omega (Ω). If a voltage is applied to a conductor, current flows. The amount of current flow depends upon the resistance of the conductor. The lower the resistance, the higher is the current flow for a given amount of voltage. The higher the resistance, the lower is the current flow. Resistance of a circuit is equal to the applied voltage divided by the circuit current. The following equation is a mathematical representation of this concept:

$$R \text{ (or } \Omega) = \frac{V}{I}$$

where
I = current (A)
V = voltage
R = resistance (Ω)

Capacitance

In electromagnetism and electronics, capacitance is the ability of a body to hold an electrical charge. Capacitance is also a measure of the amount of electrical energy stored (or separated) for a given electric potential. A common form of energy storage device is a parallel-plate capacitor. In a parallel plate capacitor, capacitance is directly proportional to the surface area of the conductor plates and inversely proportional to the separation distance between the plates. If the charges on the plates are +Q and −Q, and V gives the voltage between the plates, then the capacitance is given by

$$C = \frac{Q}{V}$$

Capacitance is defined as the ability to store an electric charge and is symbolized by the capital letter C. Capacitance, measured in farads, is equal to the amount of charge (Q) that can be stored in a device or capacitor divided by the voltage (V) applied across the device or capacitor plates when the charge was stored. The following equation is the mathematical representation for capacitance:

$$Ic = C\left(\frac{\Delta V}{\Delta t}\right)$$

where
I_c = capacitive or capacitor current
C = capacitance
ΔV= change in voltage
Δt = change in time

Inductance

Inductance is defined as the ability of a coil to store energy, induce a voltage in itself, and oppose changes in current flowing through it. The symbol used to indicate inductance in electrical formulas and equations is a capital L. The units of measurement are called *henries*. The unit henry is abbreviated by the capital letter H. One henry is the amount of inductance (L) that permits one volt to be induced when the current through the coil changes at a rate of one ampere per second.

The quantitative definition of the (self-) inductance of a wire loop in SI units (webers per ampere, known as henries) is

$$L = \frac{N\Phi}{i}$$

where *L* is the inductance, Φ denotes the magnetic flux through the area spanned by the loop, *N* is the number of wire turns, and *i* is the current in amperes.

The following equation is the mathematical representation for the voltage V_L induced in a coil with inductance L. The negative sign indicates that voltage induced opposes the change in current through the coil per unit time (ΔI/Δt):

$$V_L = -L\left(\frac{\Delta I}{\Delta t}\right)$$

Reactance

In an inductive alternating current (AC) circuit, the current is continually changing and is continuously inducing an EMF. Because this EMF opposes the continuous change in the flowing current, its effect is measured in ohms. This opposition of the inductance to the flow of an AC is called *inductive reactance* (X_L).

The following equation is the mathematical representation of the current flowing in a circuit that contains only inductive reactance:

$$I = \frac{V}{X_L}$$

where
I = effective current (A)
X_L = inductive reactance (Ω)
V = effective voltage across the reactance

The value of X_L in any circuit is dependent on the inductance of the circuit and on the rate at which the current is changing through the circuit. This rate of change depends on the frequency of the applied voltage. The following equation is the mathematical representation for X_L:

$$X_L = 2\pi f L$$

where
π = ~3.14
f = frequency (hertz [Hz])
L = inductance (H)

The magnitude of an induced EMF in a circuit depends on how fast the flux that links the circuit is changing.

In considering the relationship between resistance impedance and reactive impedance, the associated equation is used:

$$Z = R + j\,(X_L + X_C)$$

where
Z = total reactive impedance
R = resistance
j = square root of -1
X_L = inductive reactance
X_C = capacitive reactance

The voltage across a circuit that has resistance and reactive impedance would then be as follows:

$$V = I \times Z$$

Capacitive reactance (X_C) is the opposition by a capacitor or a capacitive circuit to the flow of current. The current flowing in a capacitive circuit is directly proportional to the capacitance and to the rate at which the applied voltage is changing. The rate at which the applied voltage is changing is determined by the frequency of the supply; therefore, if the frequency of the capacitance of a given circuit is increased, the current flow will increase. It can also be said that if the frequency or capacitance is increased, the opposition to current flow decreases; therefore, capacitive reactance, which is the opposition to current flow, is inversely proportional to frequency and capacitance. Capacitive reactance is measured in ohms, as is inductive reactance. The following equation is a mathematical representation for capacitive reactance:

$$X_C = \frac{1}{2\pi f C}$$

where
f = frequency (Hz)
π = ~3.14
C = capacitance (farads)

c. Explain the following fundamental laws of circuit analysis:
- **Ohm's Law**
- **Kirchhoff's Law**

The following is taken from DOE-HDBK-1011/1-92.

Ohm's Law

In 1827, Georg Simon Ohm discovered that there was a definite relationship between voltage, current, and resistance in an electrical circuit. Ohm's law defines this relationship and can be stated in three ways.

1. Applied voltage equals circuit current times the circuit resistance. This is represented by the equation:

$$V = I \times R$$

2. Current is equal to the applied voltage divided by the circuit resistance. This is represented by the equation:

$$I = \frac{V}{R}$$

3. Resistance of a circuit is equal to the applied voltage divided by the circuit current:

$$R \text{ or } \Omega = \frac{V}{I}$$

where
I = current
V = voltage
R = resistance (Ω)

Similarly, Ohm's law can be applied for total reactive impedance, and the following equations can be used:

$$V = I \times Z$$

$$I = \frac{V}{Z}$$

and

$$Z = \frac{V}{I}$$

Kirchhoff's Laws

Ohm's law describes the relationship between current, voltage, and resistance. It can be applied to circuits that are relatively simple in nature. However, many circuits are extremely complex and cannot be solved with Ohm's law. These circuits have many power sources and branches that would make the use of Ohm's law impractical or impossible.

Through experimentation in 1857, the German physicist Gustav Kirchhoff developed methods to solve complex circuits. Kirchhoff developed two conclusions, known today as *Kirchhoff's laws*:

Kirchhoff's voltage law: The sum of the voltage drops around a closed loop is equal to the sum of the voltage sources of that loop.

Kirchhoff's current law: The current arriving at any junction point in a circuit is equal to the current leaving that junction.

The voltage law gives the relationship between the voltage drops around any closed loop in a circuit, and the voltage sources in that loop. The total of these two quantities is always equal. In equation form,

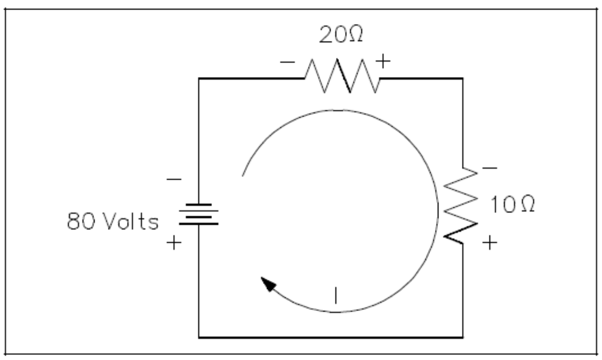
$$V_{source} = V_1 + V_2 + V_3 + \text{etc.} = I_1 R_1 + I_2 R_2 + I_3 R_3 + \text{etc.}$$

$$\Sigma V_{source} = \Sigma IR$$

where the symbol Σ (the Greek letter sigma) means "the sum of."

For a simple series circuit, Kirchhoff's voltage law corresponds to Ohm's law.

Find the current in the circuit shown in figure 4.



Source: DOE-HDBK-1011/1-92

Figure 4. Using Kirchhoff's voltage law to find current with one source

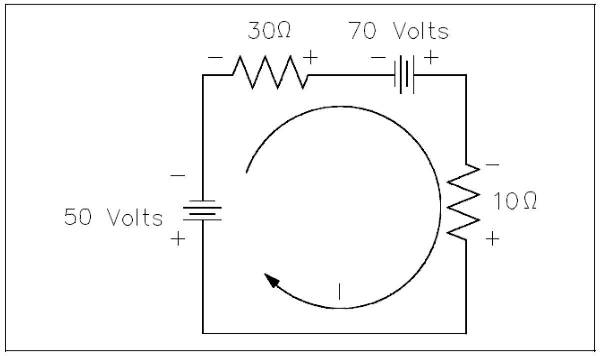
Use the following equation to apply Kirchhoff's voltage law:

$$\Sigma V_{source} = \Sigma IR$$
$$80 = 20(I) + 10(I)$$
$$80 = 30(I)$$
$$I = 80/30 = 2.66 \text{ amperes}$$

In the problem above, the direction of current flow was known before solving the problem.

When there is more than one voltage source, the direction of current flow may or may not be known. In such a case, a direction of current flow must be assumed in the beginning of the problem. All the sources that would aid the current in the assumed direction of current flow are then positive, and all that would oppose current flow are negative. If the assumed direction is correct, the answer will be positive. The answer would be negative if the direction assumed was wrong. In any case, the correct magnitude will be attained.

For example, what is the current flow in figure 5? Assume that the current is flowing in the direction shown.



Source: DOE-HDBK-1011/1-92

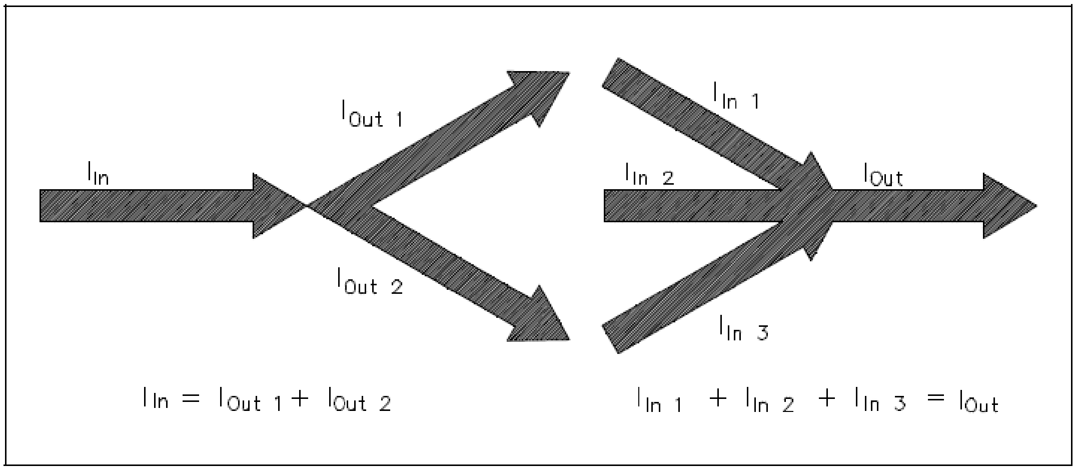
Figure 5. Using Kirchhoff's voltage law to find current with multiple battery sources

Using Kirchhoff's voltage law:

$$\Sigma V_{source} = \Sigma IR$$
$$50 - 70 = 30I + 10I$$
$$-20 = 40I$$
$$I = -20/40$$
$$I = -0.5$$

The result is negative. The current is actually 0.5 ampere in the opposite direction to that of the assumed direction.

Kirchhoff's second law (illustrated in figure 6), called his current law, states: "At any junction point in a circuit, the current arriving is equal to the current leaving." Thus, if 15 amperes of current arrive at a junction that has two paths leading away from it, 15 amperes will divide between the two branches, but a total of 15 amperes must leave the junction. From Kirchhoff's current law, the sum of the branch currents is equal to the total current entering the branches, as well as the total current leaving the branches.



Source: DOE-HDBK-1011/1-92

Figure 6. Illustration of Kirchhoff's current law

In equation form, Kirchhoff's current law may be expressed as follows:

$$I_{IN} - I_{OUT} = 0$$
or
$$I_{IN} = I_{OUT}$$

Kirchhoff's laws are powerful tools in solving complex and difficult circuits. Kirchhoff's laws can be related to conservation of energy and charge if we look at a circuit with one load and source. Since all of the power provided from the source is consumed by the load, energy and charge are conserved. Since voltage and current can be related to energy and charge, then Kirchhoff's laws are only restating the laws governing energy and charge conservation.

d. Explain the use of the following theorems in network analysis and describe their application in circuit reduction techniques:

- **Thevenin's Theorem**
- **Norton's Theorem**
- **Maximum Power Transfer Theorem**
- **Superposition Theorem**

The following is taken from *All About Circuits.com* vol. I, ch 10.

Thevenin's Theorem

Thevenin's Theorem states that it is possible to simplify any linear circuit, no matter how complex, to an equivalent circuit with just a single voltage source and **series** resistance connected to a load. The qualification of linear means that all the underlying equations must be linear (no exponents or roots). Thevenin's Theorem is the basis of the Thevenin Equivalent Circuit, which is especially useful in analyzing power systems and other circuits where one particular resistor in the circuit (called the load resistor) is subject to change, and re-calculation of the circuit is necessary with each trial value of load resistance, to determine voltage across it and current through it.

Norton's Theorem

Norton's Theorem (the basis of the Norton equivalent circuit) states that it is possible to simplify any linear circuit, no matter how complex, to an equivalent circuit with just a single current source and **parallel** resistance connected to a load. Just as with Thevenin's Theorem, the qualification of linear means that all underlying equations must be linear (no exponents or roots). As with the Thevenin equivalent circuit, the only useful information from this analysis is the voltage and current values for the load resistor; the rest of the information is irrelevant to the original circuit. However, the same advantages seen with Thevenin's Theorem apply to Norton's as well: if we wish to analyze load resistor voltage and current over several different values of load resistance, we can use the Norton equivalent circuit again and again, applying nothing more complex than simple parallel circuit analysis to determine what's happening with each trial load.

Maximum Power Transfer Theorem

The Maximum Power Transfer Theorem is not so much a means of analysis as it is an aid to system design. Simply stated, the maximum amount of power will be dissipated by a load resistance when that load resistance is equal to the Thevenin/Norton resistance of the network supplying the power. If the load resistance is lower or higher than the Thevenin/Norton resistance of the source network, its dissipated power will be less than maximum.

This is essentially what is aimed for in radio transmitter design, where the antenna or transmission line impedance is matched to final power amplifier impedance for maximum radio frequency (RF) power output. Impedance, the overall opposition to AC and DC current, is very similar to resistance, and must be equal between source and load for the greatest amount of power to be transferred to the load. A load impedance that is too high will result in low power output. A load impedance that is too low will not only result in low power output, but possibly overheating of the amplifier due to the power dissipated in its internal (Thevenin or Norton) impedance.

Superposition Theorem

The strategy used in the Superposition Theorem is to eliminate all but one source of power within a network at a time, using series/parallel analysis to determine voltage drops (and/or currents) within the modified network for each power source separately. Then, once voltage drops and/or currents have been determined for each power source working separately, the values are all "superimposed" on top of each other (added algebraically) to find the actual voltage drops/currents with all sources active.

It must be noted, though, that the Superposition Theorem works only for circuits that are reducible to series/parallel combinations for each of the power sources at a time (thus, this theorem is useless for analyzing an unbalanced bridge circuit), and it only works where the underlying equations are linear (no mathematical powers or roots). The requisite of linearity means that Superposition Theorem is only applicable for determining voltage and current, not power. Power dissipations, being nonlinear functions, do not algebraically add to an accurate total when only one source is considered at a time. The need for linearity also means this Theorem cannot be applied in circuits where the resistance of a component changes with voltage or current. Hence, networks containing components like lamps (incandescent or gas-discharge) or varistors could not be analyzed.

Another prerequisite for the Superposition Theorem is that all components must be bilateral, meaning that they behave the same with electrons flowing either direction through them. Resistors have no polarity-specific behavior, and so the circuits we've been studying so far all meet this criterion.

The Superposition Theorem finds use in the study of AC circuits, and semiconductor (amplifier) circuits, where sometimes AC is often mixed (superimposed) with DC. Because AC voltage and current equations (Ohm’s Law) are linear just like DC, we can use Superposition to analyze the circuit with just the DC power source, then just the AC power source, combining the results to tell what will happen with both AC and DC sources in effect. For now, though, Superposition will suffice as a break from having to do simultaneous equations to analyze a circuit.

e. Discuss the fundamental relationships in Direct Current (DC) circuits among voltage, current, resistance, and power.

The information for KSAs ‘e’ and ‘f’ is taken from DOE-HDBK-1011/1-92 (in this source Q = charge).

Voltage

Voltage, EMF, or potential difference, is described as the pressure or force that causes electrons to move in a conductor. In electrical formulas and equations, voltage is symbolized with a capital E, while on laboratory equipment or schematic diagrams, voltage is often represented with a capital V. In this guide, voltage will always be represented with a capital V.

Current

Electron current, or amperage, is described as the movement of free electrons through a conductor. In electrical formulas, current is symbolized with a capital I, while in the laboratory or on schematic diagrams, it is common to use a capital A to indicate amps or amperage (amps). In this guide, current will always be represented with a capital I.

Resistance

Now that we have discussed the concepts of voltage and current, we are ready to discuss a third key concept called resistance. Resistance is defined as the opposition to current flow. The amount of opposition to current flow produced by a material depends upon the amount of available free electrons it contains and the types of obstacles the electrons encounter as they attempt to move through the material. Resistance is measured in ohms and is represented by the symbol (R) in equations. One ohm is defined as that amount of resistance that will limit the current in a conductor to one ampere when the potential difference (voltage) applied to the conductor is one volt. The shorthand notation for ohm is the Greek letter capital omega (Ω). If a voltage is applied to a conductor, current flows. The amount of current flow depends upon the resistance of the conductor. The lower the resistance, the higher the current flow for a given amount of voltage. The higher the resistance, the lower the current flow.

Ohm's Law

Ohm's Law is discussed in detail in KSA 'c' of this competency. In summary, it defines the relationship between voltage, current, and resistance in an electrical circuit, and can be represented by the equation:

$$E = I \text{ x } R \text{ or } E = IR$$

where
E = voltage (V)
I = current (A)
R = resistance (Ω)

Power

Electricity is generally used to do some sort of work, such as turning a motor or generating heat. Specifically, *power* is the rate at which work is done, or the rate at which heat is generated. The unit commonly used to specify electric power is the watt. In equations, power is abbreviated with the capital letter P, and watts, the units of measure for power, are abbreviated with the capital letter W. Power is also described as the current (I) in a circuit times the voltage (E) across the circuit. The following equation is a mathematical representation of this concept.

$$P = I \text{ x } E \text{ or } P = IE$$

f. Explain the treatment of inductance and capacitance values in steady-state direct current circuits.

Inductance is defined as the ability of a coil to store energy, induce a voltage in itself, and oppose changes in current flowing through it. The symbol used to indicate inductance in electrical formulas and equations is a capital L. The units of measurement are called henries. The unit henry is abbreviated by using the capital letter H. One henry is the amount of inductance (L) that permits one volt to be induced (VL) when the current through the coil changes at a rate of one ampere per second. The equation below is the mathematical representation of the rate of change in current through a coil per unit time.

$$\left(\frac{\Delta I}{\Delta T}\right)$$

The next equation is the mathematical representation for the voltage VL induced in a coil with inductance L. The negative sign indicates that voltage induced opposes the change in current through the coil per unit time (Δ I/Δ t).

$$V_L = -L\left(\frac{\Delta I}{\Delta T}\right)$$

Capacitance is defined as the ability to store an electric charge and is symbolized by the capital letter C. Capacitance (C), measured in farads, is equal to the amount of charge (Q) that can be stored in a device or capacitor divided by the voltage (E) applied across the device or capacitor plates when the charge was stored. The following equation is the mathematical representation for capacitance.

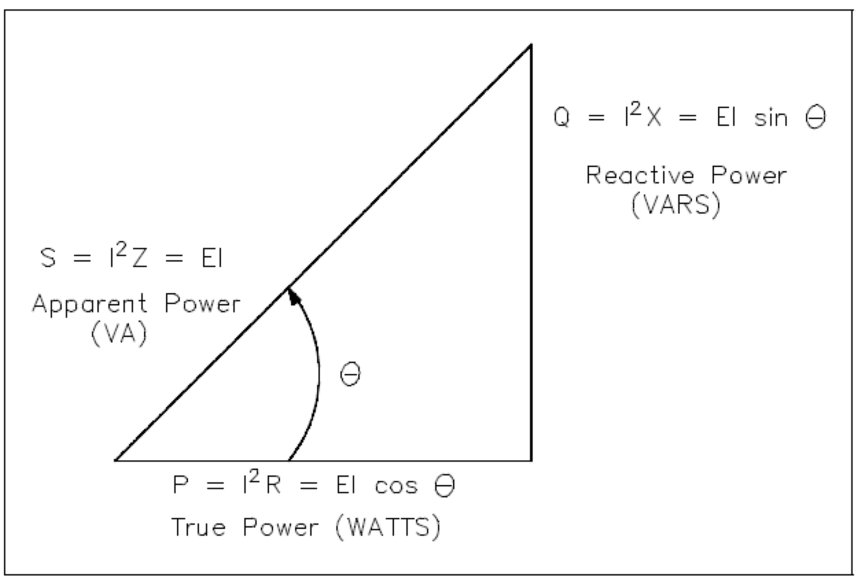
$$C = \frac{Q}{E}$$

g. Discuss the fundamental relationships in Alternating Current (AC) circuits among voltage, current, resistance, reactance, impedance, power, and power factor.

The following is taken from DOE-HDBK-1011/3-92 (in this source Q = reactive power).

These relationships are very complex and thus are discussed only briefly here. See modules 7, 8 & 9 of the above reference for a much more detailed discussion.

In AC circuits, voltage and current are normally out of phase and as a result, not all the power produced by the generator can be used to accomplish work. By the same token, power cannot be calculated in AC circuits in the same manner as in DC circuits. The power triangle (figure 7) equates AC power to DC power by showing the relationship between generator output (apparent power—S) in volt-amperes (VA), usable power (true power—P) in watts, and wasted or stored power (reactive power—Q) in volt-amperes-reactive (VAR). The phase angle (θ) represents the efficiency of the AC circuit and corresponds to the total reactive impedance (Z) to the current flow in the circuit.



Source: DOE-HDBK-1011/3-92

Figure 7. Power triangle

Apparent power, reactive power, and true power can be calculated by using the DC equivalent (root-mean-square [RMS] value) of the AC voltage and current components along with the power factor.

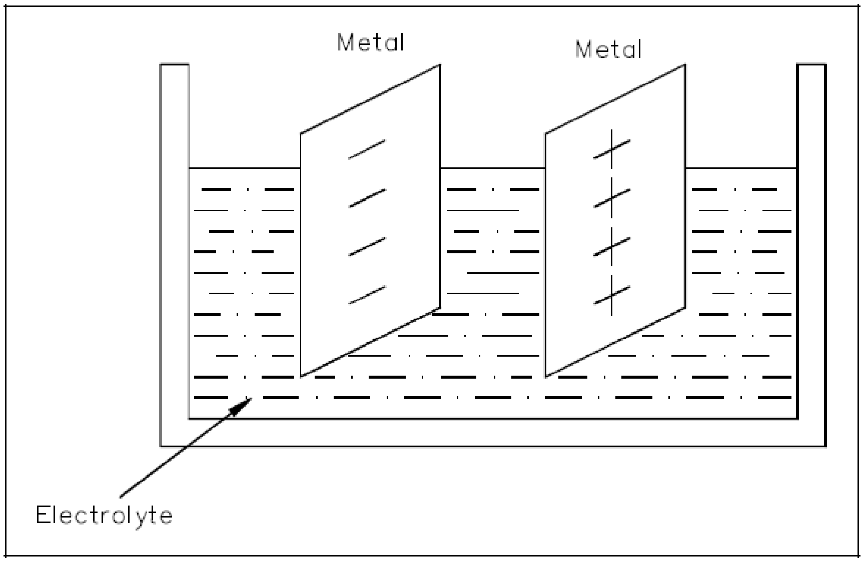
h. Describe how the following methods produce a voltage:

- **Electrochemistry**
- **Static electricity**
- **Magnetic induction**
- **Piezoelectric effect**
- **Thermoelectricity**
- **Photoelectric effect**
- **Thermionic emission**

The information for KSAs 'h' through 'j' is taken from DOE-HDBK-1011/1-92.

Electrochemistry

As illustrated in figure 8, chemicals can be combined with certain metals to cause a chemical reaction that will transfer electrons to produce electrical energy. A chemical reaction produces and maintains opposite charges on two dissimilar metals that serve as the positive and negative terminals. The metals are in contact with an electrolyte solution. Connecting together more than one of these cells will produce a battery.

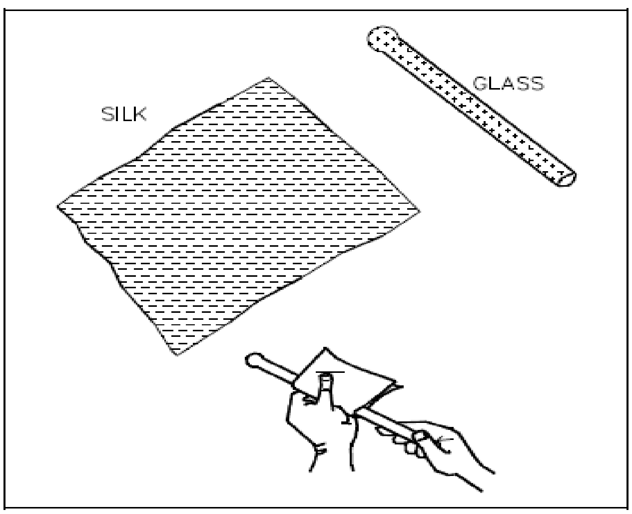


Source: DOE-HDBK-1011/1-92

Figure 8. Voltaic chemical cell

Static Electricity

If electrons are removed from the atoms in a body of matter, as happens due to friction when one rubs a glass rod with a silk cloth, it will become electrically positive, as illustrated in figure 9. If this body of matter (i.e., the glass rod) comes near, but not in contact with another body having a normal charge, an electric force is exerted between them because of their unequal charges. The existence of this force is referred to as *static electricity* or *electrostatic force*.

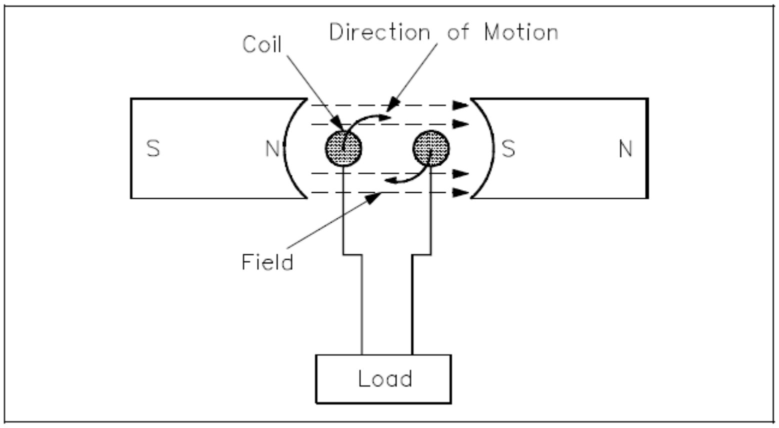


Source: DOE-HDBK-1011/1-92

Figure 9. Static electricity model

Magnetic Induction

Magnetic induction is used to produce a voltage by rotating coils of wire through a stationary magnetic field (figure 10), or by rotating a magnetic field through stationary coils of wire. This is one of the most useful and widely employed applications of producing vast quantities of electric power.

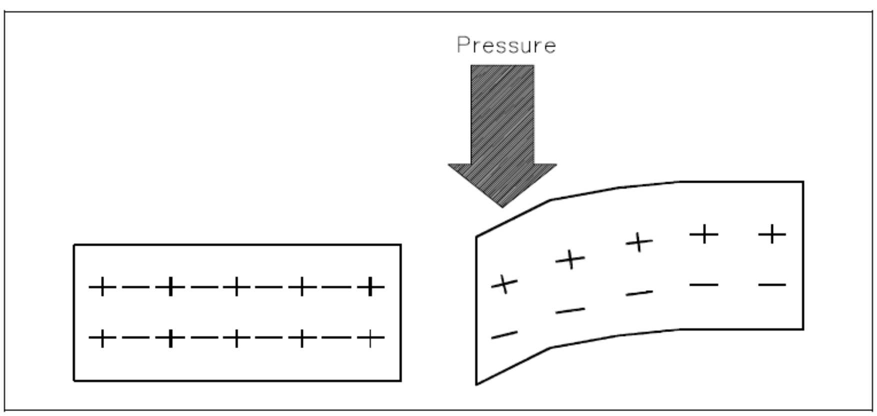


Source: DOE-HDBK-1011/1-92

Figure 10. Magnetic induction model

Piezoelectric Effect

By applying pressure to certain crystals, electrons can be driven out of orbit in the direction of the force. Electrons leave one side of the material and accumulate on the other side, building up positive and negative charges on opposite sides (figure 11). When the pressure is released, the electrons return to their orbits.

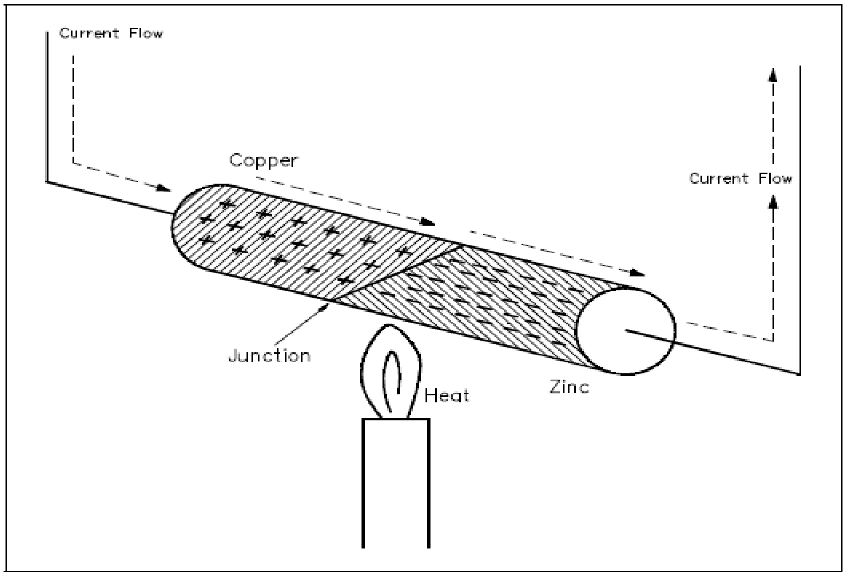


Source: DOE-HDBK-1011/1-92

Figure 11. Piezoelectric model

Thermoelectricity

When two dissimilar metals, such as copper and zinc, are joined, a transfer of electrons can take place. A voltage potential is created across the junction of the two metals. As heat energy is applied to the junction, more electrons are released, and the voltage potential becomes greater (figure 12). When heat is removed and the junction cools, the charges will dissipate and the voltage potential will decrease.

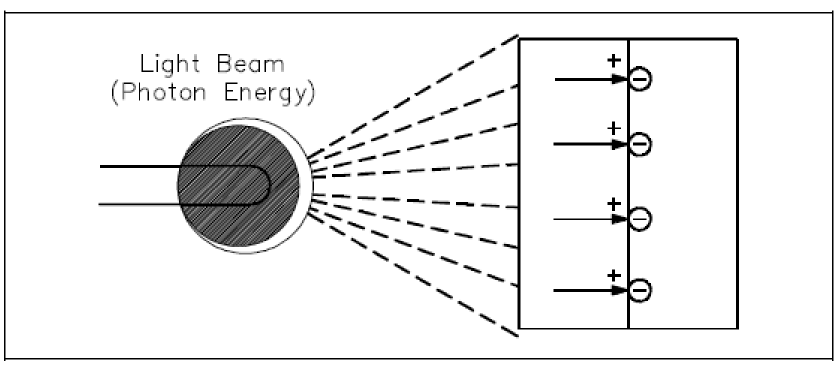


Source: DOE-HDBK-1011/1-92

Figure 12. Thermoelectricity model

Photoelectric Effect

Light is a form of energy and is considered by many scientists to consist of small particles of energy called *photons*. When the photons in a light beam strike the surface of a material, they release their energy and transfer it to the atomic electrons of the material, which may dislodge electrons from their orbits around the surface of the material. Upon losing electrons, the photosensitive (light sensitive) material becomes positively charged and an electric force is created (figure 13).

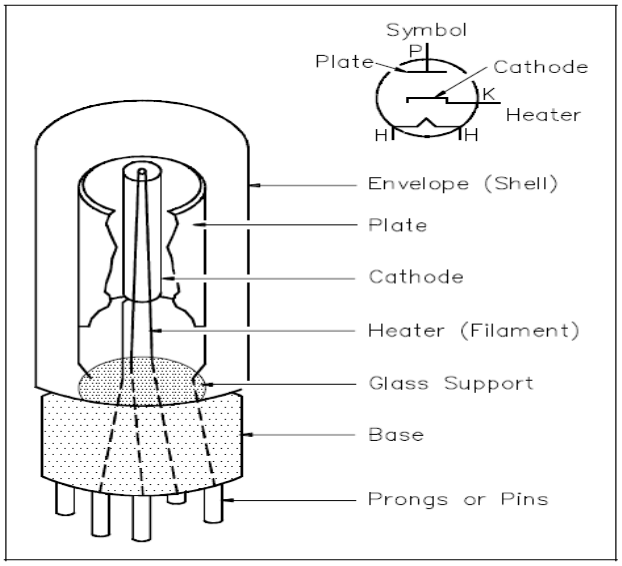


Source: DOE-HDBK-1011/1-92

Figure 13. Photoelectric effect

Thermionic Emission

A thermionic energy converter is a device consisting of two electrodes placed near one another in a vacuum. One electrode is normally called the *cathode* (or emitter), and when the cathode is very hot, the electron energies are greatly increased by thermal motion. The liberation of electrons from a hot surface is called *thermionic emission*. The simplest example of a thermionic device is a vacuum tube diode in which the only electrodes are the cathode and plate, or anode, as shown in figure 14.



Source: DOE-HDBK-1011/1-92

Figure 14. Thermionic emission

i. Using appropriate data, calculate the total resistance for a circuit containing combinations of parallel and series resistance.

Resistance in a Series Circuit

The total resistance in a series circuit is equal to the sum of all the parts of that circuit, as shown in the following equation:

$$R_T = R_1 + R_2 + R_3 \text{ ... etc.}$$

where
R_T = resistance total
R_1, R_2, and R_3 = resistance in series

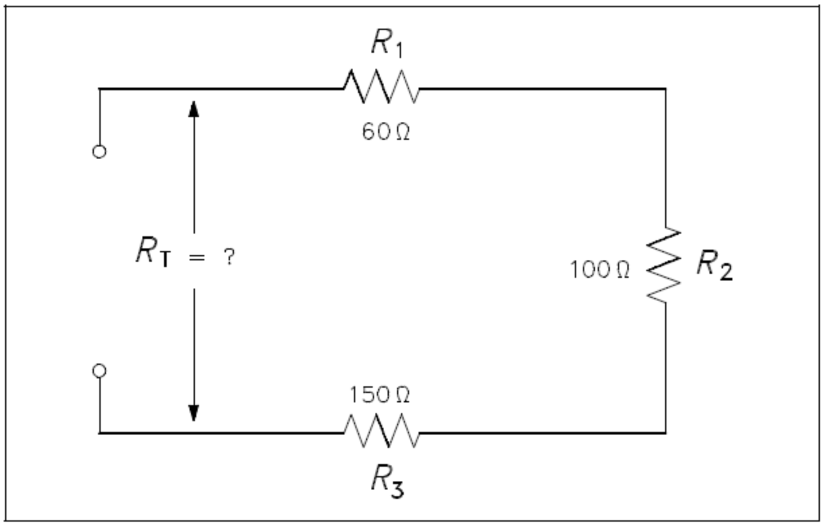
Example: A series circuit has a 60 Ω, a 100 Ω, and a 150 Ω resistor in series (figure 15).

What is the total resistance of the circuit?

Solution:

$$R_T = R_1 + R_2 + R_3$$

$$= 60 + 100 + 150$$
$$= 310\ \Omega$$



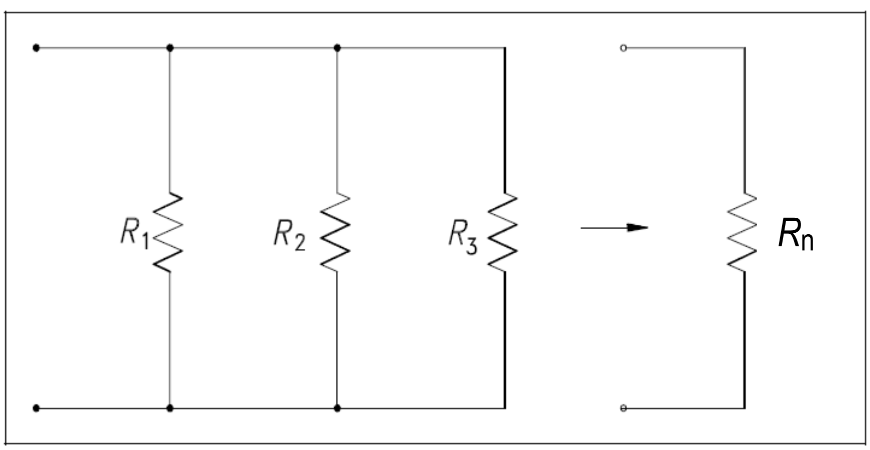
Source: DOE-HDBK-1011/1-92

Figure 15. Resistance in a series circuit

Resistance in a Parallel Circuit

The equation for calculating parallel resistances R_1, R_2, R_3....up to R_n (figure 16) is as follows:

$$\text{Total parallel resistance: } R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}}$$



Source: DOE-HDBK-1011/1-92

Figure 16. Resistance in a parallel circuit

Similar to the equations for calculating series and parallel resistance, the following equations can be used for series and parallel impedance:

$$\text{Total series impedance: } Z = Z_1 + Z_2 + Z_3 + \cdots + Z_n$$

and

$$\text{Total parallel impedance: } Z = \frac{1}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} + \cdots + \frac{1}{Z_n}}$$

j. Using appropriate data for a circuit, calculate the reactance of that circuit.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

k. Discuss the importance of step potential.

The information for KSAs ‘k’ and ‘l’ is taken from 29 CFR 1910.269, Appendix C.

Step potential is the voltage between the feet of a person standing near an energized grounded object (i.e., foot to foot). It is equal to the difference in voltage, given by the voltage distribution curve, between two points at different distances from the electrode. A person could be at risk of injury during a fault simply by standing near the grounding point.

An engineering analysis of the power system under fault conditions must be used to determine whether or not hazardous step and touch voltages will develop. The result of this analysis can ascertain the need for protective measures and can guide the selection of appropriate precautions. These include, but are not limited to: restricting employees from areas where hazardous step or touch potentials could arise can protect employees not directly involved in the operation being performed; employees on the ground in the vicinity of transmission structures should be kept at a distance where step voltages would be insufficient to cause injury; employees should not handle grounded conductors or equipment likely to become energized to hazardous voltages unless the employees are within an equipotential zone or are protected by insulating equipment.

l. Discuss the importance of touch potential.

Touch potential is the voltage between the energized object and the feet of a person in contact with the object (i.e., hand to foot). It is equal to the difference in voltage between the object (which is at a distance of 0 feet) and a point some distance away. It should be noted that the touch potential could be nearly the full voltage across the grounded object if that object is grounded at a point remote from the place where the person is in contact with it. For example, a crane that was grounded to the system neutral and that contacted an energized line would expose any person in contact with the crane or its un-insulated load line to a touch potential nearly equal to the full fault voltage.

An engineering analysis of the power system under fault conditions must be used to determine whether or not hazardous step and touch voltages will develop. The result of this analysis can ascertain the need for protective measures and can guide the selection of appropriate precautions. These include, but are not limited to: restricting employees from areas where hazardous step or touch potentials could arise can protect employees not directly involved in the operation being performed; employees on the ground in the vicinity of transmission structures should be kept at a distance where step voltages would be insufficient to cause injury; employees should not handle grounded conductors or equipment likely to become energized to hazardous voltages unless the employees are within an equipotential zone or are protected by insulating equipment.

2. Electrical personnel shall demonstrate a working level knowledge of basic AC theory.

The information for competency statements '2' and '3' and their associated KSAs is taken from DOE-HDBK-1011/3-92.

a. Define the effective value of an AC relative to DC.

Effective value of AC is the amount of AC that produces the same heating effect as an equal amount of DC. In simpler terms, one ampere effective value of AC will produce the same amount of heat in a conductor, in a given time, as one ampere of DC.

Effective value of AC can be calculated by squaring all the amplitudes of the voltage sine wave over one period, taking the average of these values, and then taking the square root. The effective voltage value, being the root of the mean (average) square of the voltages, is known as the *root-mean-square*, or RMS, voltage value.

The RMS voltage (V_{rms}) value is

$$V_{rms} = \frac{\sqrt{2}}{2} V_{max} = 0.707\ V_{max}$$

The associated RMS current (I_{rms}) can then be calculated using the equation below. Note: The current of any electrical circuit is derived by the applied voltage source and the total impedance of that circuit.

$$I_{rms} = V_{rms} \times Z$$

b. Describe the relationship between maximum, average, and Root-Mean-Square (RMS) values of voltage and current in an AC waveform.

One way to refer to AC voltage or current is by peak voltage (V_{max}) or peak current (I_{max}), these values representing the maximum voltage or current for an AC sine wave.

The values of current (I) and voltage (V) that are normally encountered are assumed to be RMS values; therefore, no subscript is normally used.

Another useful value is the average value of the amplitude during the positive half of the cycle. The following equations show the mathematical relationship between maximum (V_{max}, I_{max}), RMS (V, I), and average (V_{av}, I_{av}) voltage and current:

$$\text{Voltage} = 0.637\ V_{max} - 0.90\ V$$
$$\text{Current} = 0.637\ I_{max} - 0.90\ I$$

c. Using a diagram of two sine waves, describe the phase relationship between the two waves.

The output voltage of an AC generator can be expressed in two ways. One way is represented algebraically. Another way is represented graphically by use of a sine wave (figure 17).

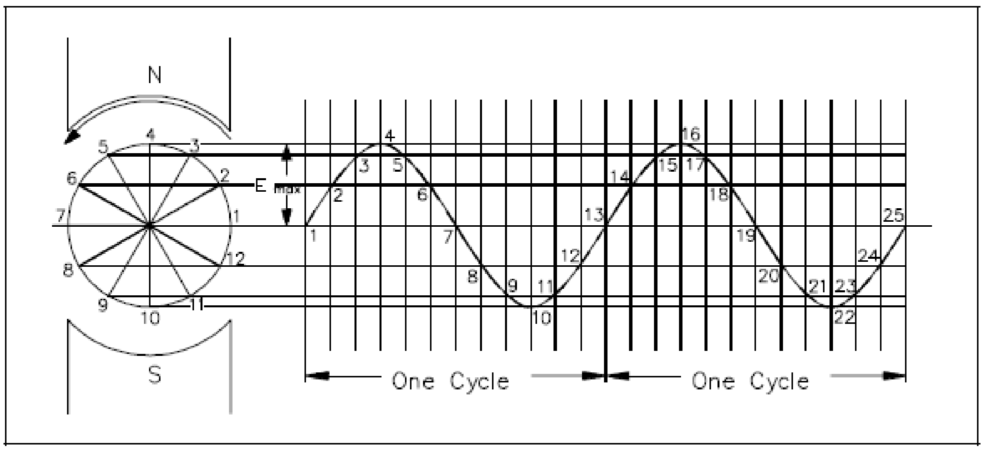


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Figure 17. Graphical representation of a sine wave

Of additional importance is phase angle. Phase angle is the fraction of a cycle, in degrees, that has gone by since a voltage or current has passed through a given value. The given value is normally zero. Referring to figure 17, take point 1 as the starting point, or zero phase. The phase at point 2 is 30°, point 3 is 60°, point 4 is 90°, and so on, until point 13, where the phase is 360°, or zero. A term more commonly used is *phase difference*. The phase difference can be used to describe two different voltages that have the same frequency, which pass through zero values in the same direction at different times.

In figure 18, which illustrates the phase relationship between the two waves, the angles along the axis indicate the phases of voltages e_1 and e_2 at any point in time. At 120°, e_1 passes through the zero value, which is 60° ahead of e_2 (e_2 equals zero at 180°). The voltage e_1 is said to lead e_2 by 60 electrical degrees, or it can be said that e_2 lags e_1 by 60 electrical degrees.

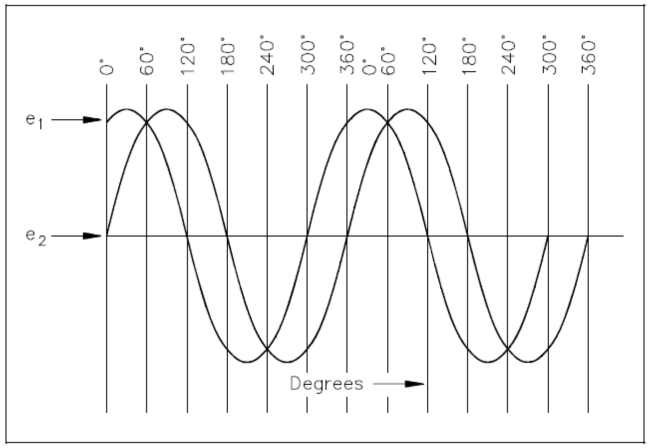

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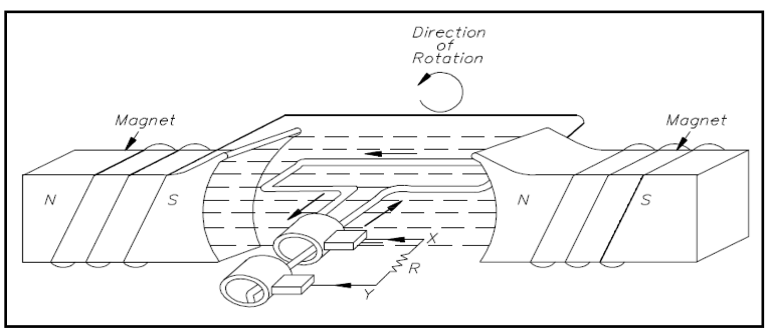
Figure 18. Phase relationship between two sine waves

3. Electrical personnel shall demonstrate a working level knowledge of the construction and operation of AC generators (such as operating characteristics, method of torque production, and the advantages of specific motor types).

a. Describe the basic construction and operation of a simple AC generator.

The elementary AC generator (figure 19) consists of a conductor, or loop of wire in a magnetic field that is produced by an electromagnet. The two ends of the loop are connected to slip rings, and they are in contact with two brushes. When the loop rotates it cuts magnetic lines of force, first in one direction and then the other.



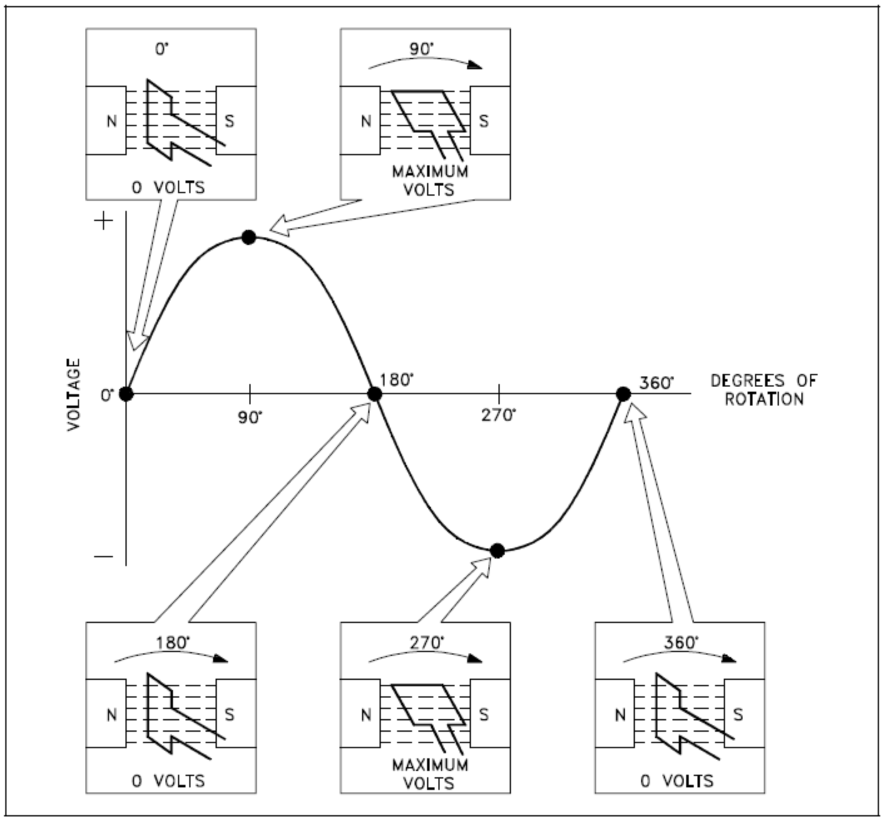
Source: DOE-HDBK-1011/3-92

Figure 19. Simple AC Generator

b. Describe the development of a sine-wave output in an AC generator.

At the instant the loop is in the vertical position (figure 20, 0°), the coil sides are moving parallel to the field and do not cut magnetic lines of force. In this instant, there is no voltage induced in the loop. As the coil rotates in a counterclockwise direction, the coil sides will cut the magnetic lines of force in opposite directions. The direction of the induced voltages depends on the direction of movement of the coil.

The induced voltages add in series, making slip ring X (figure 19) positive (+) and slip ring Y (figure 19) negative (-). The potential across resistor R will cause a current to flow from Y to X through the resistor. This current will increase until it reaches a maximum value when the coil is horizontal to the magnetic lines of force (figure 20, 90°). The horizontal coil is moving perpendicular to the field and is cutting the greatest number of magnetic lines of force. As the coil continues to turn, the voltage and current induced decrease until they reach zero, where the coil is again in the vertical position (figure 20, 180°). In the other half revolution, an equal voltage is produced except that the polarity is reversed (figure 20, 270°, 360°). The current flow through R is now from X to Y (figure 19).



Source: DOE-HDBK-1011/3-92

Figure 20. Development of sine-wave output in an AC generator

The periodic reversal of polarity results in the generation of a voltage, as shown in figure 20. The rotation of the coil through 360° results in an AC sine wave output.

c. Define the following terms in relation to AC generation:

- **Radians/second**
- **Hertz**
- **Period**

Regarding AC generation, *radians/second* refers to the velocity the loop turns, *hertz* (frequency) refers to the number of cycles in one second, and *period* refers to the time it takes to complete one cycle. The following equation further illustrates the relationship of these terms:

$$T = 1/f$$

which can be represented inversely as

$$f = 1/T$$

where
f = Hz
T = period

Radians/Second

The frequency of an alternating voltage or current can be related directly to the angular velocity of a rotating coil. The unit of angular velocity is radians per second, and 2π radians is a full revolution. A radian is an angle that subtends an arc equal to the radius of a circle. One radian equals 57.3 degrees. One cycle of the sine wave is generated when the coil rotates 2π radians. The following equation is the mathematical relationship between frequency (f) and the angular velocity (ω) in an AC circuit:

$$\varpi = 2\pi f$$

where
ϖ = angular velocity (radians/second)
f= frequency (Hz)

Hertz and Period

When a voltage is produced by an AC generator, the resulting current varies in step with the voltage. As the generator coil rotates 360°, the output voltage goes through one complete cycle. In one cycle, the voltage increases from zero to Emax in one direction, decreases to zero, increases to Emax in the opposite direction (negative Emax), and then decreases to zero again. The value of Emax occurs at 90° and is referred to as peak voltage. The time it takes for the generator to complete one cycle is called the period, and the number of cycles per second is called the frequency (measured in hertz).

d. Using the type and application of an AC generator, describe the operating characteristics of that generator, including methods of voltage production, advantages of each type, and methods for paralleling.

There are two types of AC generators: the stationary field, rotating armature; and the rotating field, stationary armature.

Stationary Field, Rotating Armature AC Generator

Small AC generators usually have a stationary field and a rotating armature (figure 21). One important disadvantage to this arrangement is that the slip ring and brush assembly is in series with the load circuits and because of worn or dirty components, may interrupt the flow of current. This generator produces modest amounts of voltage.

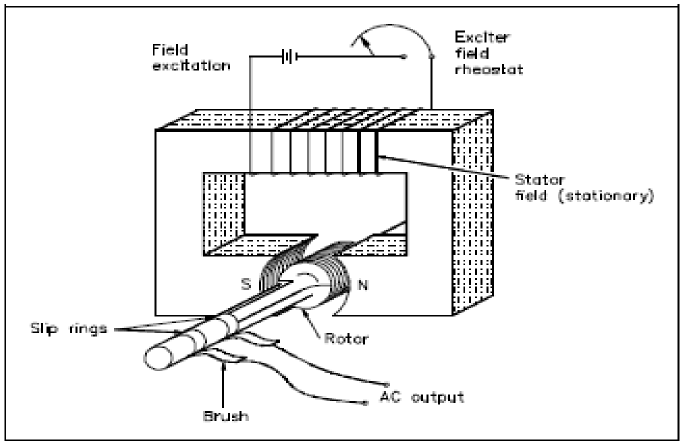


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Figure 21. Stationary field, rotating armature AC generator

Rotating Field, Stationary Armature AC Generator

If DC field excitation is connected to the rotor, the stationary coils will have AC induced in them (figure 22). This arrangement is called a *rotating field, stationary armature AC generator*. The rotating field, stationary armature type AC generator is used when large power generation is involved. In this type of generator, a DC source is supplied to the rotating field coils, which produces a magnetic field around the rotating element. As the rotor is turned by the prime mover, the field will cut the conductors of the stationary armature, and an EMF will be induced in the armature windings.

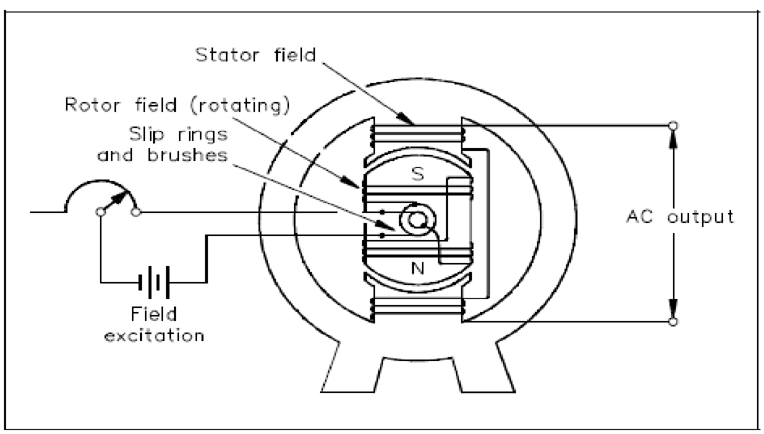

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Figure 22. Rotating field, stationary armature AC generator

This type of AC generator has several advantages over the stationary field, rotating armature AC generator: (1) a load can be connected to the armature without moving contacts in the circuit; (2) it is much easier to insulate stator fields than rotating fields; and (3) much higher voltages and currents can be generated.

Paralleling AC Generators

Three conditions must be met prior to paralleling (or synchronizing) AC generators:

1. Their terminal voltages must be equal. If the voltages of the two AC generators are not equal, one of the AC generators could be picked up as a reactive load to the other AC generator. This causes high currents to be exchanged between the two machines, possibly causing generator or distribution system damage.
2. Their frequencies must be equal. A mismatch in frequencies of the two AC generators will cause the generator with the lower frequency to be picked up as a load on the other generator (a condition referred to as *motoring*). This can cause an overload in the generators and the distribution system.
3. Their output voltages must be in phase. A mismatch in the phases will cause large opposing voltages to be developed. The worst-case mismatch would be 180° out of phase, resulting in an opposing voltage between the two generators of twice the output voltage. This high voltage can cause damage to the generators and distribution system due to high currents.

During paralleling operations, voltages of the two generators that are to be paralleled are indicated through the use of voltmeters. Frequency matching is accomplished through the use of output frequency meters. Phase matching is accomplished through the use of a synchroscope, a device that senses the two frequencies and gives an indication of phase differences and a relative comparison of frequency differences.

e. State the purpose of the following components of an AC generator:

- **Field**
- **Armature**
- **Prime mover**
- **Rotor**
- **Stator**
- **Slip rings**

Field

The field in an AC generator consists of coils of conductors within the generator that receive a voltage from a source (called *excitation*) and produce a magnetic flux. The magnetic flux in the field cuts the armature to produce a voltage. This voltage is ultimately the output voltage of the AC generator.

Armature

The armature is the part of an AC generator in which voltage is produced. This component consists of many coils of wire that are large enough to carry the full-load current of the generator.

Prime Mover

The prime mover is the component that is used to drive the AC generator. The prime mover may be any type of rotating machine, such as a diesel engine, a steam turbine, or a motor.

Rotor

The rotor of an AC generator is the rotating component of the generator, as shown in figure 21. The rotor is driven by the generator's prime mover, which may be a steam turbine, gas turbine, or diesel engine. Depending on the type of generator, this component may be the armature or the field. The rotor will be the armature if the voltage output is generated there; the rotor will be the field if the field excitation is applied there.

Stator

The stator of an AC generator is the part that is stationary (refer to figure 21). Like the rotor, this component may be the armature or the field, depending on the type of generator. The stator will be the armature if the voltage output is generated there; the stator will be the field if the field excitation is applied there.

Slip Rings

Slip rings are electrical connections that are used to transfer power to and from the rotor of an AC generator (refer to figure 21). A slip ring consists of a circular, conducting material that is connected to the rotor windings and insulated from the shaft. Brushes ride on the slip ring as the rotor rotates. The electrical connection to the rotor is made by connections to the brushes. Slip rings are used in AC generators because the desired output of the generator is a sine wave. In a DC generator, a commutator is used to provide an output whose current always flows in the positive direction, as shown in figure 23. This is not necessary for an AC generator. Therefore, an AC generator may use slip rings, which will allow the output current and voltage to oscillate through positive and negative values. This oscillation of voltage and current takes the shape of a sine wave.

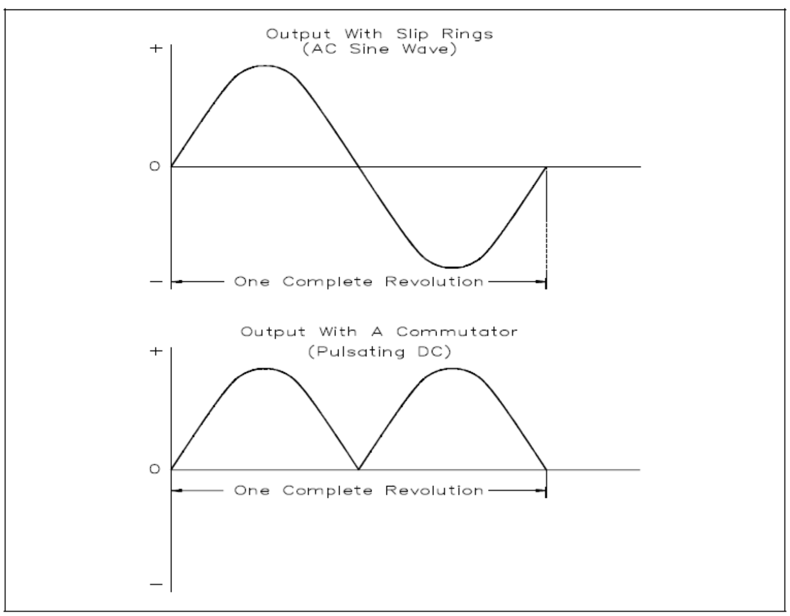

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Figure 23. Sine-wave output with slip rings

f. Using the speed of rotation and number of poles, calculate the frequency output of an AC generator.

A simple AC generator consists of (1) a strong magnetic field, (2) conductors that rotate through that magnetic field, and (3) a means by which a continuous connection is provided to the conductors as they are rotating (see figure 19). The strong magnetic field is produced by a current flowing through the field coil of the rotor. The field coil in the rotor receives excitation through the use of slip rings and brushes. Two brushes are spring-held in contact with the slip rings to provide the continuous connection between the field coil and the external excitation circuit. The armature is contained within the windings of the stator and is connected to the output. Each time the rotor makes one complete revolution, one complete cycle of AC is developed. A generator has many turns of wire wound into the slots of the rotor.

The magnitude of AC voltage generated by an AC generator depends on the field strength and speed of the rotor. Most generators are operated at a constant speed; therefore, the generated voltage depends on field excitation, or strength.

The frequency of the generated voltage depends on the number of field poles and the speed at which the generator is operated, as indicated in the following equation:

$$f = \frac{NP}{120}$$

where
f = frequency (Hz)
N = rotor speed (rpm)
P = total number of poles
120 = conversion from minutes to seconds and from poles to pole pairs

g. List the three losses found in an AC generator.

Internal Resistance Losses

The load current flows through the armature in all AC generators. Like any coil, the armature has some amount of resistance and inductive reactance. The combination of these make up what is known as the *internal resistance*, which causes a loss in an AC generator. When the load current flows, a voltage drop is developed across the internal resistance. This voltage drop subtracts from the output voltage and, therefore, represents generated voltage and power that is lost and not available to the load.

Hysteresis Losses

Hysteresis losses occur when iron cores in an AC generator are subject to effects from a magnetic field. The magnetic domains of the cores are held in alignment with the field in varying numbers, dependent upon field strength. The magnetic domains rotate, with respect to the domains not held in alignment, one complete turn during each rotation of the rotor. This rotation of magnetic domains in the iron causes friction and heat. The heat produced by this friction is called *magnetic hysteresis loss*.

Mechanical Losses

Rotational or mechanical losses can be caused by bearing friction, brush friction on the commutator, and air friction (called *windage*), which is caused by the air turbulence due to armature rotation.

h. Given the prime mover input and generator output, determine the efficiency of an AC generator.

Efficiency of an AC generator is the ratio of the useful power output to the total power input. Because any mechanical process experiences some losses, no AC generators can be 100 percent efficient. Efficiency of an AC generator can be calculated using the following equation:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100$$

i. Describe the basis for the kilowatt and kilovolt-amperes ratings of an AC generator.

Typical nameplate data for an AC generator (see figure 24) includes (1) manufacturer; (2) serial number and type number; (3) speed (RPM), number of poles, frequency of output, number of phases, and maximum supply voltage; (4) capacity rating in kilovolt-amperes (kVA) and kilowatts (kW) at a specified power factor and maximum output voltage; (5) armature and field current per phase; and (6) maximum temperature rise. Power (kW) ratings of an AC generator are based on the ability of the prime mover to overcome generator losses and the ability of the machine to dissipate the internally generated heat. The voltage rating of an AC generator is based on the insulation rating of the machine.

Westinghouse
AC generator air cooled NO. 6750616 Type ATB 3600 RPM
2 poles 60 hertz 3-phase wye-connected for 13800 volts
Rating 15625 kVA 12500 kW 0.80 PF exciter 250 volts
Armature 654 amp field 183 amp
Guaranteed temp. rise not to exceed 60° C on armature by detector 80° C on field by resistance

Source: DOE-HDBK-1011/3-92

Figure 24. AC generator nameplate ratings

j. Describe the conditions that must be met prior to paralleling two AC generators, including the consequences of not meeting these conditions.

Paralleling AC Generators

Three conditions must be met prior to paralleling (or synchronizing) AC generators:

1. Their terminal voltages must be equal. If the voltages of the two AC generators are not equal, one of the AC generators could be picked up as a reactive load to the other AC generator. This causes high currents to be exchanged between the two machines, possibly causing generator or distribution system damage.
2. Their frequencies must be equal. A mismatch in frequencies of the two AC generators will cause the generator with the lower frequency to be picked up as a load on the other generator (a condition referred to as *motoring*). This can cause an overload in the generators and the distribution system.
3. Their output voltages must be in phase. A mismatch in the phases will cause large opposing voltages to be developed. The worst-case mismatch would be 180° out of phase, resulting in an opposing voltage between the two generators of twice the output voltage. This high voltage can cause damage to the generators and distribution system due to high currents.

During paralleling operations, voltages of the two generators that are to be paralleled are indicated through the use of voltmeters. Frequency matching is accomplished through the use of output frequency meters. Phase matching is accomplished through the use of a synchroscope, a device that senses the two frequencies and gives an indication of phase differences and a relative comparison of frequency differences.

k. Describe the difference between a stationary field, rotating armature AC generator, and a rotating field, stationary armature AC generator.

Stationary Field, Rotating Armature AC Generator

Small AC generators usually have a stationary field and a rotating armature (see figure 21). One important disadvantage to this arrangement is that the slip ring and brush assembly is in series with the load circuits and because of worn or dirty components, may interrupt the flow of current. This generator produces modest amounts of voltage.

Rotating Field, Stationary Armature AC Generator

If DC field excitation is connected to the rotor, the stationary coils will have AC induced in them (see figure 19). This arrangement is called a *rotating field, stationary armature AC generator*. The rotating field, stationary armature type AC generator is used when large power generation is involved. In this type of generator, a DC source is supplied to the rotating field coils, which produces a magnetic field around the rotating element. As the rotor is turned by the prime mover, the field will cut the conductors of the stationary armature, and an EMF will be induced in the armature windings.

This type of AC generator has several advantages over the stationary field, rotating armature AC generator: (1) a load can be connected to the armature without moving contacts in the circuit; (2) it is much easier to insulate stator fields than rotating fields; and (3) much higher voltages and currents can be generated.

I. Explain the differences between a wye-connected and delta-connected AC generator, including advantages and disadvantages of each type.

In the delta connection, all three phases are connected in series to form a closed loop. In the wye connection, three common ends of each phase are connected together at a common terminal (marked “N” for neutral), and the other three ends are connected to a three-phase line.

The advantage of a wye-connected AC generator is that each phase only has to carry 57.7 percent of line voltage and, therefore, can be used for high voltage generation. However, the wye-connected AC generator provides an increase in voltage, but no increase in current. The following equations are the mathematical representation of line voltage and line current in a balanced wye load:

$$V_L = \sqrt{3}\, V_\varphi$$
$$I_L = I_\phi$$

where
V_L = line voltage
V_ϕ = phase voltage
I_L = line current
I_ϕ = phase current

The advantage of the delta-connected AC generator is that if one phase becomes damaged or open, the remaining two phases can still deliver three-phase power at a reduced capacity of 57.7 percent. However, a delta-connected generator provides an increase in current, but no increase in voltage. The following equations are the mathematical representation of line voltage and line current in a balanced delta load:

$$V_L = V_\phi$$
$$I_L = \sqrt{3}\, I_\varphi$$

where
V_L = line voltage
V_ϕ = phase voltage
I_L = line current
I_ϕ = phase current

4. Electrical personnel shall demonstrate a working level knowledge of the construction and operation of AC motors (such as operating characteristics, method of torque production, and the advantages of specific motor types).

The information for KSAs 'a' through 'i' and 'k' is taken from DOE-HDBK-1011/4-92.

a. Describe how an AC motor produces a rotating magnetic field.

A magnetic field is produced in an AC motor through the action of the three-phase voltage that is applied. Each of the three phases is 120° from the other phases. From one instant to the next, the magnetic fields combine to produce a magnetic field whose position shifts through a certain angle. At the end of one cycle of AC, the magnetic field will have shifted through 360°, or one revolution.

b. Describe how an AC motor produces torque.

Torque in an AC motor is developed through interactions with the rotor and the rotating magnetic field, and is dependent upon the strength of the interacting rotor and stator fields and the phase relationship between them. The rotating magnetic field cuts the bars of the rotor and induces a current in them due to generator action. This induced current will produce a magnetic field around the conductors of the rotor, which will try to line up with the magnetic field of the stator. Torque can be calculated by using the following equation:

$$T = K\,\Phi\,I_R \cos\theta_R$$

where
T = torque (pounds-feet)
K = constant
Φ = stator magnetic flux
I_R = rotor current (A)
$\cos\theta_R$ = power factor of rotor

c. Using field speed and rotor speed, calculate percent slip in an AC motor.

The percentage difference between the speed of the rotor and the speed of the rotating magnetic field is called *slip*. The smaller the percentage, the closer the rotor speed is to the rotating magnetic field speed. Percent slip can be found by using the following equation:

$$\text{SLIP} = \frac{N_S - N_R}{N_S} \times 100\%$$

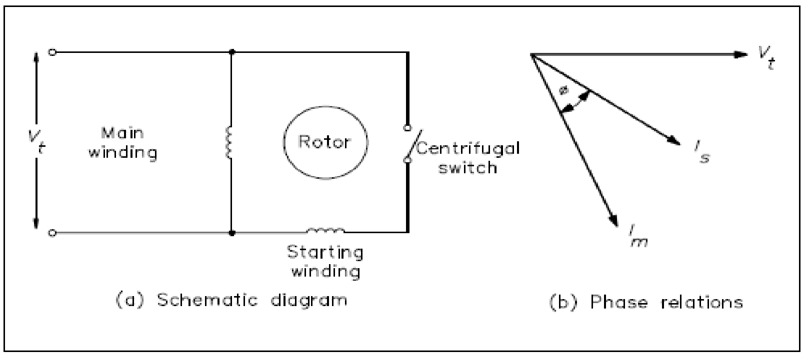
where
N_S = synchronous speed (rpm)
N_R = rotor speed (rpm)

d. Explain the relationship between speed and torque in an AC induction motor.

In an AC induction motor, as slip increases from 0 to ~10%, the torque increases linearly. As the load and slip are increased beyond full-load torque, the torque will reach a maximum value at about 25% slip. If load is increased beyond this point, the motor will stall and come to a rapid stop. The typical induction motor breakdown torque varies from 200% to 300% of full-load torque. Starting torque is the value of torque at 100% slip and is normally 150% to 200% of full-load torque.

e. Describe how torque is produced in a single-phase AC motor.

In a split-phase motor, a starting winding is utilized. This winding has a higher resistance and lower reactance than the main winding. When the same voltage V_T is applied to the starting and main windings, the current in the main winding (I_M) lags behind the current of the starting winding I_S (figure 25). The angle between the two windings is enough phase difference to provide a rotating magnetic field to produce a starting torque.



Source: DOE-HDBK-1011/4-92

Figure 25. Split-phase motor

f. Explain why an AC synchronous motor does not have starting torque.

Torque is only developed when a motor is running at synchronous speed, and an AC synchronous motor is not a self-starting motor.

g. Describe how an AC synchronous motor is started.

A synchronous motor may be started by a DC motor on a common shaft. When the motor is brought to synchronous speed, AC current is applied to the stator windings. The DC motor now acts as a DC generator and supplies DC field excitation to the rotor of the synchronous motor. The load may now be placed on the synchronous motor.

h. Describe the effects of over- and under-exciting an AC synchronous motor.

Keeping the load constant, when the field excitation is increased on a synchronous motor, the motor operates at a leading power factor. If the field excitation is reduced, the motor will operate at a lagging power factor.

i. State some applications of the following types of AC motors:
- **Induction**
- **Single-phase**
- **Synchronous**

Induction

Previous explanations of the operation of an AC motor dealt with induction motors. The induction motor is the most commonly used AC motor in industrial applications because of its simplicity, rugged construction, and relatively low manufacturing costs.

Single-Phase

Single-phase motors are used for very small commercial applications such as household appliances and buffers.

Synchronous

Synchronous motors are used to accommodate large loads and to improve the power factor of transformers in large industrial complexes.

j. Describe the differences in starting and operating characteristics of premium efficiency motors.

The following is taken from The Consortium for Energy Efficiency, *Efficient Motors: Selection and Application Considerations.*

Premium efficiency motors offer increased reliability when starting, 20% to 60% more copper in the windings, more and thinner laminations of higher-quality steel, optimized air gap between stator and rotor, more efficient rotor-bar designs, reduced fan losses, higher quality control (QC) during manufacturing, and longer cores to reduce I^2R (resistance) losses.

Many efficient motors run cooler and are more likely to withstand voltage variations and harmonics better than less-efficient motors. Many efficient motors have a slightly higher power factor on average than their standard counterparts. Most efficient motors operate more quietly than standard motors.

k. Describe the characteristics and operation of motor controllers.

Motor controllers range from simple toggle switches to complex systems using solenoids, relays, and timers. The basic functions of a motor controller are to control and protect the operation of a motor. This includes starting and stopping the motor, and protecting the motor from overcurrent, undervoltage, and overheating conditions that would cause damage to the motor. There are two basic categories of motor controllers: the manual controller and the magnetic controller.

The manual controller is operated by hand and is provided with thermal and direct-acting overload units to protect the motor from overload conditions. It is basically an “ON-OFF” switch with overload protection. Manual controllers are normally used on small loads such as machine tools, fans, blowers, pumps, and compressors. They do not provide low voltage protection or low voltage release.

Magnetic controllers are operated from remote locations or operate automatically in response to control signals. Because manual controllers cannot provide this type of control magnetic controllers must be used for this type of application. Overload devices are incorporated into magnetic controllers. These overload devices protect the motor from overcurrent conditions that would be extremely harmful.

I. Explain the following motor terms:

- **Nameplate revolutions per minute (RPM)**
- **National Electrical Manufacturers Association (NEMA) frame size**
- **Service factor**
- **Insulation class**
- **National Electrical Manufacturers Association (NEMA) design designation (letter)**
- **Non-symmetrical load**

The information for all the terms in this KSA, except for non-symmetrical load, is taken from PDHonline, *Understanding Motor Nameplate Information*. The information for non-symmetrical load is taken from DOE-HDBK-1011/3-92.

Nameplate Revolutions per Minute (RPM)

RPM of the motor is approximate speed under full-load conditions when voltage and frequency are at the rated values. It is generally given as RPM on the nameplate. Multi-speed shaded pole motors show maximum speed first, followed by the total number of speeds (e.g., 3000/3-Spd). Multi-speed split-phase and capacitor-start motors have maximum speed shown first, followed by the second speed (e.g., 1725/1140). The RPM rating for a gear motor represents output shaft speed.

National Electrical Manufacturers Association (NEMA) Frame Size

Under the NEMA system, most motor dimensions are standardized and categorized by a frame size number and letter designation. The number describes the mounting dimensions, including foot hole mounting pattern, shaft diameter, shaft height, etc. It does not define overall length and height, conduit box extension length, etc. NEMA frame size refers to mounting only and has no direct bearing on the motor body diameter. As a frame number becomes higher so in general does the physical size of the motor and the horsepower (HP). There are many motors of the same HP built on different frames. Two digit frame numbers represent the shaft height of the motor from the bottom of the base in sixteenths of an inch. For example, a motor with a frame size of 56 will always have a shaft height above the base of 3½ inches.

Service Factor

The service factor is a multiplier that indicates the amount of overload a motor can be expected to handle. For example, a motor with a 1.0 service factor cannot be expected to handle more than its nameplate HP on a continuous basis. Similarly, a motor with a 1.15 service factor can be expected to safely handle intermittent loads amounting to 15% beyond its nameplate HP.

Insulation Class

Insulation class is an industry standard classification of the thermal tolerance of the motor winding. Insulation is crucial in a motor. This is determined by the ambient temperature, the heat generated at fully loaded conditions (temperature rise) and the thermal capacity of the motor insulation. These materials are classified as A, B, F and H. The letter designation indicates the thermal tolerance, or winding's ability to survive a specified operating temperature for a specified period of time.

The classes are based on adding the ambient temperature and the operational heat created by the motor. Insulation classes of a letter deeper into the alphabet perform better. For example, class F insulation has a longer nominal life at a given operation temperature than class A, or for a given life it can survive higher temperatures.

National Electrical Manufacturers Association (NEMA) Design Designation (letter)

There are standard definitions for designs A, B, C, and D.

Design A motors have normal starting torques, but high starting currents. This is useful for applications with brief heavy overloads. Injection molding machines are good applications for this type of motor

Design B motors are the most common. They feature normal starting torque combined with a low starting current. These motors have sufficient locked rotor torques to start a wide variety of industrial applications.

Design C motors have high starting torques with low starting currents. They are designed for starting heavy loads due to their high locked rotor torques and high full load slip.

Design D motors have high starting torques with low starting currents, however they feature high slip. This reduces power peaks. In the event that peak power is encountered, motor slip will increase.

Non-symmetrical Load

A three-phase (3ϕ) system is a combination of three single-phase systems. In a 3ϕ balanced system, power comes from a 3ϕ AC generator that produces three separate and equal voltages, each of which is 120° out of phase with the other voltages.

An important property of a three-phase balanced system is that the phasor sum of the three line or phase voltages is zero, and the phasor sum of the three line or phase currents is zero. When the three load impedances are not equal to one another, the phasor sums and the neutral current (I_n) are not zero, and the load is, therefore, unbalanced (i.e., non-symmetrical). The imbalance occurs when an open or short circuit appears at the load.

m. Describe the importance of rotational checks prior to placing a three-phase motor in service.

The following is taken from DOE-HDBK-1011/4-92.

A magnetic field is produced in an AC motor through the action of the three-phase voltage that is applied. Each of the three phases is 120° from the other phases. From one instant to the next, the magnetic fields combine to produce a magnetic field whose position shifts through a certain angle. At the end of one cycle of AC, the magnetic field will have shifted through 360°, or one revolution. A rotational check prior to applying voltage ensures proper clockwise rotation, thus eliminating the potential for current spikes, damage to the motor or decreased efficiency.

5. Electrical personnel shall demonstrate a working level knowledge of AC reactive components, including inductive and capacitive reactance and phase relationships in reactive circuits.

The information for all of the KSAs of this competency statement is taken from DOE-HDBK-1011/3-92.

a. Define the following:

- **Inductive reactance**
- **Capacitive reactance**
- **Impedance**
- **Resonance**
- **Power factor**
- **Non-symmetrical load**

Inductive Reactance

In an inductive AC circuit, the current is continually changing and is continuously inducing an EMF. Because this EMF opposes the continuous change in the flowing current, its effect is measured in ohms. This opposition of the inductance to the flow of an AC is called *inductive reactance* (X_L) and is measured in ohms.

Capacitive Reactance

Capacitive reactance is the opposition by a capacitor or a capacitive circuit to the flow of current. The current flowing in a capacitive circuit is directly proportional to the capacitance and to the rate at which the applied voltage is changing. The rate at which the applied voltage is changing is determined by the frequency of the supply; therefore, if the frequency of the capacitance of a given circuit is increased, the current flow will increase. It can also be said that if the frequency or capacitance is increased, the opposition to current flow decreases; therefore, capacitive reactance, which is the opposition to current flow, is inversely proportional to frequency and capacitance. Capacitive reactance X_C is measured in ohms, as is inductive reactance

Impedance

No circuit is without some resistance, whether desired or not. Resistive and reactive components in an AC circuit oppose current flow. The total opposition to current flow in a circuit depends on its resistance, its reactance, and the phase relationships between them. Impedance (Z) is defined as the total opposition to current flow in a circuit and is measured in ohms.

Resonance

Resonance occurs in an AC circuit when inductive reactance and capacitive reactance are equal to one another: $X_L = X_C$. When this occurs, the total reactance, $X = X_L – X_C$, becomes zero, and the impedance is totally resistive. Because inductive reactance and capacitive reactance are both dependent on frequency, it is possible to bring a circuit to resonance by adjusting the frequency of the applied voltage. Resonant frequency (f_{Res}) is the frequency at which resonance occurs, or where $X_L = X_C$ Resonant frequency is measures in hertz.

Power Factor

Power factor (pf) is the ratio between true power and apparent power. Apparent power is the total power of the power triangle (see figure 7 of this guide) and is equal to the vector sum of true and reactive power. Cos θ is called the *power factor* of an AC circuit where θ is the phase angle between the applied voltage and current sine waves and also between P and S on the power triangle of figure 7.

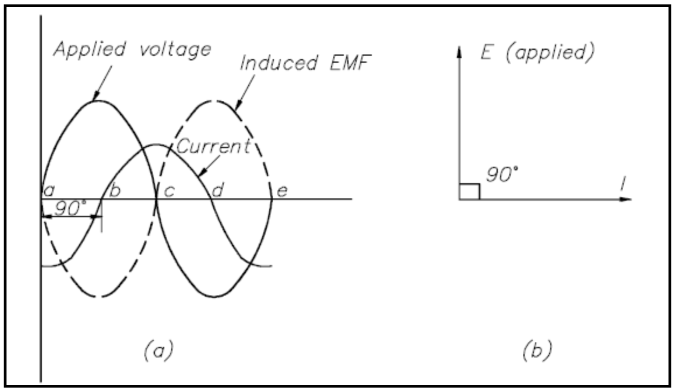
Non-symmetrical Load

An important property of a three-phase balanced system is that the phasor sum of the three line or phase voltages is zero, and the phasor sum of the three line or phase currents is zero. When the three load impedances are not equal to one another, the phasor sums and the neutral current (I_n) are not zero, and the load is, therefore, unbalanced (i.e., a non-symmetrical load).

b. Describe the effect of the phase relationship between current (I) and voltage (V*) in an inductive circuit.

[*In DOE-STD-1170-2007, voltage is represented by the letter E in this statement.]

Any change in current in a coil (either a rise or a fall) causes a corresponding change of the magnetic flux around the coil. Because the current changes at its maximum rate when it is going through its zero value at 90° (point b in figure 26(a)) and 270° (point d), the flux change is also the greatest at those times. Consequently, the self-induced EMF in the coil is at its maximum (or minimum) value at these points, as shown in figure 26. Because the current is not changing at the point when it is going through its peak value at 0° (point a), 180° (point c), and 360° (point e), the flux change is zero at those times. Therefore, the self-induced EMF in the coil is at its zero value at these points.



Source: DOE-HDBK-1011/3-92

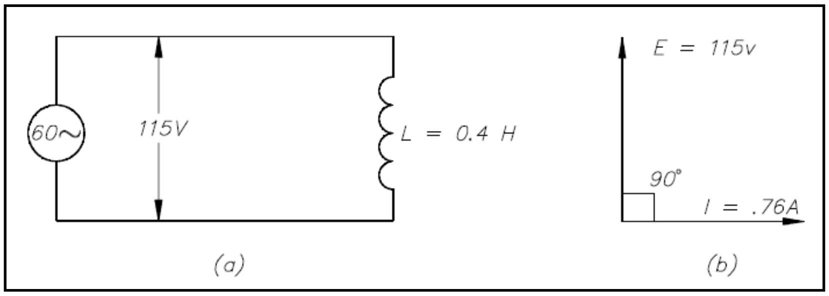
Figure 26. Current, self-induced EMF, and applied voltage in an inductive circuit

According to Lenz's law, the induced voltage always opposes the change in current. Referring to figure 26, with the current at its maximum negative value (point a), the induced EMF is at a zero value and falling. Thus, when the current rises in a positive direction (point a to point c), the induced EMF is of opposite polarity to the applied voltage and opposes the rise in current. Notice that as the current passes through its zero value (point b) the induced voltage reaches its maximum negative value. With the current now at its maximum positive value (point c), the induced EMF is at a zero value and rising. As the current is falling toward its zero value at 180° (point c to point d), the induced EMF is of the same polarity as the current and tends to keep the current from falling. When the current reaches a zero value, the induced EMF is at its maximum positive value. Later, when the current is increasing from zero to its maximum negative value at 360° (point d to point e), the induced voltage is of the opposite polarity as the current and tends to keep the current from increasing in the negative direction. Thus, the induced EMF can be seen to lag the current by 90°.

The value of the self-induced EMF varies as a sine wave and lags the current by 90°, as shown in figure 26. The applied voltage must be equal and opposite to the self-induced EMF at all times; therefore, the current lags the applied voltage by 90° in a purely inductive circuit.

If the applied voltage is represented by a vector rotating in a counterclockwise direction, then the current can be expressed as a vector that is lagging the applied voltage by 90°. Diagrams of this type are referred to as phasor diagrams.

Figure 27(b), a phasor diagram, shows the applied voltage (V) vector leading (above) the current (I) vector by the amount of the phase angle differential due to the relationship between voltage and current in an inductive circuit.



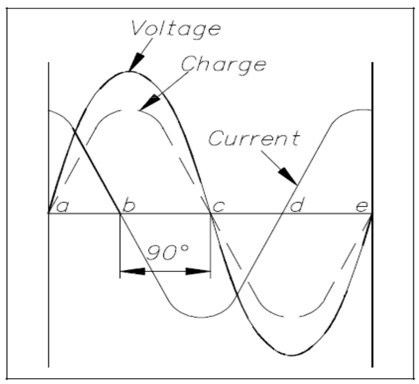
Source: DOE-HDBK-1011/3-92

Figure 27. Coil circuit and phasor diagram

c. Describe the effect on phase relationship between current (I) and voltage (V*) in a capacitive circuit.

[*In DOE-STD-1170-2007 voltage is represented by the letter E in this statement.]

The variation of an alternating voltage applied to a capacitor, the charge on the capacitor, and the current flowing through the capacitor are shown in figure 28.



Source: DOE-HDBK-1011/3-92

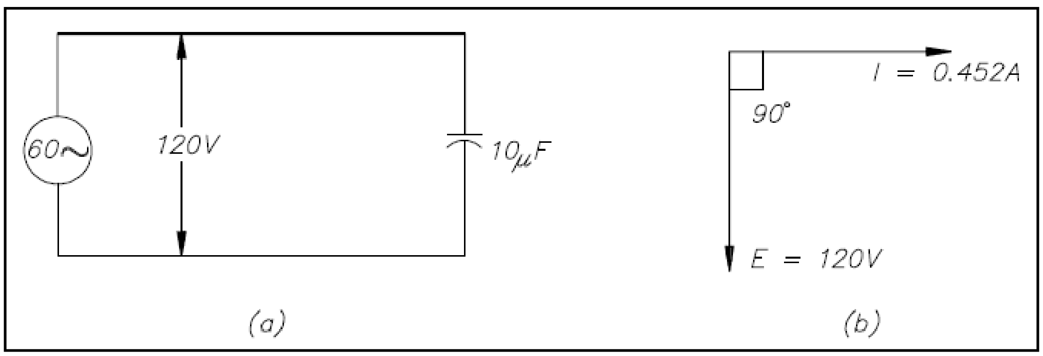
Figure 28. Voltage, charge, and current in a capacitor

The current flow in a circuit containing capacitance depends on the rate at which the voltage changes. The current flow depicted in figure 28 is greatest at points a, c, and e. At these points, the voltage is changing at its maximum rate (i.e., passing through zero). Between points a and b, the voltage and charge are increasing, and the current flow is into the capacitor, but decreasing in value. At point b, the capacitor is fully charged, and the current is zero. From points b to c, the voltage and charge are decreasing as the capacitor discharges, and its current flows in a direction opposite to the voltage. From points c to d, the capacitor begins to charge in the opposite direction, and the voltage and current are again in the same direction.

At point d, the capacitor is fully charged, and the current flow is again zero. From points d to e, the capacitor discharges, and the flow of current is opposite to the voltage. Figure 28 shows the current leading the applied voltage by 90°. In any purely capacitive circuit, current leads applied voltage by 90°.

Capacitive reactance is the opposition by a capacitor or a capacitive circuit to the flow of current. The current flowing in a capacitive circuit is directly proportional to the capacitance and to the rate at which the applied voltage is changing. The rate at which the applied voltage is changing is determined by the frequency of the supply; therefore, if the frequency of the capacitance of a given circuit is increased, the current flow will increase. It can also be said that if the frequency or capacitance is increased, the opposition to current flow decreases; therefore, capacitive reactance, which is the opposition to current flow, is inversely proportional to frequency and capacitance. Capacitive reactance X_C, is measured in ohms, as is inductive reactance.

Figure 29(b), a phasor diagram, shows the applied voltage (V) vector leading (below) the current (I) vector by the amount of the phase angle differential due to the relationship between voltage and current in a capacitive circuit.



Source: DOE-HDBK-1011/3-92

Figure 29. Circuit and phasor diagram

d. Determine the value for total current (I_T) in a simple parallel Resistance-Capacitance-Inductance (R-C-L) AC circuit.

Total current in a parallel R-C-L circuit is equal to the square root of the sum of the squares of the current flows through the resistance, inductive reactance, and capacitive reactance branches of the circuit. The equations below are the mathematical representations of total current in a parallel R-C-L circuit. Because the difference between I_L and I_C is squared, the order in which the quantities are subtracted does not affect the answer.

$$I_T = \sqrt{I_R^2 + (I_C - I_L)^2}$$

$$I_T = \sqrt{I_R^2 + (I_L - I_C)^2}$$

where
I_T = total current (A)

I_R = current through resistance leg of circuit (A)
I_C = current through capacitive reactance leg of circuit (A)
I_L = current through inductive reactance leg of circuit (A)

e. Describe the relationship between apparent, true, and reactive power.

Apparent power (S) is the total power delivered to the electrical circuit, and is the vector sum of the true and reactive powers. True power (P) is the power consumed by the resistive loads in an electrical circuit. Reactive power (Q) is the power consumed in an AC circuit because of the expansion and collapse of magnetic (inductive) and electrostatic (capacitive) fields.

The power triangle in figure 7 represents comparable values that can be used directly to find the efficiency level of generated power to usable power, which is expressed as the power factor. Apparent power, reactive power, and true power can be calculated by using the DC equivalent (RMS value) of the AC voltage and current components along with the power factor.

f. Describe the indications of an unbalanced load in a three-phase power system.

In a fault condition or during asymmetrical loading of circuits, the neutral connection in a wye-connected load will carry more current than the phase under a balanced load. Unbalanced three-phase circuits are indicated by abnormally high currents in one or more of the phases. This may cause damage to equipment if the imbalance is allowed to continue.

g. Discuss circuit considerations required for non-symmetrical loads.

An important property of a three-phase balanced system is that the phasor sum of the three line or phase voltages is zero, and the phasor sum of the three line or phase currents is zero. When the three load impedances are not equal to one another, the phasor sums and the neutral current (I_n) are not zero, and the load is, therefore, unbalanced. The imbalance occurs when an open or short circuit appears at the load.

If a three-phase system has an unbalanced load and an unbalanced power source, the methods of fixing the system are complex.

6. Electrical personnel shall demonstrate a working level knowledge of electrical transmission and distribution systems (IEEE Brown Book; reference IEEE Std-399).

a. Explain the differences between transmission and distribution systems.

The following is taken from the OSHA *Electric Power Generation, Transmission, and Distribution Industry eTool - Illustrated Glossary*.

A transmission system consists of substations that receive power from the generating stations and transmission lines that deliver this power to the distribution system.

A distribution system consists of all the facilities and equipment connecting a transmission system to the customer’s equipment. A typical distribution system can consist of substations, distribution feeder circuits, switches, protective equipment, primary circuits, distribution transformers, secondaries and circuits.

b. Identify and discuss the advantages and disadvantages associated with underground and above-ground distribution systems.

The following is taken from Florida Power & Light Company website FAQs.

> While underground facilities are not as susceptible to wind and debris-blown damage, they are more susceptible to water intrusion and local flood damage, which can make repairs more time consuming and costly.
>
> Overhead facility damage is easier to locate than underground and can generally be repaired quicker.
>
> Underground interruptions may be less frequent, but typically last longer due to more complex repair requirements.
>
> Following recent hurricanes, the areas that took the longest to repair were generally those served by underground facilities still flooded days after the storm passed.
>
> Damage and corrosion of underground electrical systems often shows up days or even months later, causing additional outages and inconvenience to customers.
>
> Storm winds can damage both types of systems causing outages. Overhead systems face outages resulting from trees and debris blowing into lines. Underground systems face outages from trees collapsing on above-ground transformers and switch boxes or from tree root systems uprooting buried cable when trees topple.
>
> Also, we often forget that while a neighborhood may be locally served by underground cable, all electric service eventually comes back above-ground and connects to overhead service, either in the neighborhood next door, or further down the street where overhead main lines and transmission lines move power from power plants and substations into our neighborhoods. Thus, exposure to above-ground electric service from weather, animals, and trees is never fully eliminated.

c. Describe the function and importance of the following control and protective devices:

- **Circuit breakers**
- **Protective relays**
- **Fuses**
- **Transient protection**

The information for all the terms in this KSA, except for transient protection, is taken from DOE-HDBK-1011/4-92. The information for transient protection is taken from D & B Power Associates, Inc., *Surge and Transient Protection.*

Circuit Breakers

The purpose of a circuit breaker is to break the circuit and stop the current flow when the current exceeds a predetermined value without causing damage to the circuit or the circuit breaker. Circuit breakers are commonly used in place of fuses and sometimes eliminate the need for a switch. A circuit breaker differs from a fuse in that it “trips” to break the circuit and may be reset, while a fuse melts and must be replaced.

Protective Relays

Protective relays are designed to cause the prompt removal of any part of a power system that might cause damage or interfere with the effective and continuous operation of the rest of the system. Protective relays are aided in this task by circuit breakers that are capable of disconnecting faulty components or subsystems.

Protective relays can be used for types of protection other than short circuit or overcurrent. The relays can be designed to protect generating equipment and electrical circuits from any undesirable condition, such as undervoltage, underfrequency, or interlocking system lineups.

There are only two operating principles for protective relays: (1) electromagnetic attraction and (2) electromagnetic induction. Electromagnetic attraction relays operate by a plunger being drawn up into a solenoid or an armature that is attracted to the poles of an electromagnet. This type of relay can be actuated by either DC or AC systems. Electromagnetic induction relays operate on the induction motor principle whereby torque is developed by induction in a rotor. This type of relay can be used only in AC circuits.

Fuses

A fuse is a device that protects a circuit only from an overcurrent condition. It has a fusible link directly heated and destroyed by the current passing through it. A fuse contains a current-carrying element sized so that the heat generated by the flow of normal current through it does not cause it to melt the element; however, when an overcurrent or short-circuit current flows through the fuse, the fusible link will melt and open the circuit.

Transient Protection

Power surges and transients are electrical fluctuations caused by lightning or other power utility issues. The surge or transient is conducted through both power and data lines and can damage or destroy downstream equipment. Vulnerable circuitry exists in an extremely hostile environment. A properly applied surge protector can prevent equipment damage, downtime, and data corruption.

d. Compare and contrast the characteristics of three-phase and single-phase distribution systems.

The following is taken from DOE-HDBK-1011/4-92.

Unlike the single-phase wiring scheme that must make a provision for a neutral leg and separate ground, the three-phase system needs neither a separate neutral nor a ground to operate safely. However, to prevent any unsafe condition, all 3- and 4-wire, three-phase systems can include an effective ground path. As with a single-phase, only the secondary side of the transformer and its connected load need to be studied.

A three-phase system is a combination of three single-phase systems. In a three-phase balanced system, power comes from a three-phase AC generator that produces three separate and equal voltages each of which is 120° out of phase with the other voltages. Three-phase equipment (motors, transformers, etc.) weighs less than single-phase equipment of the same power rating. They have a wide range of voltages and can be used for single-phase loads. Three-phase equipment is smaller, weighs less, and is more efficient than single-phase equipment.

One of the major advantages of three-phase systems is lower current requirements for load capacity. For example, a single-phase, 2 hp motor operating at 240 volts might require 6 amps for operation, whereas a three-phase, 2 hp motor operating at 240 volts may require less than 4 amps, resulting in a line capacity reduction of almost 35% to 50%.

e. Discuss the principles associated with ensuring continual power availability during electrical outages.

The following is taken from IEEE Std 446-1995.

The nature of electric power failures, interruptions, and their duration covers a range in time from microseconds to days. Voltage excursions occur within a range from 20 times normal (or more) to a complete absence of voltage. Frequency excursions can vary as widely in many forms, from harmonics to DC. These variables occur due to a multitude of conditions both in the power system ahead of the user’s service entrance and following the service entrance within the user’s area of distribution.

Such elements as lightning, automobiles striking power poles, ice storms, tornadoes, switching to alternate lines, and equipment failure are but a few of the causes of interruptions in the electric power supply ahead of the service entrance.

Within the user’s area of distribution are such elements as short and open circuits, undersized feeders, equipment failures, operator errors, temporary overloads, single-phasing unbalanced feeders, fire, switching, and many other causes of power interruption or failure.

The following 4 systems are available to ensure continual power. The needs of the individual facility affected must be considered in making a decision as to which method or combination of methods is appropriate for that facility. Once installed, protection, grounding and maintenance of these systems is critical to ensure they will be available when needed.

Emergency power systems are of the following two basic types:

- An electric power source separate from the prime source of power, operating in parallel, which maintains power to the critical loads should the prime source fail.

- An available reliable power source to which critical loads are rapidly switched automatically when the prime source of power fails.

Standby power systems are made up of the following main components:

- An alternative reliable source of electric energy separate from the prime power source.
- Starting and regulating control if onsite standby generation is selected as the source.
- Controls that transfer loads from the prime or emergency power source to the standby source.

Battery systems store energy in electrochemical cells that convert chemical energy into electrical energy.

Mechanical systems store energy in the form of kinetic energy in a rotating mass. This energy is converted to useful power by using the kinetic energy to turn an AC generator.

f. Explain the following terms as they relate to power systems:

- **Fault current**
- **Available fault current**
- **Fault duty**

The following is taken from IEEE Std 666-2007.

Fault Current

Fault current, also called *short-circuit current*, describes current flow during a short. Fault current passes through all components in the affected circuit. Fault current is generally very large and, therefore, hazardous. Only the combined impedance of the object responsible for the short, the wire, and the transformer limits its magnitude.

Available Fault Current

Fault current calculations are a critical piece of the electrical design/engineering puzzle for electrical distribution systems in commercial and industrial installations. A fault current calculation determines the maximum available current that will be available (the available fault current) at a given node or location. Once the fault currents have been calculated, then overcurrent protection equipment, breakers, and fuses with a fault current rating equal to or greater than those values can be selected.

Fault Duty

Fault duties are classified as type 1, type 2, or type 3, and pertain to analysis levels that are explained in greater detail in IEEE Std 666-2007, *IEEE Design Guide for Electric Power Service Systems for Generating Stations*.

g. Discuss the safety considerations associated with high voltage transmission systems.

High voltage is defined by DOE-HDBK-1011/4-92 as “the voltage that is above 15,000 volts.”

The following is taken from DOE-HDBK-1092-2004 and delineates the responsibilities of workers and supervisors.

Workers

The greatest responsibility for a worker's safety lies directly with the worker. This means that all workers are responsible for performing their work in a manner that does not endanger themselves, their co-workers, or others in the area and for complying with safety rules and requirements. Workers should not rely solely on the care exercised by another for their protection. Workers are encouraged to contribute to the safety program and bring to the attention of their supervisors or safety representative any condition they believe is unsafe.

Other safety responsibilities of workers include the following:

- The worker should examine the work area for existing hazards and proceed in a safe manner.
- When seen in a dangerous situation, fellow workers should be warned in such a manner as to avoid confusing, startling, or suddenly alarming them.
- Before climbing poles, ladders, or other such structures or before working on scaffolds, workers shall make a careful inspection to determine whether the structures are safe and are properly supported. Workers should not carry anything in their hands while ascending or descending ladders. Small objects or tools may be carried in pockets or pouches. Larger objects, however, should be raised or lowered by use of hand lines or ropes and blocks. Others working nearby or below should remain out of line of the work area in case anything should accidentally be dropped.
- It is the responsibility of each worker to attend safety meetings. Workers should also make a practice of learning safety information made available to them that will help them perform their work more safely.
- The worker shall report to the supervisor any personal injury as defined by the facility as soon as possible.
- The worker should exercise care and good judgment when lifting heavy material, obtaining help if the object is too heavy or awkward for one person to handle.

Supervisors

Supervisors are responsible for knowing and implementing applicable safety policies and directives and taking action as required to provide for the safety of the personnel and operations they supervise. This includes taking positive action to determine and reduce, as necessary, the hazards associated with their operations; instructing employees in safe work methods and associated safety requirements; allowing only those employees that are qualified for the work to perform the work; and ensuring that employees perform their work safely. Supervisors shall be responsible for the safety of all employees under their supervision. They shall enforce the rules that apply to the hazards involved.

Supervisors shall make certain that each new or transferred employee is instructed in the safe practices pertaining to his or her work. Supervisors shall ensure that the appropriate employees receive instruction in appropriate emergency techniques, such as cardio-pulmonary resuscitation, first aid, pole top, and confined space rescue, warranted by the employee's duties.

Other duties of supervisors include the following:

- Provide instructions on safe practices for the crew and see that they are followed.
- Periodically examine supervised employees on their knowledge of the safety rules and approved emergency techniques.
- Not allow a worker to perform any task that cannot be performed safely or for which the worker is not qualified.
- Report every injury in the established manner prescribed for the facility.
- Be responsible for the care and proper use of all protective devices.
- Be responsible for proper posting of hazardous work areas as a safeguard to those supervised. Under no circumstances shall the supervisor allow work to continue if safety precautions are ignored.
- Designate a qualified worker to be in charge of work during the supervisor's absence. The supervisor should not leave the job while dangerous work is in progress.
- Coach and direct employees who are working near exposed, energized wires, equipment, or apparatus.
- Prescribe, along with employees, the appropriate personal protective equipment (PPE) when establishing safety related work practices.

h. Explain the requirements for and uses of alternate power supplies.

The following is taken from IEEE Std 446-1995. Much greater detail is available from this source.

Alternate power supplies include emergency power systems, standby power systems, battery systems and mechanical systems. These supplies provide response, recovery, and continuity of operations during emergencies and/or outages.

Requirements for alternate power supplies include

- protection for their individual components from short circuits;
- grounding requirements, including the coordinated design, proper installation, and maintenance of components such as circuit-protective equipment, systems grounding, equipment grounding and transfer switching equipment;
- preventive maintenance (PM) for electrical equipment, which consists of planned inspections, testing, cleaning, drying, monitoring, adjusting, corrective modification, and minor repair in order to maintain equipment in optimum operating condition and maximum reliability.

i. Discuss the uses of different voltages in a facility.

The following is taken from IEEE Std 141-1993.

Standard nominal system voltages for the United States

These voltages and their associated tolerance limits are listed in ANSI C84.1-1989 for voltages from 120 V to 230 000 V and in ANSI C92.2-1987 for voltages above 230 kV nominal.

Table 1, reprinted from ANSI C84.1-1989 and containing information from ANSI C92.2-1987, provides all the standard nominal system voltages and their associated tolerance limits for the United States. Preferred nominal system voltages and voltage ranges are shown in boldface type while other systems in substantial use that are recognized as standard voltages are shown in regular type. Other voltages may be encountered on older systems but they are not recognized as standard voltages.

Two sets of tolerance limits are defined: range A, which specifies the limits under most operating conditions, and range B, which allows minor excursions outside the range A limits.

Application of voltage classes

a) Low-voltage class voltages are used to supply utilization equipment.

b) Medium voltage (MV) class voltages are used for subtransmission and primary distribution. MVs often supply distribution transformers which step the MV down to low voltage to supply utilization equipment. MVs may also supply distribution substations that transform the voltage from a higher to a lower voltage in the MV class. MVs of 13 800 V and below are also used to supply utilization equipment such as large motors.

c) High-voltage class voltages are used to transmit large amounts of electric power between transmission substations. Transmission substations located adjacent to generating stations step the generator voltage up to the transmission voltage. Other transmission substations transform the high voltage down to MV for subtransmission and primary distribution. Transmission lines also interconnect transmission substations to provide alternate paths for power transmission for higher reliability.

Table 1. Standard nominal system voltages and voltage ranges

VOLTAGE CLASS	NOMINAL SYSTEM VOLTAGE (Note a): Two-wire	Three-wire	Four-wire	Nominal Utilization Voltage (Note i) Two-wire Three-wire Four-wire	VOLTAGE RANGE A (Note b): Maximum — Utilization and Service Voltage (Note c)	Minimum — Service Voltage	Minimum — Utilization Voltage	VOLTAGE RANGE B (Note b): Maximum — Utilization and Service Voltage	Minimum — Service Voltage	Minimum — Utilization Voltage
					Single-Phase Systems					
Low Voltage (Note 1)	120			115	126	114	110	127	110	106
		120/240		115/230	126/252	114/228	110/220	127/254	110/220	106/212
					Three-Phase Systems					
			208Y/120 (Note d)	200	218Y/126	197Y/114	191Y/110	220Y/127	191Y/110 (Note 2)	184Y/106 (Note 2)
			240/120	230/115	252/126	228/114	220/110	254/127	220/110	212/106
		240		230	252	228	220	254	220	212
			480Y/277	460	504Y/291	456Y/263	440Y/254	508Y/293	440Y/254	424Y/245
		480		460	504	456	440	508	440	424
		600 (Note e)		575	630 (Note e)	570	550	635 (Note e)	550	530
Medium Voltage		2 400			2 520	2 340	2 160	2 540	2 280	2 080
			4 160Y/2 400		4 370/2 520	4 050Y/2 340	3 740Y/2 160	4 400Y/2 540	3 950Y/2 280	3 600/2 080
		4 160			4 370	4 050	3 740	4 400	3 950	3 600
		4 800			5 040	4 680	4 320	5 080	4 560	4 160
		6 900			7 240	6 730	6 210	7 260	6 560	5 940
			8 320Y/4 800		8 730Y/5 040	8 110Y/4 680	(Note f)	8 800Y/5 080	7 900Y/4 560	(Note f)
			12 000Y/6 930		12 600Y/7 270	11 700Y/6 760		12 700Y/7 330	11 400Y/6 580	
			12 470Y/7 200		13 090Y/7 560	12 160Y/7 020		13 200Y/7 620	11 850Y/6 840	
			13 200Y/7 620		13 860Y/8 000	12 870Y/7 430		13 970Y/8 070	12 504Y/7 240	
			13 800Y/7 970		14 490Y/8 370	13 460Y/7 770		14 520Y/8 380	13 110Y/7 570	
		13 800			14 490	13 460	12 420	14 520	13 110	11 880
			20 780Y/12 000		21 820Y/12 600	20 260Y/11 700	(Note f)	22 000Y/12 700	19 740Y/11 400	(Note f)
			22 860Y/13 200		24 000Y/13 860	22 290Y/12 870		24 200Y/13 970	21 720Y/12 540	
		23 000			24 150	22 430		24 340	21 850	
			24 940Y/14 400		26 190Y/15 120	24 320Y/14 040		26 400Y/15 240	23 690Y/13 680	
			34 500Y/19 920		36 230Y/20 920	33 640Y/19 420		36 510Y/21 080	32 780Y/18 930	
		34 500			36 230	33 640		36 510	32 780	
					Maximum Voltage (Note g)					
		46 000			48 300					
		69 000			72 500					
High Voltage		115 000			121 000					
		138 000			145 000					
		161 000			169 000					
		230 000			242 000					
		(Note h)								
Extra-High Voltage		345 000			362 000					
		500 000			550 000					
		765 000			800 000					
Ultra-High Voltage		1 100 000			1 200 000					

NOTES: (1) Minimum utilization voltages for 120-600 volt circuits not supplying lighting loads are as follows.

Nominal System Voltage	Range A	Range B
120	108	104
120/240	108/216	104/208
208Y/120 (Note 2)	187Y/108	180Y/104
240/120	216/108	208/104
240	216	208
480Y/277	432Y/249	416Y/240
480	432	416
600	540	520

(2) Many 220 volt motors were applied on existing 208 volt systems on the assumption that the utilization voltage would not be less than 187 volts. Caution should be exercised in applying the Range B minimum voltages of Table 1 and Note (1) to existing 208 volt systems supplying such motors.

Source: ANSI C84.1-1989

j. Discuss the reasons for using single-phase versus three-phase power systems in a facility.

The following is taken from DOE-HDBK-1011/3-92.

Three-phase power systems are used in the industry because three-phase circuits weigh less than single-phase circuits of the same power rating; they have a wide range of voltages and yet can also be used for single-phase loads; they are smaller; and they are overall more efficient than single-phase equipment (three-phase systems have more load capacity for less current demand).

However, despite the advantages of three-phase systems, most residential and much commercial power and lighting loads are single-phase. Single-phase systems are generally less expensive and are, therefore, more commonly used in residential and commercial systems. Examples include air-conditioning loads, lighting, receptacles, and utilization equipment (e.g., toasters, microwave ovens, washing machines, refrigerators, etc.).

k. Discuss which systems would benefit from line filtering.

The information for KSAs ‘k’ through ‘o’ is taken from IEEE Std. 399-1997.

Many types of filters are applied in power systems for different purposes. A single-tuned filter is used to suppress a specific harmonic at or near the tuned frequency. High-pass filters can be of first, second, or third order. The second-order filter is often used to suppress higher frequencies. A more recent type of high-pass filter, a C-type filter, is becoming popular due to its smaller losses at the fundamental frequency. Application of filters is one of the commonly employed solutions to limit the effects of harmonics. Other remedial measures such as moving the disturbing loads to higher voltage levels, reinforcing the system, changing capacitor sizes, and adding tuning reactors to capacitor banks are also used. In any case, economics will dictate the most appropriate solution. Recent studies advocate the utilization of active filtering in an effort to counter the injected harmonics close to the source, but primarily in low-voltage systems.

l. Discuss the types of noise for which systems benefiting from line filtering would be susceptible to without implementation of line filtering.

Noise is undesirable electrical signals in an electrical or electronic circuit. It can be introduced into a circuit from a multitude of sources. In a three-phase system, neutral-to-ground voltage or ground circuit can be a result of common mode noise. Transverse mode noise occurs in phase on all 3-phase conductors and neutral. Electromagnetic interference (EMI) and RF interference (RFI) can also appear as transverse or common mode noise.

m. Define the terms harmonics, positive, negative and zero sequence currents.

Harmonics

Harmonics are those voltages or currents whose frequencies are integer multiples of the fundamental frequency. The fundamental frequency (usually 60 Hz) is the predominant, intended frequency of a power system. Harmonics distort and change the magnitude of the fundamental. Harmonics are identified by their harmonic number. For example, with a 60 Hz fundamental frequency, 120 Hz is the second harmonic, 180 Hz the third harmonic, and 300 Hz the fifth harmonic. Harmonics are usually expressed as a percentage.

Positive-, Negative-, and Zero-Sequence Currents

Three-phase systems can be analyzed through the derivation of symmetrical components, which is most meaningful when applied to three-phase systems. The analysis uses three sets of balanced phasors, termed the positive-, negative-, and zero-sequence voltages (or currents), to analyze phase-to-neutral voltages.

The positive-sequence phasor set (voltage or current) is denoted by a subscript 1 and is defined as a set of vectors equal in magnitude, separated by 120°, and having the same phase rotation sequence as the power system being represented (figure 30a).

The negative-sequence phasor set (voltage or current) is denoted by a subscript 2 and is defined as a set of vectors equal in magnitude, separated by 120°, and having the opposite phase rotation sequence as the power system being represented (figure 30b).

The zero-sequence phasor set (voltage or current) is denoted by a subscript 0 and is defined as a set of vectors equal in magnitude, in phase with each other (separated by 360°), and having the same phase rotation sequence as the power system being represented (figure 30c).

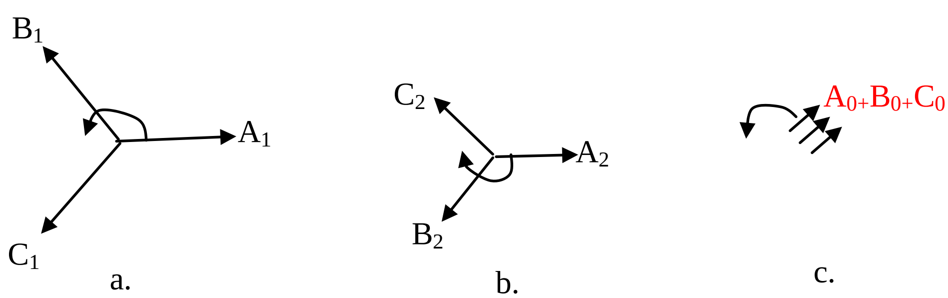
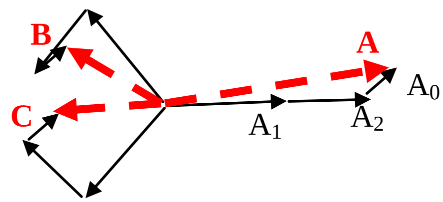


Figure 30. Positive-, negative-, and zero-sequence voltages for respective phases of a 3-phase system

The analysis is generally conducted by adding the respective vectors for each phasor set to obtain a voltage (or current) amplitude and phase relationship for each phase of the three-phase system. Thus, if figure 30 represents the respective phase-sequence voltages for a system under investigation at a particular state in time, the unbalanced system (for example, a fault condition) would be the vector sum of these sequences, as shown in figure 31.



Source: Figures 30 and 31, original; derived from IEEE 399-1997

Figure 31. Symmetrical component sums (dashed vectors) of positive, negative, and zero sequences showing the unbalanced magnitudes and phase relationships

The following terminology applies to figures 32–34, example sequence networks:

- X_S = source reactance (e.g., generator or transformer reactance)
- R_L and X_L = line resistance and line reactance respectively
- R_D and X_D = load resistance and load reactance respectively
- Note that R_S is not referenced because source generators and transformers are designed for negligible resistance
- In the subscript notation, positive (+), negative (-), and zero (0) designate the positive-, negative-, and zero-sequence values
- V_D= load voltage
- $V_{L\text{-}N}$ = line-to-neutral voltage
- F = fault connection
- N = neutral connection

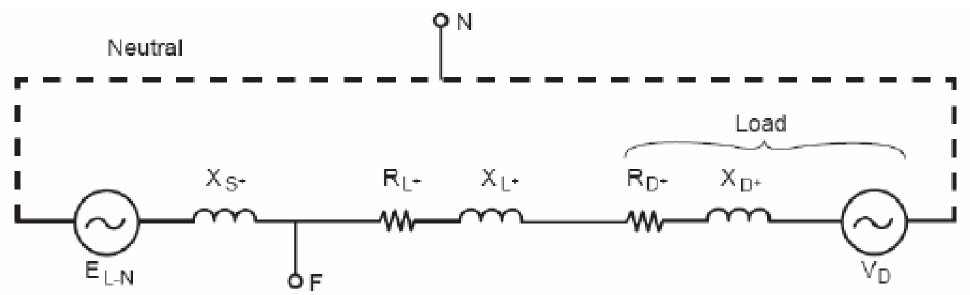


Figure 32. Positive-sequence network

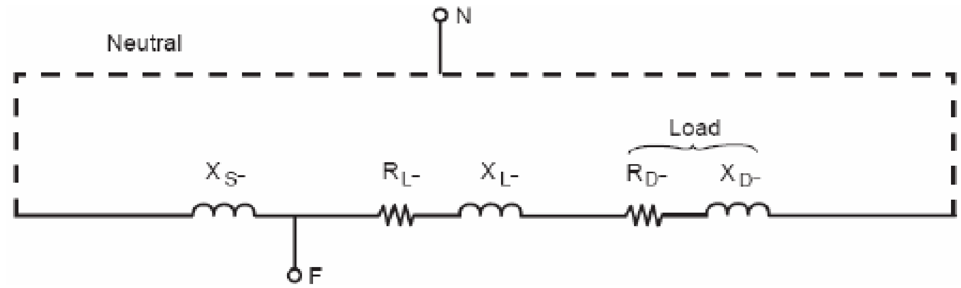
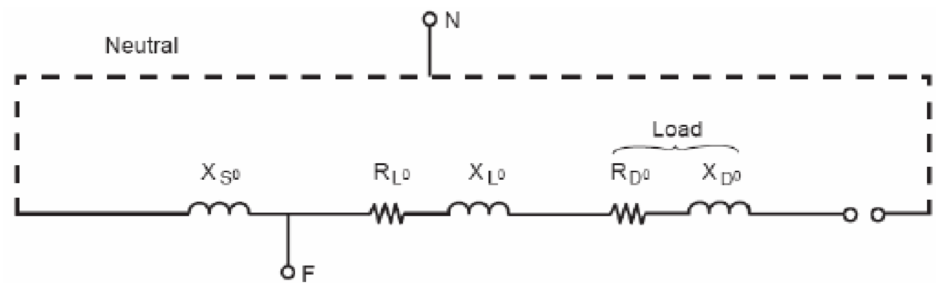


Figure 33. Negative-sequence network



Source: Figures 32–34, IEEE Std 399-1997

Figure 34. Zero-sequence network

n. Describe the sources of harmonics.

In general, a major contributor of harmonics is electrical equipment, especially equipment that utilizes a rectified-input switching-mode power supply. Traditionally, the main source of harmonics in power systems has been the static power converter used as rectifiers for various industrial processes.

Harmonics originate on the premises in most cases, but harmonics from neighboring utility customers can be introduced to the premises by the incoming utility supply. Equipment operating on the principle of ferromagnetics is another source, as all such equipment produces harmonics when operating in the saturation region of the magnetic core. Arc-producing equipment, such as welding machines and arc furnaces, also develops harmonics.

o. Describe the effect of harmonics on the power system and equipment.

The effects of harmonics are due to both current and voltage, although current-produced effects are more likely to be seen in day-to-day performance. Voltage effects are more likely to degrade the insulation and hence shorten the life of the equipment. The following are some of the common effects of harmonics:

- Increased losses within the equipment and associated cables, lines, and so forth
- Pulsating and reduced torque in rotating equipment
- Premature aging due to increased stress in the equipment insulation
- Increased audible noise from rotating and static equipment
- Misoperation of equipment sensitive to waveforms

- Substantial amplification of currents and voltages due to resonances
- Communication interference due to inductive coupling between power and communication circuits

p. Describe the typical means of mitigating harmonics and their effects.

The information for KSAs ‘p’ and ‘q’ is taken from National Fire Protection Association (NFPA) 70B.

Solutions to harmonic problems are unique and depend on the results of a harmonic survey and testing and subsequent analysis. Solutions include the following:

- De-rating of existing equipment
- Replacing of existing equipment with higher-rated equipment
- Use of delta-wye- or delta-delta-connected transformers as appropriate
- Use of equipment specifically rated for harmonic circuits
- Better selection and application of protective and metering devices
- Use of rms-sensing protective devices
- Balancing of single-phase loads on 3-phase systems
- Use of 3-phase rectifiers instead of single-phase rectifiers
- Relocating power-factor improvement capacitors
- Shielding of conductors and electronic equipment
- Isolation of harmonic-sensitive loads
- Use of filters to block or shunt off harmonics
- Specification of new equipment for low harmonic content
- Periodic surveys and power-stream adjustments/modifications as indicated by survey results
- Increased neutral conductor size
- Replacement or repair of harmonic producing equipment
- Utilization of a motor or generator with an insulated bearing

q. Describe how load calculations are made to determine/verify system or facility power requirements.

Article 220 of NFPA 70 provides requirements for calculating branch-circuit, feeder, and service loads. Part I provides for general requirements for calculation methods. Part II provides calculation methods for branch-circuit loads. Parts III and IV provide calculation methods for feeders and services. Part V provides calculation methods for farms.

In other articles applying to the calculation of loads in specialized applications, there are requirements provided in Table 220.3 that are in addition to, or modifications of, those within this article.

7. **Electrical personnel shall demonstrate a working level knowledge of transformers.**

The information for KSAs ‘a’ through ‘d’ is taken from DOE-HDBK-1011/4-92.

a. **Define the following terms as they apply to transformers:**

- **Mutual induction**
- **Turns ratio**
- **Impedance ratio**
- **Efficiency**

Mutual Induction

If flux lines from the expanding and contracting magnetic field of one coil cut the windings of another nearby coil, a voltage will be induced in that coil. The inducing of an EMF in a coil by magnetic flux lines generated in another coil is called mutual induction. The amount of EMF that is induced depends on the relative positions of the two coils and the number of turns of coils in the conductors.

Turns Ratio

Each winding of a transformer contains a certain number of turns of wire. The turns ratio is defined as the ratio of turns of wire in the primary winding to the number of turns of wire in the secondary winding. Turns ratio can be expressed using the following equation:

$$\text{Turns ratio} = \frac{N_P}{N_S}$$

where
N_P = number of turns on the primary coil
N_S = number of turns on the secondary coil

The coil of a transformer that is energized from an AC source is called the *primary winding (coil),* and the coil that delivers this AC to the load is called the *secondary winding (coil).*

Impedance Ratio

Maximum power is transferred from one circuit to another through a transformer when the impedances are equal, or matched. A transformer winding constructed with a definite turns ratio can perform an impedance-matching function. The turns ratio will establish the proper relationship between the primary and secondary winding impedances. The ratio between the two impedances is the *impedance ratio* and is expressed by the following equation:

$$\left(\frac{N_P}{N_S}\right)^2 = \frac{Z_P}{Z_S}$$

Another way to express the impedance ratio is to take the square root of both sides of the equation. This puts the ratio in terms of the turn ratio, which is always given for a transformer:

$$\frac{N_P}{N_S} = \sqrt{\frac{Z_P}{Z_S}}$$

where
N_P = number of turns in the primary
N_S = number of turns in the secondary
Z_P = impedance of primary
Z_S = impedance of secondary

Efficiency

Efficiency of a transformer is the ratio of the power output to the power input, as illustrated by the following equation:

$$\text{Efficiency} = \frac{\text{Power Output}}{\text{Power Input}} = \frac{P_S}{P_P} \times 100$$

where
P_S = power of secondary
P_P = power of primary

b. Describe the differences between a wye-connected and delta-connected transformer.

In a delta connection, all three phases are connected in series to form a closed loop, while in a wye connection, three common ends of each phase are connected together at a common terminal, and the other three ends are connected to a three-phase line.

The mathematical representation of line current in a balanced delta load is

$$V_L = V_\phi$$
$$I_L = \sqrt{3}\, I_\varphi$$

The mathematical representation of line current in a balanced wye load is

$$V_L = \sqrt{3}\, V_\varphi$$
$$I_L = I_\phi$$

c. Using the type of connection and turns ratios for the primary and secondary of a transformer, calculate voltage, current, and power for each of the following types:

- **Delta - delta**
- **Delta - wye**
- **Wye - delta**
- **Wye - wye**

Table 2 and the examples that follow it provide an overview of calculations.

Table 2. Voltage and current ratings of transformers

Transformer Connection (Primary to Secondary)	Primary				Secondary			
	Line		Phase		Line		Phase	
	Volt.	Current	Volt.	Current	Volt. *	Current	Volt.	Current
Δ-Δ	V	I	V	$\frac{I}{\sqrt{3}}$	$\frac{V}{a}$	aI	$\frac{V}{a}$	$\frac{aI}{\sqrt{3}}$
Y-Y	V	I	$\frac{V}{\sqrt{3}}$	I	$\frac{V}{a}$	aI	$\frac{V}{\sqrt{3}\,a}$	aI
Y-Δ	V	I	$\frac{V}{\sqrt{3}}$	I	$\frac{V}{\sqrt{3}\,a}$	$\sqrt{3}\,aI$	$\frac{V}{\sqrt{3}\,a}$	aI
Δ-Y	V	I	V	$\frac{I}{\sqrt{3}}$	$\frac{\sqrt{3}\,V}{a}$	$\frac{aI}{\sqrt{3}}$	$\frac{V}{a}$	$\frac{aI}{\sqrt{3}}$

*a = N_1/N_2; $\sqrt{3}$ = 1.73

Example 1: If line voltage is 440 V to a 3ϕ transformer bank, find the voltage across each primary winding for all four types of transformer connections.

Δ-Δ: primary voltage = V = 440 volts

Y-Y: primary voltage $= \frac{V}{\sqrt{3}} = \frac{440}{1.73}$ = 254.3 volts

Y-Δ: primary voltage $= \frac{V}{\sqrt{3}} = \frac{440}{1.73}$ = 254.3 volts

Δ-Y: primary voltage = V = 440 volts

Example 2: If line current is 10.4 A in a 3ϕ transformer connection, find the primary phase current.

Δ-Δ: primary phase current $= \frac{I}{\sqrt{3}} = \frac{10.4}{1.73}$ = 6 amps

Y-Y: primary phase current = I = 10.4 amps

Y-Δ: primary phase current = I = 10.4 amps

Δ-Y: primary phase current $= \frac{I}{\sqrt{3}} = \frac{10.4}{1.73}$ = 6 amps

Example 3: Find the secondary line current and phase current for each type of transformer connection, if primary line current is 20 amps, and the turns ratio is 4:1.

Δ-Δ: secondary line current = 4(20) = 80 amps

secondary phase current $= \dfrac{aI}{\sqrt{3}} = \dfrac{4\,(20)}{1.73} = 46.2$ amps

Y-Y: second line current = aI = 4(20) = 80 amps

second phase current = aI = 4(20) = 80 amps

Y-Δ: secondary line current $= \sqrt{3}$ aI = (1.73)(4)(20) = 138.4 amps

secondary phase current = aI = 4(20) = 80 amps

Δ-Y: secondary line current $= \dfrac{aI}{\sqrt{3}} = \dfrac{4\,(20)}{1.73} = 46.2$ amps

secondary phase current $= \dfrac{aI}{\sqrt{3}} = \dfrac{4\,(20)}{1.73} = 46.2$ amps

d. State the applications of each of the following types of transformers:
- **Distribution**
- **Power**
- **Control**
- **Auto**
- **Isolation**
- **Instrument potential**
- **Instrument current**

Distribution

Distribution transformers are generally used in electrical power distribution and transmission systems. This class of transformer has the highest power, or volt-ampere ratings, and the highest continuous voltage rating. The power rating is normally determined by the type of cooling methods the transformer may use. Some commonly-used methods of cooling are by using oil or some other heat-conducting material. Ampere rating is increased in a distribution transformer by increasing the size of the primary and secondary windings; voltage ratings are increased by increasing the voltage rating of the insulation used in making the transformer.

Power

Power transformers are used in electronic circuits and come in many different types and applications. Electronics or power transformers are sometimes considered to be those with ratings of 300 volt-amperes and below. These transformers normally provide power to the power supply of an electronic device, such as in power amplifiers in audio receivers.

Control

Control transformers are generally used in electronic circuits that require constant voltage or constant current with a low power or volt-amp rating. Various filtering devices, such as capacitors, are used to minimize the variations in the output. This results in a more constant voltage or current.

Auto

The auto transformer is generally used in low power applications where a variable voltage is required. The auto transformer is a special type of power transformer. It consists of only one winding. By tapping or connecting at certain points along the winding, different voltages can be obtained.

Isolation

Isolation transformers are normally low power transformers used to isolate noise from or to ground electronic circuits. Since a transformer cannot pass DC voltage from primary to secondary, any DC voltage (such as noise) cannot be passed, and the transformer acts to isolate this noise.

Instrument Potential

The instrument potential transformer (PT) steps down voltage of a circuit to a low value that can be effectively and safely used for operation of instruments such as ammeters, voltmeters, watt meters, and relays used for various protective purposes.

Instrument Current

The instrument current transformer (CT) steps down the current of a circuit to a lower value and is used in the same types of equipment as a PT. This is done by constructing the secondary coil consisting of many turns of wire, around the primary coil, which contains only a few turns of wire. In this manner, measurements of high values of current can be obtained.

A CT should always be short-circuited when not connected to an external load. Because the magnetic circuit of a CT is designed for low magnetizing current when under load, this large increase in magnetizing current will build up a large flux in the magnetic circuit and cause the transformer to act as a step-up transformer, inducing an excessively high voltage in the secondary when under no load.

e. Describe the hazardous materials that are associated with transformers.

The following is taken from U.S. EPA, Technical Factsheet on: Polychlorinated Biphenyls (PCBs).

Transformers manufactured before 1979 may contain PCBs as a cooling medium. The health effects are of two levels: acute and chronic.

- Acute, short-term exposure to PCBs above the maximum contaminant level (MCL) may potentially cause acne-like eruptions and pigmentation of the skin, vision and hearing problems, and spasms.

- Chronic exposure to PCBs above the MCL has the potential to cause effects similar to acute poisoning, irritation of nose, throat and gastrointestinal tracts, and changes in liver function. There is some evidence that PCBs have the potential to cause cancer from a lifetime exposure at levels above the MCL.

Polychlorinated biphenyls were banned from new use and sale in 1979. Modern transformers are now cooled with oil-based media, which are not inherently hazardous, though may pose an environmental hazard should the transformer become damaged and leakage occur onto the ground or into water.

f. Describe the conditions that must be met prior to paralleling two transformers, including consequences of not meeting these conditions.

The following is taken from Schneider Electric U.S.A., *Loading Considerations When Paralleling Transformers*,

Transformers connected in parallel have the same voltage on each primary and the same voltage on each secondary. The difference in the voltage between the primary and secondary windings is the turn ratios. For these terminal voltages to be the same for the paralleled transformers, their impedance drops must be identical. Therefore, under any condition of load, the current will be divided such that the product of impedance and current in one transformer is equal to the product of impedance and current in the other. Also, if the turn ratios of the transformers are different, but the primary and secondary terminal voltages are the same in both transformers, then circulating currents must flow between the transformers, even at no load. Transformers are suitable for parallel operation when their turn ratios, percent impedances, and X/R ratios are the same. Connecting transformers when one of these parameters is different results in either circulating currents or unwanted current division. Both of these situations lower the efficiency and reduce the maximum amount of load the combined transformers can carry.

The standard method of connecting transformers in parallel is to have the same turn ratios, percent impedances, and kVA ratings. Paralleling is typically accomplished by maintaining a tie breaker in the normally closed position. Connecting transformers in parallel with the same parameters results in equal load sharing and no circulating currents in the transformer windings.

Although it is not common practice for new installations, sometimes two transformers with different kVAs and the same percent impedances are connected to one common bus. In this situation, the current division causes each transformer to carry its rated load. There will be no circulating currents because the voltages (turn ratios) are the same.

Frequently in practice, engineers try to enhance their plant power system by connecting existing transformers in parallel that have the same kVA rating, but with different percent impedances. This is common when budget constraints limit the purchase of a new transformer with the same parameters. What the engineer needs to understand is that the current divides in inverse proportions to the impedances, and larger current flows through the smaller impedance. Thus, the lower percent impedance transformer can be overloaded when subjected to heavy loading while the other higher percent impedance transformer will be lightly loaded.

Loading considerations for paralleling transformers are simple unless kVA, percent impedances, or ratios are different. When paralleled transformer turn ratios and percent impedances are the same, equal load division will exist on each transformer. When paralleled transformer kVA ratings are the same, but the percent impedances are different, then unequal load division will occur. The same is true for unequal percent impedances and unequal kVA. Circulating currents only exist if the turn ratios do not match on each transformer. The magnitude of the circulating currents will also depend on the X/R ratios of the transformers.

Paralleling delta-delta to delta-wye transformers should never be attempted because there is a 30^{o} phase shift in delta-wye and wye-delta configurations. This causes extremely high circulating currents in the transformers. These circulating currents would overheat the transformers.

8. Electrical personnel shall demonstrate a working level knowledge of Uninterruptible Power Supplies (UPS).

a. Describe how a UPS works.

The following is taken from NFPA 70B.

The basic function of UPS systems is to preserve power to electrical or electronic equipment. Most UPS systems are intended to provide regulated power to prevent power supply fluctuations or aberrations that can damage or cause malfunction of systems electrical/electronic equipment, such as computers and process controllers. There are two basic types of UPS systems: static and rotary.

b. Identify the various UPS components.

The following is summarized from IEEE Std 446-1995. Much greater detail is available from this source.

The basic components of a static UPS system are the battery, rectifier or battery charger, inverter, and often a static transfer switch. A basic rotary UPS system is essentially a motor-generator set that provides isolation between the incoming power supply and the load and that buffers power supply aberrations by flywheel mechanical inertia effect. Another significant component of a UPS system is the isolation transformer that diminishes or removes system harmonics and surges to the UPS.

c. Describe the use of UPS in safety systems (such as a radiation criticality accident alarm system).

The following is taken from NFPA 70B.

When periodic checks are conducted in the maintenance of system alarms, on a quarterly basis, a visual inspection should be made for signs of overheating and corrosion. Wherever additional loads are connected to the UPS, the protective-device coordination, calibration, and proper operation of the modified system should be checked.

9. Electrical personnel shall demonstrate a working level knowledge of Variable Frequency (speed) Drives (VFDs).

a. Describe the major components and operation of a VFD.

The following is taken from DOE/GO-102001-1165.

Variable-frequency drives (VFDs), a type of variable-speed drive, are controllers that vary the speed of induction motors. VFDs save substantial energy when applied to variable-torque loads, thus reducing electricity bills for most facilities. These energy savings are possible with variable-torque loads, such as fans and pumps, because torque varies as the square of speed, and HP varies as the cube of speed. For example, if fan speed is reduced by 20 percent, motor HP (and energy consumption) is reduced by 50 percent.

VFDs generate variable voltage and frequency output in the proper volts/hertz ratio for an induction motor from the fixed utility-supplied power. VFDs can be retrofitted into existing motor systems and can operate both standard and high-efficiency motors ranging in size from 1/3 hp to several thousand hp. Unlike mechanical or hydraulic motor controllers, they can be located remotely and do not require mechanical coupling between the motor and the load. This simplifies the installation and alignment of motor systems.

Three major VFD designs are commonly used: pulsewidth modulation (PWM), current source inverter (CSI), and variable source inverter (VSI). A fourth type, the flux vector PWM drive, is gaining popularity but is considered too expensive and sophisticated for most applications. Knowing the characteristics of the load is critical in evaluating the advantages and disadvantages of each technology.

- **Pulse-width modulation** is the dominant VFD design in the ½ hp to 500 hp range because of its reliability, affordability, and availability. PWM outputs emulate sinusoidal power waves by varying the width of voltage pulses in each half cycle. Advantages of PWMs are low harmonic motor heating, excellent input displacement power factor, high efficiencies at 92–96%, and ability to control multiple motor systems with a single drive.
- **Current source inverter** designs are quite reliable because of their inherent current-limiting characteristics and simple circuitry. CSIs have regenerative power capabilities, meaning that CSI drives can reverse the power flow back from the motor through the drive. However, CSIs “reflect” large amounts of power harmonics back to the source, have poor input power factors, and produce jerky motor operations (cogging) at very low speeds. CSIs are typically used for large (over 300 hp) induction and synchronous motors.
- **Voltage source inverter** designs are similar to CSI designs, but VSIs generate variable-frequency outputs to motors by regulating *voltage* rather than current. Harmonics, power factor, and cogging at low frequencies can be problems.

b. Give examples where VFDs are used in safety systems and in other applications.

The following is taken from Alliant Energy, *Variable Frequency Drives.*

VFDs accomplish part load control by varying electric motor speed. Energy savings of 50 percent or more over other part load control strategies are common.

The majority of variable frequency drive applications are for centrifugal pumps and fans. The savings potential for these devices is the largest since the theoretical input power varies with the cube of fan/pump speed and volume.

For example, a fan operating at half speed will require only about 13 percent of full-speed power. Losses in the variable frequency drive will reduce savings somewhat, but the savings are still very impressive.

There are several methods for air and water flow control, including recirculating a portion of the flow, throttling, variable inlet vanes, and variable frequency drives.

Recirculating part of the flow results in the fan or pump operating at full volume all the time. Only a portion of the flow is used for the system or process and the rest is recirculated back to the inlet of the fan or pump. This is the least-efficient means of controlling flow.

Throttling essentially chokes the outlet of the pump or fan to decrease flow much like holding your thumb over the end of a garden hose. The pressure increases and the flow decreases. This results in some energy savings over a constant volume recirculating system but is still wasteful.

Variable inlet vanes apply only to fans and compressors, not pumps. Inlet vanes control flow by pre-spinning the air entering a fan wheel or compressor impeller in the direction of rotation, which effectively varies its capacity.

VFDs can also be applied to what are called constant torque loads. Unlike the fan and pump power that varies with the cube of speed, constant torque applications vary power in direct proportion to speed. This results in lower savings for a given reduction in speed but there are still significant savings available in some applications.

VFDs can be installed with manual or automatic bypasses. In the early days of the variable frequency drives, bypasses were more common since variable frequency drives were not as reliable as they are at the present time. The bypasses were installed in the event of a drive failure to ensure the system or process would remain on line. Bypasses are still available but not always installed. The criticality of the application must be considered in each case to determine whether the added cost and security of a bypass is warranted.

Nearly all variable frequency drives manufactured today are referred to as pulse width modulation drives. These drives contain electronic circuitry that converts the 60 Hz line power to DC, then pulses the output voltage for varying lengths of time to mimic an AC at the frequency desired.

c. Describe the importance of line filtering for VFD equipment.

The following is taken from Alliant Energy, *Variable Frequency Drives*.

Harmonic filtering may be necessary in some applications. VFDs can produce harmonics that can make their way back to the rest of the building and interfere with sensitive electronic equipment and machines. Line reactors can be used on smaller drives of 20 hp and less to dampen and mitigate harmonics.

The following is taken from Pacific Gas and Electric Company, *Solution of EMI Problems from Operation of Variable Frequency Drives*.

Electromagnetic interference filters for VFD applications are typically structured as low-pass filters with series inductance and bypass capacitors connected in line-to-ground mode. These filters are usually installed on the input leads of the VFD. The line-to-ground by-pass capacitors in the filter provide a low impedance path for the common-mode noise currents to flow back to the VFD input out of the ground. The common-mode and phase inductors or the EMI filter provide high impedance to the high-frequency noise current. Drive-based equipment that must meet the European Conformity requirements must use an EMI/RFI filter connected to the drive input.

d. Describe the importance of proper selection of the cable and lead wires for use with VFDs to minimize the effect of electromagnetic interference on nearby equipment and adjacent systems.

The following is taken from Pacific Gas and Electric Company, *Solution of EMI Problems from Operation of Variable Frequency Drives*.

Abrupt voltage transitions on the output terminals of a VFD are an inherent source of radiated and conducted EMI. These voltage transition times are essentially determined by the rise and fall time of the semiconductor devices used in the inverter section of VFDs.

Electromagnetic interference problems can be minimized to a great degree by adopting preventive measures during the installation phase of VFDs. The most successful preventive measure is to use a shielded power cable to connect the VFD to the motor. This forces the noise current to flow through the shield back to the inverter, before it gets out into the system grid and takes multiple high-frequency paths that are difficult to track down in an installation.

The use of shielded power cables also reduces the area of the loop antenna that is responsible for radiated interference. The shield should be connected to ground at both ends. It is important to ensure good electrical contact from the installation plate through the installation screws to the metal cabinet of the VFD. Cable clamps should be used instead of twisted shield ends, since this ruins the shielding effect at high frequencies.

If a shielded cable is not used, avoid random lay of unshielded cables in cable troughs. Using 3-wire plus ground conductor (green wire) in a conduit ensures some degree of noise abatement as the conduit and the green wire carry most of the return current. However, accidental contact with grid ground structure due to strap supports, or other equipment, is still a possibility. In contrast, with a shielded cable, this situation can be avoided by using a polyvinyl chloride outer coating.

In addition to the use of shielded power cable, the following noise reduction practices are usually employed for control signal wiring practice:

- Twist the leads to provide a balanced capacitive coupling.
- Use shielded cable to return the noise current flowing in the shield back to the source, instead of through the signal leads.
- Maintain at least 8-inch separation between control and power wires in open air, conduit, or cable trays.
- Use a common-mode choke wound with multiple turns of both signal and shield.
- Use optical isolation modules for control signal communications.

e. Describe other issues related to the transients and harmonics generated by use of VFDs, and how they need to be addressed to obtain reliable and safe system operation and long cable life (IEEE Emerald Book; reference IEEE Std-1100 and IEEE Std-1050).

The following is taken from Electrical Construction & Maintenance Magazine, *Line Reactors and VFDs.*

Address harmonics by using line reactors on the line side of a VFD. Harmonic-compensated line reactors are specially designed to handle the waveform’s harmonic content. By inserting inductive reactance into the circuit, which is a high impedance to harmonic frequencies, line reactors reduce the amount of harmonics produced by a VFD system. For harmonic reduction purposes, 5% impedance line reactors are typically applied to the input of motor drives 20 hp and higher. This reduces input harmonics to 35% total harmonic current distortion or less and minimizes the effects of harmonics on motors and other devices powered off the same electrical system.

In situations where drives are located very close to the incoming facility power source, such as a substation, they may be susceptible to any incoming spikes and other transients. This is because there may not be enough impedance (in the form of transformers, power feeders, and the like) to help counteract these transient voltage spikes. This situation can damage the front end (diode section) of the drives or cause nuisance overvoltage tripping on the system. Installing a 5% impedance line reactor at the input to each drive helps counteract line spikes, keeping them from tripping or damaging the drives.

On the other hand, if drives are located far from the facility power source (as often seen in hospitals), they may be affected by line harmonics caused by other harmonic-generating equipment (nonlinear loads). In most applications, harmonic problems are best solved at their source. Large nonlinear loads, such as VFDs, should have a 5% impedance line reactor applied on the input to those pieces of equipment to minimize the system harmonics.

10. Electrical personnel shall demonstrate a working level knowledge of electrical test instruments and measuring devices.

a. Describe the purpose and method of operation of the following in-place measuring devices, and explain how to use the correct electrical instrument/measuring device in accordance with the manufacturer's specifications and instructions (i.e., within the device's rated voltage of 600 volts or less):

- **Voltmeter**
- **Ammeter**
- **Ohmmeter**
- **Wattmeter**
- **Ampere-hour meter**
- **Power factor meter**
- **Ground detector**
- **Synchroscope**
- **Megger**
- **Power quality monitors**

The information for all the terms in this KSA, except for power quality monitors, is taken from DOE-HDBK-1011/4-92. The information on power quality monitors is taken from NFPA 70B.

Voltmeter

A simple DC voltmeter can be constructed by placing a resistor, called a *multiplier*, in series with the ammeter meter movement, and marking the meter face to read voltage. Voltmeters are connected in parallel with the load being measured. When constructing a voltmeter, the resistance of the multiplier must be determined to measure the desired voltage.

When a voltmeter is connected in a circuit, the voltmeter will draw current from that circuit. This current causes a voltage drop across the resistance of the meter, which is subtracted from the voltage being measured by the meter. This reduction in voltage is known as the *loading effect* and can have a serious effect on measurement accuracy, especially for low-current circuits. The accuracy of a voltmeter is defined as the ratio of measured voltage when the meter is in the circuit to the voltage measured with the meter out of the circuit.

Ammeter

The ammeter measures electric current. It may be calibrated in amperes, milliamperes, or microamperes. In order to measure current, the ammeter must be placed in series with the circuit to be tested. When an ammeter is placed in series with a circuit, it will increase the resistance of that circuit by an amount equal to the internal resistance of the meter.

The percent loading error is that percent of error due to loading effects that result from the added resistance of the meter. A second error that occurs in an ammeter is calibration error. Calibration error is an error that occurs due to inaccurately marked meter faces. Typical values of calibration error in terms of full-scale current are about 3%.

Ohmmeter

The ohmmeter is an instrument used to determine resistance. A simple ohmmeter consists of a battery, a meter movement calibrated in ohms, and a variable resistor. Ohmmeters are connected to a component that is removed from the circuit. The reason for removing the component is that measurement of current through the component determines the resistance. If the component remains in the circuit and a parallel path exists in the circuit, the current will flow in the path of least resistance and give an erroneous reading.

When the unknown resistance is connected across the ohmmeter terminals, the current is measured by calculating the total series resistance. An easy way to determine ohmmeter deflection is by use of a deflection factor, which is the ratio of circuit current to meter current.

Wattmeter

The wattmeter is an instrument that measures DC power or true AC power. The wattmeter uses fixed coils to indicate current, while the movable coil indicates voltage. Wattmeters are rated in terms of their maximum current, voltage, and power. All of these ratings must be observed to prevent damage to the meter.

Total power in a 3ϕ circuit is the sum of the powers of the separate phases. The total power could be measured by placing a wattmeter in each phase; however, this method is not feasible since it is often impossible to break into the phases of a delta load. It also may not be feasible for the Y load, since the neutral point to which the wattmeters must be connected is not always accessible. Normally, only two wattmeters are used in making 3ϕ power measurements. In balanced 3ϕ systems, with any power factor, total power is calculated by adding the A and B phase powers.

Ampere-Hour Meter

The ampere-hour meter registers ampere-hours and is an integrating meter similar to the watt-hour meter used to measure electricity usage in a home. Typical ampere-hour meters are digital indicators similar to the odometer used in automobiles. The ampere-hour meter is a DC meter that will register in either direction depending on the direction of current flow. For example, starting from a given reading, it will register the amount of discharge of a battery; when the battery is placed on charge, it will operate in the opposite direction, returning once again to its starting point. When this point is reached, the battery has received a charge equal to the discharge, and the charge is stopped. It is normally desired to give a battery a 10% overcharge. This is accomplished by designing the ampere-hour meter to run 10% slow in the charge direction.

These meters are subject to inaccuracies and cannot record the internal losses of a battery. They attempt to follow the charge and discharge, but inherently do not indicate the correct state of charge. Similar to an ammeter, the ampere-hour meter is connected in series. Although the ampere-hour meters were used quite extensively in the past, they have been largely superseded by the voltage-time method of control.

Power Factor Meter

A power factor meter is a type of electrodynamometer movement when it is made with two movable coils set at right angles to each other. At a power factor of unity, one potential coil current leads and one lags the current in phase B by 30°; thus, the coils are balanced. A change in power factor will cause the current of one potential coil to become more in phase and the other potential coil to be more out of phase with the current in phase B, so that the moving element and pointer take a new position of balance to show the new power factor.

Ground Detector

The ground detector is an instrument that is used to detect conductor insulation resistance to ground. An ohmmeter, or a series of lights, can be used to detect the insulation strength of an ungrounded distribution system. Most power distribution systems in use today are of the grounded variety; however, some ungrounded systems still exist. In the ohmmeter method, a DC voltage is applied to the conductor. If a leakage path exists between the conductor insulator and ground, a current will flow through the ground to the ohmmeter proportional to the insulation resistance of the conductor. In the ground detector lamp method, a set of three lamps connected through transformers to the system is used. To check for grounds, the switch is closed and the brilliance of the lamps is observed. If the lamps are equally bright, no ground exists and all the lamps receive the same voltage. If any one lamp is dark, and the other two lamps are brighter, the phase in which the darkened lamp is in is grounded. In this case, the primary winding of the transformer is shorted to ground and receives no voltage.

Synchroscope

A synchroscope indicates when two AC generators are in the correct phase relation for connecting in parallel and shows whether the incoming generator is running faster or slower than the on-line generator. The synchroscope consists of a two-phase stator. The two stator windings are at right angles to one another, and by means of a phase-splitting network, the current in one phase leads the current of the other phase by 90°, thereby generating a rotating magnetic field. The stator windings are connected to the incoming generator, and a polarizing coil is connected to the running generator.

The rotating element is unrestrained and is free to rotate through 360°. It consists of two iron vanes mounted in opposite directions on a shaft, one at the top and one at the bottom, and magnetized by the polarizing coil.

If the frequencies of the incoming and running generators are different, the synchroscope will rotate at a speed corresponding to the difference. It is designed so that if incoming frequency is higher than running frequency, it will rotate in the clockwise direction; if incoming frequency is less than running frequency, it will rotate in the counterclockwise direction. When the synchroscope indicates 0^{o}° phase difference, the pointer is at the “12 o’clock” position and the two AC generators are in phase.

Megger

The megger is a portable instrument used to measure insulation resistance. The megger consists of a hand-driven DC generator and a direct reading ohmmeter. The moving element of the ohmmeter consists of two coils, A and B, which are rigidly mounted to a pivoted central shaft and are free to rotate over a C-shaped core. These coils are connected by means of flexible leads. The moving element may point in any meter position when the generator is not in operation.

As current provided by the hand-driven generator flows through coil B, the coil will tend to set itself at right angles to the field of the permanent magnet. With the test terminals open, giving an infinite resistance, no current flows in coil A. Coil B will govern the motion of the rotating element, causing it to move to the extreme counterclockwise position, which is marked as infinite resistance.

Power Quality Monitors

Power quality monitors assist the troubleshooter in identifying and solving many power quality problems. Disturbance waveshapes from these monitors provide important clues for locating the source of problems.

Monitoring can be used to determine the presence of transients. Storage-type, high-bandwidth oscilloscopes with high-voltage capability can be used, but more information can be obtained from the use of power disturbance analyzers specifically designed for transient and other types of power-quality problems. Monitoring might be required over an extended period of time, due to the characteristics of transients, which vary as loads and system configurations change. Monitoring is often performed at specific locations where a sensitive load is connected or is to be connected. Other devices on the monitored circuit, such as the power quality monitor itself, can contain surge-protection devices that limit transients and distort the results. An alternative power source for powering monitoring equipment should be used if possible.

Power monitoring instruments are quite sensitive, and outside factors can influence their accuracy.

b. Describe safe methods for using the following portable test equipment:

- **Ammeter**
- **Voltmeter**
- **Ohmmeter**

The following is taken from IEEE Std 242-2001.

Portable equipment should be handled in a manner that will not cause damage. Flexible electric cords connected to equipment should not be used for raising or lowering the equipment. Flexible cords should not be fastened with staples or hung in such a fashion as could damage the outer jacket or insulation.

Employees' hands should not be wet when plugging and unplugging flexible cords and cord-and-plug-connected equipment if energized equipment is involved. Energized plug and receptacle connections should be handled only with insulating protective equipment if the condition of the connection could provide a conductive path to the employee's hand (if, for example, a cord connector is wet from being immersed in water). Locking-type connectors should be secured after connection.

Before use on any shift, portable cord-and-plug-connected equipment should be visually inspected for external defects (such as loose parts, deformed and missing pins) and for evidence of possible internal damage (such as pinched or crushed outer jacket).

Overcurrent protection of circuits and conductors should not be modified, even on a temporary basis, beyond that permitted by NFPA 70E, Article 410.9, "Overcurrent Protection."

Trailing cables should be of minimal length, of adequate construction, and properly protected (e.g., by ground-fault circuit-interrupting circuit breakers); and cable connectors should be of suitable design for the environment in which they are operating. All portable equipment should be regularly inspected and tested; should have a label attached showing the due date for the next test; and, where feasible, should be inspected before each use.

c. Describe the importance of tolerances and calibration requirements for test instruments.

The following is taken from NFPA 70B.

All test equipment should be calibrated at regular intervals to ensure the validity of the data obtained. In order to get valid test results, it might be necessary to regulate the power input to the test equipment for proper waveform and frequency and to eliminate voltage surges.

Equipment calibrations should be scheduled on a routine basis, with the frequency depending on the operating conditions particular to the process or equipment. In general, any test equipment used for the calibration of other equipment should have an accuracy at least twice the accuracy of the equipment under test. The test equipment should be maintained in good condition and should be used only by qualified test operators.

Each facility differs in its tolerance to harmonic distortion. There are guidelines that can be followed to determine if harmonics are within acceptable limits. IEEE Std 519, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems,* is one such standard. Other information sources include the following: American National Standards Institute (ANSI)/IEEE C57.110, *Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents,* and IEEE Std 1100, *Recommended Practice for Powering and Grounding Sensitive Electronic Equipment*.

d. Describe the importance of different category meters (such as CAT I, CAT II, CAT III, and CAT IV; reference UL 3111-1).

[Note: UL 3111-1 has been superseded by UL 61010B-1. Other UL 3111-series standards referenced in the discussion have also been superseded. Their successors are shown parenthetically. The candidate is encouraged to review the new standards for applicability.]

The information for KSAs 'd' and 'e' is taken from Electrical Construction & Maintenance Magazine, "What You Need to Know About Category Ratings." Both of these KSAs are discussed under KSA 'e' below.

e. Describe the types of meters used for over 600 volts.

Test instruments are rated on their ability to withstand a voltage spike, which is applied through a specified level of resistance (table 3). The ratings are broken down by categories—Cat I, II, III, and IV.

Cat I-rated test instruments are signal-level tools for telecommunications and electronic equipment. Transient voltage risk is limited, but still exists, due to the distances between equipment locations and other equipment located between it and the primary electrical supply. The International Electrotechnical Commission (IEC) no longer specifies protection levels for Cat I instruments. Underwriters Laboratories (UL) 3111-1, *Standard for Electrical Measuring and Test Equipment; Part 1: General Requirements,* specifies that a Cat I 150 V-rated instrument must be protected to 800 V. Under IEC 61010-1, 2nd edition, *Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use,* a Cat I 150 V meter could be protected only to 500 V, as long as that information is in the user's manual.

Cat II-rated test instruments cover the local level of circuits for fixed or non-fixed power devices. This includes most lighting equipment, appliances, and 120 V or 240 V equipment inside a building.

Cat III-rated test instruments can withstand the transient voltage range found on most distribution circuits. These instruments are used primarily on fixed primary feeders or branch circuits. They're separated from Cat IV utility service or other high-voltage source equipment by at least one level or through transformer isolation.

Cat IV-rated test instruments are designed for testing on the primary supply source, which also includes 120 V or 240 V overhead or underground lines that power detached buildings or underground lines that power well pumps. The Cat IV rating covers the highest and most dangerous level of transient overvoltage electricians encounter when working on utility service equipment like exterior transformers.

The latest UL standard for electrical test instruments is UL 61010B-1, *UL Standard for Safety Electrical Measuring and Test Equipment; Part 1: General Requirements*, which is a revision of UL 3111-1. It specifies the general safety requirements, such as material, design, and testing requirements, and the environmental conditions in which the standard applies. UL 3111-2-031 (UL 61010B-2-031, *Electrical Equipment for Measurement, Control, and Laboratory Use; Part 2: Particular Requirements for Hand-Held Probe Assemblies for Electrical Measurement and Test*) lists additional requirements for test probes. The requirements for hand-held current clamps, such as the current measuring portion of clamp meters, are included in UL 3111-2-032 (UL 61010B-2-032, *Standard for Electrical Equipment for Measurement, Control, and Laboratory Use; Part 2: Particular Requirements for Hand-Held Current Clamps for Electrical Measurement and Test*).

Table 3. Category rating table

Rated voltage	IEC 61010-1 2nd Edition			UL 61010B-1 (UL 3111-1)		
	CAT IV	CAT III	CAT II	CAT III	CAT II	CAT I
150V	4,000V	2,500V	1,500V	2,500V	1,500V	800V
300V	6,000V	4,000V	2,500V	4,000V	2,500V	1,500V
600V	8,000V	6,000V	4,000V	6,000V	4,000V	2,500V
1,000V	12,000V	8,000V	6,000V	8,000V	6,000V	4,000V
Resistance	2 ohms	2 ohms	12 ohms	2 ohms	12 ohms	30 ohms

Source: Electrical Construction & Maintenance Magazine, "What You Need to Know About Category Ratings"

11. Electrical personnel shall demonstrate a familiarity level knowledge of the principles and concepts of natural phenomena hazards such as static electricity (NFPA 77) and their effects on personnel and electrical systems.

a. Discuss the potential impact of lightning on electrical systems at defense nuclear facilities.

The information for KSAs 'a' and 'b' is taken from DOE M 440.1-1A-2006.

Lightning presents a hazard to facilities as follows:

- The electrical current produced by a voltage gradient resulting from a lightning strike could cause damage or fires in electrical fixtures and equipment.
- The lightning could initiate a fire involving combustible materials in the facility.
- It could affect support systems such as fire protection and security. Lightning can reach a structure not only by direct strike, but also indirectly by coupling to a conductor that penetrates the structure.

b. Discuss various methods of lightning protection as preventive measures (e.g., surge suppressors, Faraday cages, etc.).

There are many methods for ensuring lightning protection. Several key ones are discussed here.

Strike Termination System: components

- Air Terminal: An air terminal is the component of a lightning protection system (LPS) used to intercept lightning strikes. Air terminals include vertical spikes attached to the structure (commonly referred to as Franklin Rods) and overhead wires (as used with catenary systems) or grids.
- Conductors: Conductors provide low impedance paths from air terminals to the earth electrode system. Where wires are used as down conductors, they shall meet the requirements of NFPA 780. Lightning conductors should run vertical or horizontal. If run upwards, they must have a rise of no more than 1/4 pitch. In a Faraday cage-based LPS, the structural elements have a higher current carrying capacity and lower impedance to ground than wire down conductors. Structures with such an LPS do not require wire down conductors.

Grounding

- LPSs, to include integral and catenary systems, but with the exception of Faraday cage or Faraday-like Shield systems, require an earth electrode (ground) system to dissipate the electrical energy of a lightning strike to the earth. The use of earth electrode systems with a Faraday-like shield LPS is not required as the floor of such a structure acts as the earth (ground) electrode; however, electrical safety grounding requirements do apply. Examples of earth electrode systems include ground rods, a ring electrode (counterpoise) system, buried metal plates, or Ufer grounds.

Bonding

- Bonding provides a physical and electrical connection from all parts of the LPS to the ground connection. Bonding produces electrical continuity between the LPS and metallic objects to minimize potential differences. Methods of bonding include mechanical, compression and thermal connections.

Surge Suppression for Incoming Conductors

- Surge suppression devices shall be provided in accordance with NFPA and the provisions of this Manual on each power line, signal line, or communication line conductor entering the LPS protected structure. They shall be located between the respective conductor and the structure ground and/or Faraday cage, as close as reasonably achievable to the point where the conductor penetrates the LPS zone of protection or the structure. All cabling, power cabling, communication lines, data lines, and electrical conduit shall be buried underground in metallic conduit for a minimum of 50 ft (15.2 m) before entering an explosives structure. These and other metallic utility lines and pipes shall be electrically bonded to the LPS or structural steel of the building as close as reasonably achievable to their entry point.

Sideflash (Arcing) Protection

- Sideflash is an electrical spark caused by differences of potential that occurs between conductive metal bodies or between conductive metal bodies and a component of the LPS or earth electrode system. Sideflash presents direct and indirect hazards to facility personnel and components.

For further information, see also NFPA 780, *Standard for the Installation of Lightning Protection Systems.*

c. Briefly describe the safety measures and design features commonly used as safeguards against natural hazards and identify the relevant industry consensus standards that codify accepted design and installation practices for these safeguards. Reference the following:

- **DOE-STD-1020-2002, Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities**
- **DOE-STD-1021-93, Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components**
- **DOE-STD-1022-94, Natural Phenomena Hazards Site Characterization Criteria**

DOE-STD-1020-2002, Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities

This standard, developed from UCRL-15910, *Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards,* provides criteria for design of new structures, systems, and components (SSCs) and for evaluation, modification, or upgrade of existing SSCs so that DOE facilities safely withstand the effects of natural phenomena hazards (NPHs) such as earthquakes, extreme winds, and flooding.

DOE-STD-1020-2002 provides consistent criteria for all DOE sites across the United States. These criteria are provided as the means of implementing DOE O 420.1B and the associated Guides, and Executive Orders 12699, "Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction," and 12941, "Seismic Safety of Existing Federally Owned or Leased Buildings," for earthquakes.

The design and evaluation criteria in DOE-STD-1020-2002 provide relatively straightforward procedures to evaluate, modify, or upgrade existing facilities or to design new facilities for the effects of NPHs. The intent is to control the level of conservatism in the design/evaluation process such that (1) the hazards are treated consistently; and (2) the level of conservatism is appropriate for SSC characteristics related to safety, environmental protection, importance, and cost. The requirements for each hazard are presented in separate chapters. Terminology, guidelines, and commentary material are included in appendices that follow the requirement chapters.

Prior to applying these criteria, SSCs have been placed in one of five performance categories (PCs), PC-0 to PC-4. No special considerations for NPH are needed for PC-0; therefore, no guidance is provided. Different criteria are provided for the remaining four PCs, each with a specified performance goal. Design and evaluation criteria aimed at target probabilistic performance goals require probabilistic NPH assessments. NPH loads are developed from such assessments by specifying NPH mean annual probabilities of exceedance. Performance goals may then be achieved by using the resulting loads combined with deterministic design and evaluation procedures that provide a consistent and appropriate level of conservatism. Design/evaluation procedures conform closely to industry practices using national consensus codes and standards so that the procedures will be easily understood by most engineers. SSCs comprising a DOE facility are to be assigned to a PC utilizing the approach described in the DOE G 420.1-2 and performance categorization standard, DOE-STD-1021-93, *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*. These design and evaluation criteria (DOE-STD-1020) are the specific provisions to be followed such that the performance goal associated with the PC of the SSC under consideration is achieved. For each category, the criteria include the following steps:

1. NPH loads are determined at specified NPH probabilities as per DOE-STD-1023, Natural Phenomena Hazards Assessment Criteria.
2. Design and evaluation procedures are used to evaluate SSC response to NPH loads.
3. Criteria are used to assess whether or not computed response in combination with other design loads is permissible.
4. Design detailing provisions are implemented so that the expected performance during a potential NPH occurrence will be achieved.
5. Quality assurance (QA) and peer review are applied using a graded approach.

NPH safety requirements are briefly described in 10 CFR 830, "Nuclear Safety Management," and DOE O 420.1B, *Facility Safety*. The associated Guides are

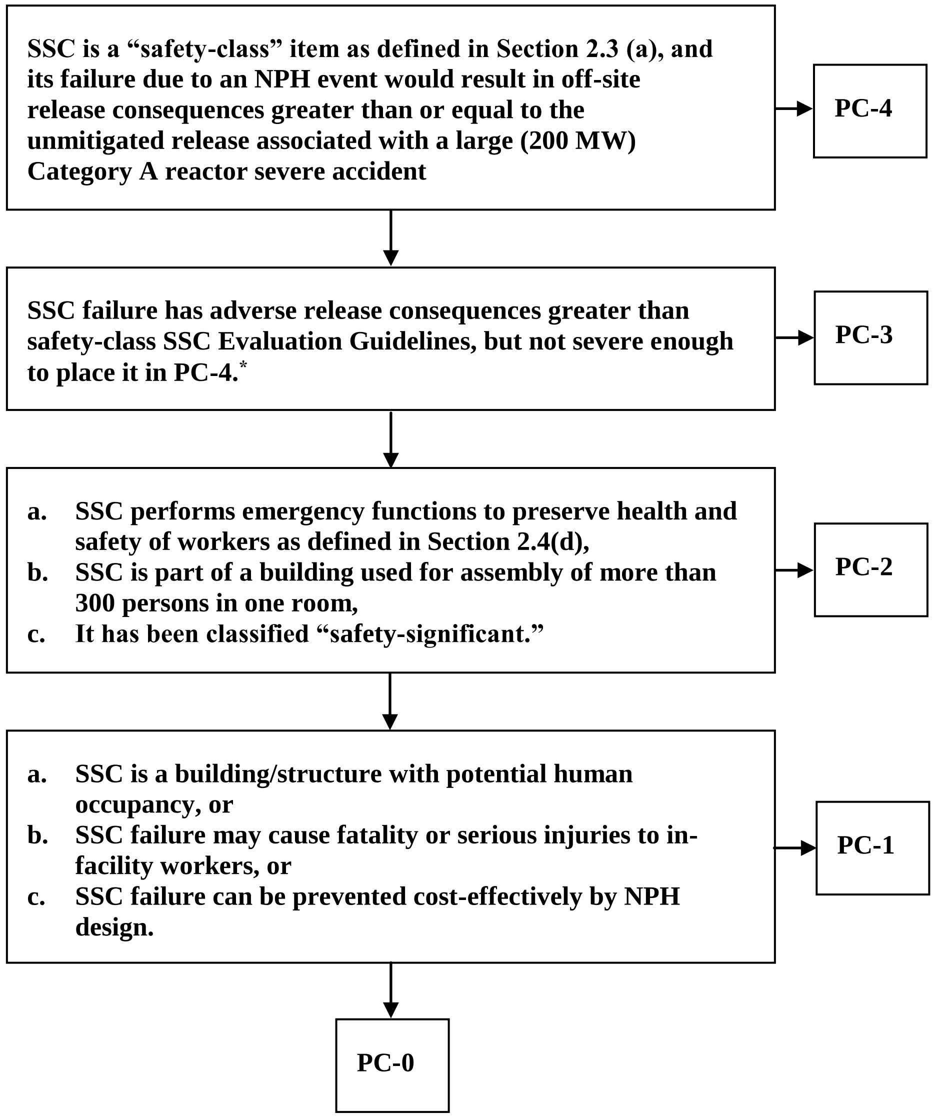
- DOE G 420.1-1, *Nonreactor Nuclear Safety Design Criteria and Explosive Safety Criteria Guide for use with DOE O 420.1 Facility Safety*
- DOE G 420.1-2, *Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Non-nuclear Facilities*
- DOE G 420.1-3, *Implementation Guide for DOE Fire Protection and Emergency Services Programs for Use with DOE O 420.1B, Facility Safety*

These guides describe acceptable methods to meet these requirements in a consistent manner throughout DOE, which include (1) providing a safe work place; (2) protecting against property loss and damage; (3) maintaining operation of essential facilities; and (4) protecting against exposure to hazardous materials during and after occurrences of NPHs. There is an established hierarchy in the set of documents that specify NPH requirements. In this hierarchy, 10 CFR part 830 is the highest authority (for nuclear facilities only), followed by DOE O 420.1B. The next set of controlling documents is the associated Guides followed by the set of NPH standards (DOE-STD-1020 through DOE-STD-1023). The NPH requirements have been developed to provide the necessary information that assesses the NPH safety basis for DOE facilities, which is documented in safety analysis reports (SARs), if available. 10 CFR part 830, DOE Order 5480.23, *Nuclear Safety Analysis Report*, and the guidance provided in the associated standard, DOE-STD-3009-94, *Preparation Guide For U. S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses,* prescribe the use of a graded approach for the effort to be expended in safety analysis and the level of detail required to be presented in the associated documentation. DOE NPH mitigation requirements are also consistent with the National Earthquake Hazards Reduction Program and Executive Orders 12699 and 12941.

DOE-STD-1021-93, Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components

DOE-STD-1021-93 provides guidelines to be used for NPH performance categorization of SSCs, and recommends systematic procedures to implement these guidelines.

The application of the basic categorization guidelines establishes the preliminary PC of SSCs, as summarized in figure 35. The preliminary PC may not account for system interactions but shall account for common-cause failure effects. Note that the hazard categorization is based on a method for assessing risk from potential hazards and follows the graded approach discussed in the NPH implementation Guide for DOE O 420.1B (DOE G 420.1-2).



Notes:
* Also refer to DOE G 420.1-2 for additional applications.

Source: DOE-STD-1021-93

Figure 35. Basic guidelines for preliminary NPH performance categorization of structures, systems, and components

Performance Category 4: An SSC shall be placed in preliminary performance category 4 (PC-4) if it is a safety-class (SC) item as defined in DOE-STD-3009-94 and if its failure during an NPH event could result in offsite release consequences greater than or equal to the unmitigated release from a large (>200 MWt) Category A reactor severe accident. There are not expected to be many such facilities in the DOE complex. Not all SC SSCs are necessarily PC-4. If the adverse offsite consequences from an NPH event are significant enough to make them SC but are substantially less than those associated with consequences from an unmitigated large Category A reactor severe accident, the SSCs should be placed in PC-3. An

SSC that does not satisfy the above criteria may also be placed in PC-4 for improved performance if justified from cost-benefit considerations.

Performance Category 3: An SSC shall be placed in preliminary performance category 3 (PC-3) if it is not covered in paragraph 2.4(b) of DOE-STD-1021-93, and if its failure results in adverse release consequences greater than SC SSC evaluation guidelines limits but much less than those associated with PC-4 SSCs. For additional applications refer to DOE G 420.1-2. An SSC that does not satisfy the criteria may also be placed in PC-3 for improved performance if justified from cost-benefit considerations. For new facilities, since it may not cost too much more to design the facility as PC-4 instead of PC-3, it may be desirable to design such PC-3 facilities in the conceptual design stage to PC-4 criteria, subject to funding constraints.

Performance Category 2: An SSC shall be placed in preliminary performance category 2 (PC-2) if it is not covered in paragraphs 2.4(b) and 2.4(c) of DOE-STD-1021-93, and if any of the following conditions apply:

- The SSC's failure by itself or in combination with one or more SSCs may result in loss of function of any emergency handling, hazard recovery, fire suppression, emergency preparedness, communication, or power system that may be needed to preserve the health and safety of workers and visitors. This includes NPH-caused release of radioactive and toxic materials that would result in these consequences.
- The SSC is part of a building that is primarily used for assembly of more than 300 persons (in one room), and the SSC failure may adversely affect the life safety of the occupants.
- The SSC has been classified safety-significant (SS). For details refer to DOE G 420.1-2. An SSC that does not satisfy the above criteria may also be placed in PC-2 from cost and mission considerations, (e.g., when SSC failure causes excessive downtime, the SSC is very difficult to replace, or SSC replacement/repair is very costly).

Performance Category 1: An SSC that is not covered in paragraphs 2.4(b), 2.4(c), and 2.4(d) in DOE-STD-1021-93 shall be placed in preliminary performance category 1 (PC-1) if any of the following conditions apply:

- It is a building/structure with potential human occupancy.
- The SSC's failure may cause a fatality or serious injuries to in-facility workers.
- The SSC's failure may cause damage that can be prevented or reduced cost-effectively by designing it to withstand NPH effects.

Performance Category 0: An SSC that is not covered in paragraphs 2.4(b) through 2.4(e) in DOE-STD-1021-93 may be placed in preliminary performance category 0 (PC-0), if it is not important because of safety, mission, or cost considerations, and if it is more cost-effective to replace or repair it than to design it to withstand NPH effects; however, an SSC whose failure may have any adverse effect on the performance of a PC-1, PC-2, PC-3, or PC-4 SSC shall not be placed in PC-0.

DOE-STD-1022-94, Natural Phenomena Hazards Site Characterization Criteria

The purpose of DOE-STD-1022-94 is to provide criteria for site characterization to provide site-specific information needed for implementing DOE O 420.1B requirements and to develop a site-wide database related to NPH that should be obtained to support individual SARs.

Criteria are presented for meteorological, hydrological, geological, seismological, and geotechnical studies to characterize the site and to provide the necessary site-specific information. The required information is necessary to complete the hazard assessments described in DOE-STD-1023-95, *Natural Phenomena Hazards Assessment Criteria*, and in turn to provide input for design and evaluation requirements described in DOE-STD-1020-2002, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*. The scope and degree of detail of investigations to address these NPHs depend on several factors, including the PCs of the SSCs making up the facilities; the hazard classification of the facilities; the subsurface conditions at the site; the meteorologic, hydrologic, and seismotectonic environment of the site region; and the extent of prior knowledge, investigations, and data regarding the site and site region. Although more detailed investigations are generally appropriate for facilities having higher PCs, investigations of lesser scope and detail may be appropriate when the existing knowledge of the site and region is extensive and up-to-date.

For a full list of design and installation practices for the many natural hazards described here, see DOE-STD-1022-94, *Natural Phenomena Hazards Site Characterization Criteria*.

12. Electrical personnel shall demonstrate a working level knowledge of DC generators.

a. Describe the relationship between shaft speed, field flux, and generated voltage.

The following is taken from DOE-HDBK-1011/2-92.

A basic DC generator has four primary parts: a magnetic field; a single conductor, or loop; a commutator (shaft); and brushes. The magnetic field may be supplied by either a permanent magnet or an electromagnet. A coil of wire is mounted in the shaft and electrical connections are made to this spinning coil via stationary carbon “brushes” contacting copper strips on the rotating shaft. The purpose of the brushes is to connect the generated voltage to an external circuit. In order to do this, each brush must make contact with one of the ends of the loop. An increase in field current will cause field flux to increase. Conversely, if the resistance of the field is increased, field flux will decrease. If the field flux of a DC motor is decreased, the motor speed will increase.

The relationship between shaft speed, field flux, and generated voltage is represented in the following equation:

$$V_G = K\Phi N$$

where
V_G = generated voltage
K = constant
Φ = generator field flux
N = shaft speed

b. Define the following:

- **Electromotive force**
- **Excitation**
- **Compounding**
- **Armature**
- **Terminal voltage**
- **Load current**
- **Shunt windings**
- **Series windings**

The definitions of all the terms in this KSA, except for EMF, are taken from DOE-HDBK-1011/2-92. The definition for EMF is taken from DOE-HDBK-1011/1-92.

Electromotive Force

EMF is the sum of the potential differences of all charged particles in an electrostatic field.

Excitation

The magnetic fields in DC generators are most commonly provided by electromagnets. A current must flow through the electromagnet conductors to produce a magnetic field. In order for a DC generator to operate properly, the magnetic field must always be in the same direction. Therefore, the current through the field winding must be DC. This current is known as the *field excitation current* and can be supplied to the field winding in one of two ways. It can come from a separate DC source external to the generator (e.g., a separately excited generator) or it can come directly from the output of the generator.

Compounding

One means of supplying a stable output voltage is by using a compound generator. The compound generator has a field winding in parallel with the generator armature (the same as a shunt-wound generator) and a field winding in series with the generator armature (the same as a series-wound generator). The two windings of the compounded generator are made such that their magnetic fields will either aid or oppose one another.

If the two fields are wound so that their flux fields oppose one another, the generator is said to be differentially compounded. Due to the nature of this type of generator, it is used only in special cases and will not be discussed further in this reference guide. If the two fields of a compound generator are wound so that their magnetic fields aid one another, the generator is said to be cumulatively compounded. As the load current increases, the current through the series field winding increases, increasing the overall magnetic field strength and causing an increase in the output voltage of the generator. With proper design, the increase in the magnetic field strength of the series winding will compensate for the decrease in shunt field strength. Therefore, the overall strength of the combined magnetic fields remains almost unchanged, so the output voltage will remain constant. In reality, the two fields cannot be made so that their magnetic field strengths compensate for each other completely. There will be some change in output voltage from the no-load to full-load conditions.

Armature

The purpose of the armature is to provide the energy conversion in a DC machine. In a DC generator, the armature is rotated by an external mechanical force, such as a steam turbine. This rotation induces a voltage and current flow in the armature. Thus, the armature converts mechanical energy to electrical energy. In a DC motor, the armature receives voltage from an outside electrical source and converts electrical energy into mechanical energy in the form of torque.

Terminal Voltage

Terminal voltage, as applied to DC generators, is defined as the voltage that can be measured at the output of the generator.

Load Current

Each electrical circuit has at least four basic parts: a source of EMF, conductors, load or loads, and some means of control. For example, the source of EMF might be the battery; the conductors could be the wires which connect the various component parts; the resistor would be the load; and a switch could be used as the circuit control device. A closed circuit is an uninterrupted, or unbroken, path for current from the source (EMF), through the load, and back to the source. An open circuit, or incomplete circuit, exists if a break in the circuit occurs; this prevents a complete path for current flow.

Shunt Windings

When the field winding of a generator is connected in parallel with the generator armature, the generator is called a shunt-wound generator. The excitation current in a shunt-wound generator is dependent upon the output voltage and the field resistance. Normally, field excitation is maintained between 0.5 and 5% of the total current output of the generator.

Series Windings

When the field winding of a DC generator is connected in series with the armature, the generator is called a *series-wound generator*. The excitation current in a series-wound generator is the same as the current the generator delivers to the load. If the load has a high resistance and only draws a small amount of current, the excitation current is also small. Therefore, the magnetic field of the series field winding is weak, making the generated voltage low. Conversely, if the load draws a large current, the excitation current is also high. Therefore, the magnetic field of the series field winding is very strong, and the generated voltage is high.

c. State the purpose of the following components of a DC machine:

- **Armature**
- **Rotor**
- **Stator**
- **Field**

The information for KSAs ‘c’ through ‘k’ is taken from DOE-HDBK-1011/2-92.

Armature

The purpose of the armature is to provide the energy conversion in a DC machine (refer to figure 36). In a DC generator, the armature is rotated by an external mechanical force, such as a steam turbine. This rotation induces a voltage and current flow in the armature. Thus, the armature converts mechanical energy to electrical energy. In a DC motor, the armature receives voltage from an outside electrical source and converts electrical energy into mechanical energy in the form of torque.

Rotor

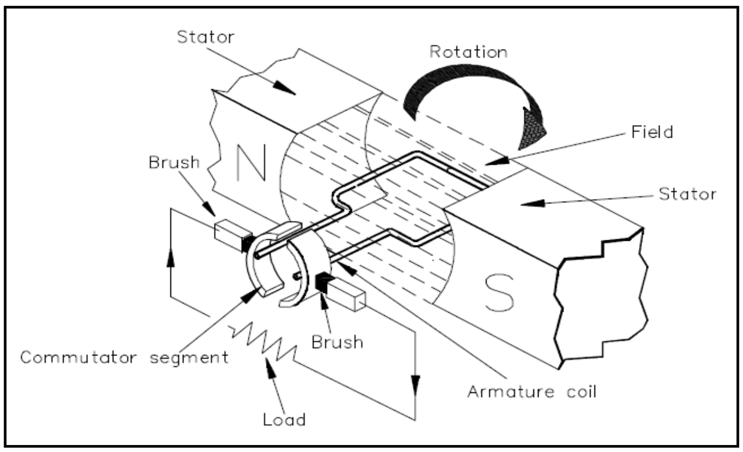
The purpose of the rotor is to provide the rotating element in a DC machine (figure 36). In a DC generator, the rotor is the component that is rotated by an external force. In a DC motor, the rotor is the component that turns a piece of equipment. In both types of DC machines, the rotor is the armature.

Stator

The stator is the part of a motor or generator that is stationary. In DC machines, the purpose of the stator is to provide the magnetic field. The stator in figure 36 is provided by a permanent magnet.

Field

The purpose of the field in a DC machine is to provide a magnetic field for producing either a voltage (generator) or a torque (motor). The field in a DC machine is produced by either a permanent magnet or an electromagnet. Normally, electromagnets are used because they have an increased magnetic strength, and the magnetic strength is more easily varied using external devices. In figure 36, the field is provided by the stator.



Source: DOE-HDBK-1011/2-92

Figure 36. Basic DC machine

d. Describe self-excited and separately excited generators.

The magnetic fields in DC generators are most commonly provided by electromagnets. A current must flow through the electromagnet conductors to produce a magnetic field. In order for a DC generator to operate properly, the magnetic field must always be in the same direction. Therefore, the current through the field winding must be DC. This current is known as the field excitation current and can be supplied to the field winding in one of two ways. It can come from a separate DC source external to the generator (e.g., a separately excited generator) or it can come directly from the output of the generator, in which case it is called a self-excited generator.

In a self-excited generator, the field winding is connected directly to the generator output. The field may be connected in series with the output, in parallel with the output, or a combination of the two. Separate excitation requires an external source, such as a battery or another DC source. It is generally more expensive than a self-excited generator. Separately excited generators are, therefore, used only where self-excitation is not satisfactory. They would be used in cases where the generator must respond quickly to an external control source or where the generated voltage must be varied over a wide range during normal operations.

e. Describe the operation of compound-wound generators.

Series-wound and shunt-wound generators have a disadvantage in that changes in load current cause changes in generator output voltage. Many applications in which generators are used require a more stable output voltage than can be supplied by a series-wound or shunt-wound generator. One means of supplying a stable output voltage is by using a compound generator. The compound generator has a field winding in parallel with the generator armature (the same as a shunt-wound generator) and a field winding in series with the generator armature (the same as a series-wound generator). The two windings of the compounded generator are made such that their magnetic fields will either aid or oppose one another. When the magnetic field flux is decreased, motor speed increases, for a constant generated voltage.

f. Describe how the terminal voltage of a DC generator is adjusted.

DC generator output voltage is dependent on three factors: the number of conductor loops in series in the armature, armature speed, and magnetic field strength. In order to change the generator output, one of these three factors must be varied. The number of conductors in the armature cannot be changed in a normally operating generator, and it is usually impractical to change the speed at which the armature rotates. The strength of the magnetic field, however, can be changed quite easily by varying the current through the field winding. This is the most widely used method for regulating the output voltage of a DC generator.

g. State the basis behind each DC generator rating.

A DC generator contains four ratings: voltage, current, power, and speed.

Voltage

The voltage rating of a machine is based on the insulation type and design of the machine.

Current

The current rating is based on the size of the conductor and the amount of heat that can be dissipated in the generator.

Power

The power rating is based on the mechanical limitations of the device that is used to turn the generator and on the thermal limits of conductors, bearings, and other components of the generator.

Speed

The speed rating, at the upper limit, is determined by the speed at which mechanical damage is done to the machine. The lower speed rating is based on the limit for field current (as speed increases, a higher field current is necessary to produce the same voltage).

h. Describe the internal losses found in a DC generator.

There are four internal losses that contribute to lower efficiency of a DC generator: copper losses, eddy-current losses, hysteresis losses, and mechanical losses.

Copper Losses

Copper loss is the power lost as heat in the windings; it is caused by the flow of current through the coils of the DC armature or DC field. This loss varies directly with the square of the current in the armature or field and the resistance of the armature or field coils.

Eddy-Current Losses

As the armature rotates within the field, it cuts the lines of flux at the same time that the copper coils of wire that are wound on the armature cut the lines of flux. Since the armature is made of iron, an EMF is induced in the iron, which causes a current to flow. These circulating currents within the iron core are called *eddy currents*. To reduce eddy currents, the armature and field cores are constructed from laminated (layered) steel sheets. The laminated sheets are insulated from one another so that current cannot flow from one sheet to the other.

Hysteresis Losses

Hysteresis losses occur when the armature rotates in a magnetic field. The magnetic domains of the armature are held in alignment with the field in varying numbers, dependent upon field strength. The magnetic domains rotate, with respect to the particles not held in alignment, by one complete turn during each rotation of the armature. This rotation of magnetic domains in the iron causes friction and heat. The heat produced by this friction is called *magnetic hysteresis loss*. To reduce hysteresis losses, most DC armatures are constructed of heat-treated silicon steel, which has an inherently low hysteresis loss. After the heat-treated silicon steel is formed to the desired shape, the laminations are heated to a dull red and then allowed to cool. This process, known as *annealing*, reduces hysteresis losses to a very low value.

Mechanical Losses

Rotational or mechanical losses can be caused by bearing friction, brush friction on the commutator, or air friction (called *windage*), which is caused by the air turbulence due to armature rotation. Careful maintenance can be instrumental in keeping bearing friction to a minimum. Clean bearings and proper lubrication are essential to the reduction of bearing friction. Brush friction is reduced by assuring proper brush seating, using proper brushes, and maintaining proper brush tension. A smooth and clean commutator also aids in the reduction of brush friction.

i. Describe the differences in construction between a shunt-wound and a series-wound DC generator with respect to the relationship between the field and the armature.

When the field winding of a generator is connected in parallel with the generator armature, the generator is called a *shunt-wound generator*. The excitation current in a shunt-wound generator is dependent upon the output voltage and the field resistance. Normally, field excitation is maintained between 0.5 and 5% of the total current output of the generator. When the field winding of a DC generator is connected in series with the armature, the generator is called a *series-wound generator*.

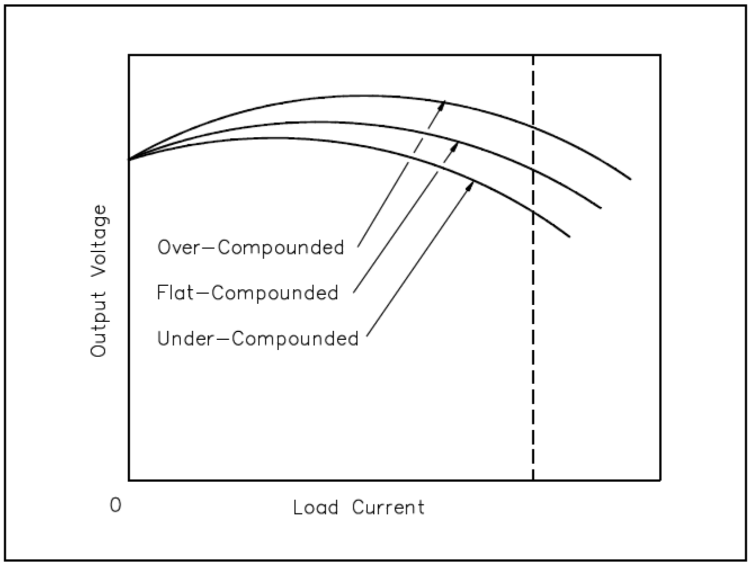
The excitation current in a series-wound generator is the same as the current the generator delivers to the load. If the load has a high resistance and only draws a small amount of current, the excitation current is also small. Therefore, the magnetic field of the series field winding is weak, making the generated voltage low. Conversely, if the load draws a large current, the excitation current is also high. Therefore, the magnetic field of the series field winding is very strong, and the generated voltage is high.

j. Describe the relationship between the shunt and series fields for cumulatively-compounded and differentially-compounded DC generators.

If the two fields are wound so that their flux fields oppose one another, the generator is said to be differentially compounded. Due to the nature of this type of generator, it is used only in special cases and will not be discussed further in this reference guide. If the two fields of a compound generator are wound so that their magnetic fields aid one another, the generator is said to be cumulatively compounded. As the load current increases, the current through the series field winding increases, increasing the overall magnetic field strength and causing an increase in the output voltage of the generator. With proper design, the increase in the magnetic field strength of the series winding will compensate for the decrease in shunt field strength. Therefore, the overall strength of the combined magnetic fields remains almost unchanged, so the output voltage will remain constant. In reality, the two fields cannot be made so that their magnetic field strengths compensate for each other completely. There will be some change in output voltage from the no-load to full-load conditions.

k. Describe the voltage-versus-current characteristics for a flat-compounded, over-compounded, and under-compounded DC generator.

In practical compounded generators, the change in output voltage from no-load to full-load is less than 5 percent. A generator with this characteristic is said to be *flat-compounded* (figure 37). For some applications, the series winding is wound so that it overcompensates for a change in the shunt field. The output gradually rises with increasing load current over the normal operating range of the machine. This type of generator is called an *over-compounded generator*. The series winding can also be wound so that it under-compensates for the change in shunt field strength. The output voltage decreases gradually with an increase in load current. This type of generator is called an *under-compounded generator*.



Source: DOE-HDBK-1011/2-92

Figure 37. Voltage vs. current for a compounded DC generator

13. Electrical personnel shall demonstrate a working level knowledge of DC motors.

a. Describe the basic construction and operation of the following four types of DC motors:
- **Shunt**
- **Separately excited**
- **Compound-wound**
- **Series**

The information for all the terms in this KSA, except for that on separately excited DC motors, is taken from DOE-HDBK-1011/2-92. The information on separately excited DC motors is taken from Freescale Semiconductor, Inc., *The Electric Motor: Here and Now.*

Shunt

A shunt-wound DC motor has a decreasing torque when speed increases. The decreasing torque vs. speed is caused by the armature resistance voltage drop and armature reaction. At a value of speed near 2.5 times the rated speed, armature reaction becomes excessive, causing a rapid decrease in field flux and a rapid decline in torque until a stall condition is reached.

The characteristics of a shunt-wound motor give it very good speed regulation, and it is classified as a constant speed motor, even though the speed does slightly decrease as load is increased.

Shunt-wound motors are used in industrial and automotive applications where precise control of speed and torque are required.

Separately Excited

In many traction applications where both armature voltage and stator current are needed to control the speed and torque of the motor from no load to full load, the separately excited DC motor is used for its high-torque capability at low speed, achieved by separately generating a high stator field current and enough armature voltage to produce the required rotor torque current. As torque decreases and speed increases, the stator field current requirement decreases and the armature voltage increases. Without a load (known as *zero torque speed*), the speed of the separately excited motor is strictly limited by the armature voltage and stator field current.

Separately excited DC motors are the first type of motor to use closed-loop control and can also be used in servo systems for control of speed and/or position.

Compound-Wound

The compounded motor is desirable for a variety of applications because it combines the characteristics of a series-wound motor and a shunt-wound motor. The compounded motor has a greater torque than a shunt motor due to the series field; however, it has a fairly constant speed due to the shunt field winding. Loads such as presses, shears, and reciprocating machines are often driven by compounded motors.

Series

Since the armature and field in a series-wound motor are connected in series, the armature and field currents become identical. As the speed decreases, the torque for a series-wound motor increases sharply. As load is removed from a series motor, the speed will increase sharply. For these reasons, series-wound motors must have a load connected to prevent damage from high speed conditions.

The advantage of a series-wound motor is that it develops a large torque and can be operated at low speed. It is a motor that is well-suited for starting heavy loads; it is often used for industrial cranes and winches where very heavy loads must be moved slowly and lighter loads moved more rapidly.

b. State the function of torque in a DC motor and explain how it is developed.

The information for KSAs ‘b’ through ‘h’ is taken from DOE-HDBK-1011/2-92.

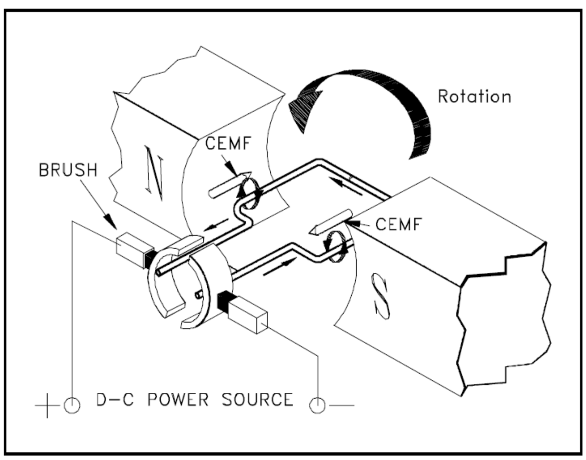
Torque is defined as that force that tends to produce and maintain rotation. The function of torque in a DC motor is to provide the mechanical output or drive the piece of equipment that the DC motor is attached to.

When a voltage is applied to a motor, current will flow through the field winding, establishing a magnetic field. Current will also flow through the armature winding, from the negative brush to the positive brush. Since the armature is a current-carrying conductor in a magnetic field, the conductor has a force exerted on it, tending to move it at right angles to that field. The left-hand rule for current-carrying conductors, which states that if the index finger of the left hand is pointed in the direction of the magnetic field (from north to south) and the thumb is pointed in the direction of motion of the conductor, the middle finger will point in the direction of current flow, shows the magnetic field on one side is strengthened at the bottom, while it is weakened on the other side. The right-hand rule for motors shows the direction in which a current-carrying conductor moves in a magnetic field. When the index finger is pointed in the direction of the magnetic field lines, and the middle finger is pointed in the direction of current flow, the thumb will point in the direction of force (motion). The sum of the forces, in pounds, multiplied by the radius of the armature, in feet, is equal to the torque developed by the motor in pound-feet.

c. Describe the function of a Counter-Electromotive Force (CEMF) and explain how it is developed in a DC motor.

In a generator using a rotating armature, the conductors cut the magnetic lines of force in the magnetic field. Voltage is induced in the armature conductors. This induced voltage opposes the applied voltage; it counteracts some of the applied voltage, which reduces the current flow through the armature. This induced voltage acts counter to applied voltage; therefore, it is called *counter-electromotive force*.

A generator action is developed in every motor. When a conductor cuts lines of force, an EMF is induced in that conductor. Current to start the armature turning will flow in the direction determined by the applied DC power source. After rotation starts, the conductor cuts lines of force. By applying the left-hand rule for generators, the EMF that is induced in the armature will produce a current in the opposite direction. The induced EMF, as a result of motor operation, is called *counter-electromotive force*, as illustrated in figure 38.



Source: DOE-HDBK-1011/2-92

Figure 38. Counter-electromotive force (CEMF)

Since the CEMF is generated by the action of the armature cutting lines of force, the value of CEMF will depend on field strength and armature speed, as shown in the following equation:

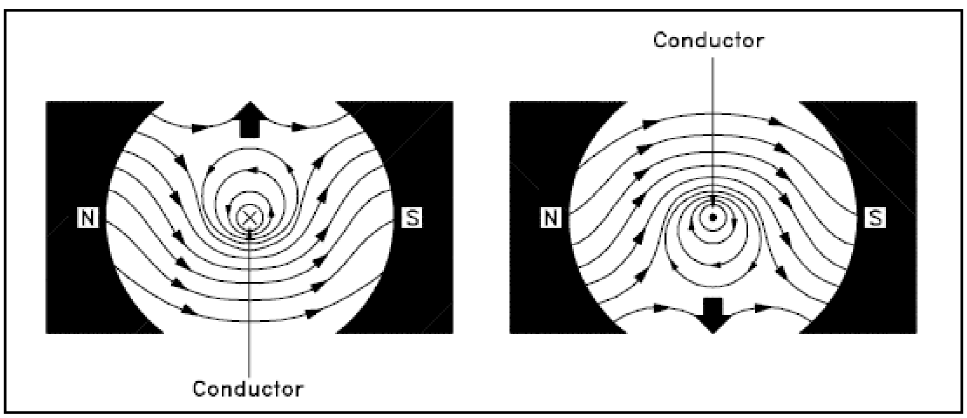
$$E_{CEMF} = K\Phi N$$

where
E_{CEMF} = counter-electromotive force
K = constant
Φ = field flux strength
N = speed of the armature

d. Describe the relationship between field current and magnetic field size in a DC motor.

There are two conditions that are necessary to produce a force on a conductor: the conductor must be carrying current, and the conductor must be within a magnetic field. When these two conditions exist, a force will be applied to the conductor, which will attempt to move the conductor in a direction perpendicular to the magnetic field. This is the basic theory by which all DC motors operate.

In figure 39, above the conductor on the left, the field caused by the conductor is in the opposite direction of the main field, and therefore opposes the main field. Below the conductor on the left, the field caused by the conductor is in the same direction as the main field, and therefore aids the main field. The net result is that above the conductor the main field is weakened, or flux density is decreased; below the conductor the field is strengthened, or flux density is increased. A force is developed on the conductor that moves the conductor in the direction of the weakened field (upward).



Source: DOE-HDBK-1011/2-92

Figure 39. Current-carrying conductors in a magnetic field

Above the conductor on the right, the field caused by the conductor is in the same direction as the main field, and therefore aids the main field. Below the conductor on the right, the field caused by the conductor is in the opposite direction of the main field, and therefore opposes the main field. The net result is that above the conductor the field is strengthened, or flux density is increased, and below the conductor, the field is weakened, or flux density is decreased. A force is developed on the conductor that moves the conductor in the direction of the weakened field (downward).

e. Describe how to adjust the speed of a DC motor.

The speed of a DC motor may be changed by using resistors to vary the field current and, therefore, the field strength. An increase in field current will cause field flux to increase. If field flux is decreased, motor speed increases, for a constant applied voltage. Conversely, if the resistance of the field is increased, field flux will decrease. If the field flux of a DC motor is decreased, the motor speed will increase. This increase in speed will then proportionately increase the CEMF. The speed and CEMF will continue to increase until the armature current and torque are reduced to values just large enough to supply the load at a new constant speed.

From the above discussion, note that DC motor speed is proportional to the applied armature voltage (V_a) and inversely proportional to field or pole flux (Φ); because flux is usually considered fixed, motor speed is therefore controlled by the applied armature voltage, V_a. The following equation shows this mathematical relationship.

$$N = V_a 1/\ \Phi$$

f. Describe the relationship between armature current and torque produced in a DC motor.

Since the armature is a current-carrying conductor in a magnetic field, the conductor has a force exerted on it, tending to move it at right angles to that field. The left-hand rule for current-carrying conductors shows the magnetic field on one side is strengthened at the bottom, while it is weakened on the other side. The right-hand rule for motors shows that there is a force exerted on the armature, which tends to turn the armature in the counter-clockwise direction. The sum of the forces, in pounds, multiplied by the radius of the armature, in feet, is equal to the torque developed by the motor in pound-feet.

If the armature current is reversed, but the field is the same, torque is developed in the opposite direction. Likewise, if the field polarity is reversed and the armature remains the same, torque is also developed in the opposite direction.

The force that is developed on a conductor of a motor armature is due to the combined action of the magnetic fields. The force developed is directly proportional to the strength of the main field flux and the strength of the field around the armature conductor. The field strength around each armature conductor depends on the amount of current flowing through the armature conductor.

The torque that is developed by the motor can be determined using the following equation:

$$T = K\Phi I_a$$

where
T = torque, pounds-feet

K = a constant depending on physical size of motor
Φ = field flux, number of lines of force per pole
I_a = armature current

g. Describe the torque-versus-speed characteristics for a shunt-wound and a series-wound DC motor.

Shunt-wound

The torque-speed relationship for a typical shunt-wound motor is shown in figure 40. A shunt-wound DC motor has decreasing torque when speed increases. The decreasing torque vs. speed is caused by the armature resistance voltage drop and armature reaction. At a value of speed near 2.5 times the rated speed, armature reaction becomes excessive, causing a rapid decrease in field flux, and a rapid decline in torque until a stall condition is reached.

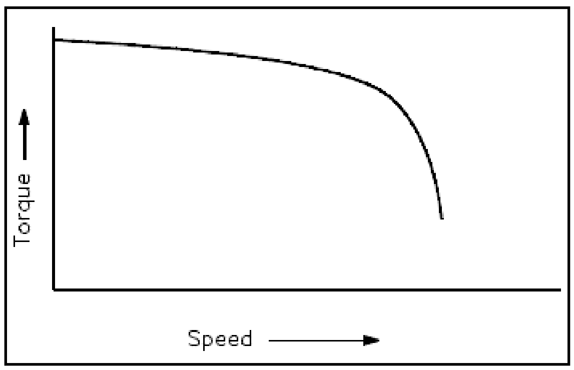
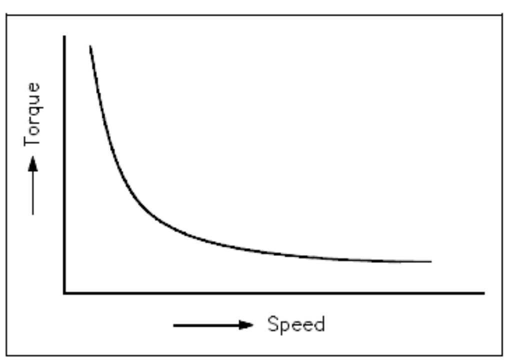


Figure 40. Torque vs. speed for a shunt-wound DC motor

Series-Wound

The torque-speed relationship for a typical series-wound motor is shown in figure 41. Since the armature and field in a series-wound motor are connected in series, the armature and field currents become identical. As the speed decreases, the torque for a series-wound motor increases sharply. As load is removed from a series motor, the speed will increase sharply. For these reasons, series-wound motors must have a load connected to prevent damage from high speed conditions.



Source: Figures 40 and 41, DOE-HDBK-1011/2-92

Figure 41. Torque vs. speed for a series-wound DC motor

h. Explain why starting resistors may be necessary for large DC motors.

The starting resistors are used in a DC motor by placing them in the starting circuit of the motor controller that is used to start the DC motor. Starting resistors are normally of variable resistances, with the value of resistance in the circuit at any time being either manually or automatically controlled. The maximum amount of resistance will always be inserted when the motor is first started. As the speed of the motor increases, CEMF will begin to increase, decreasing armature current. The starting resistors may then be cut out, in successive steps, until the motor reaches full running speed.

14. Electrical personnel shall demonstrate a working level knowledge of battery construction, voltage production, and hazards (IEEE Std-450, etc.).

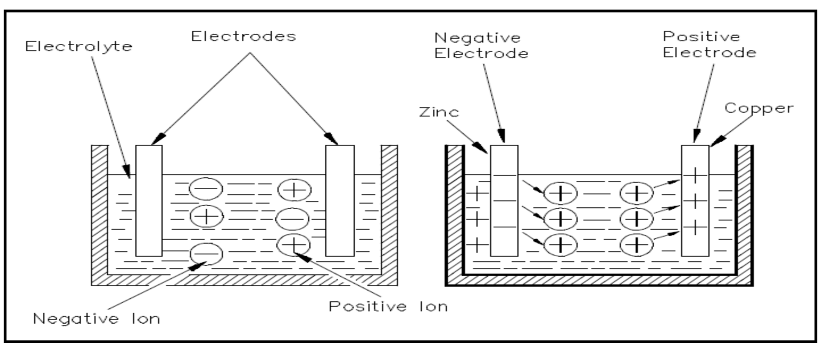
a. Using a cutaway drawing of a simple multi-cell storage battery, identify the following components and discuss their function:

- **Positive terminal**
- **Negative terminal**
- **Electrode**
- **Cell**

The information for KSAs ‘a’ and ‘b’ is taken from DOE-HDBK-1011/2-92.

The purpose of a battery is to store chemical energy and to convert this chemical energy into electrical energy when the need arises. A chemical cell (or voltaic cell) consists of two electrodes of different types of metals or metallic compounds and an electrolyte solution that is capable of conducting an electric current, as illustrated in figure 42.

A good example of a voltaic cell is one that contains zinc and copper electrodes. The zinc electrode contains an abundance of negatively charged atoms, and the copper electrode contains an abundance of positively charged atoms. When these electrodes are immersed in an electrolyte, chemical action begins. The zinc electrode will accumulate a much larger negative charge because it dissolves into the electrolyte. The atoms, which leave the zinc electrode, are positively charged and are attracted by the negatively charged ions of the electrolyte; the atoms repel the positively charged ions of the electrolyte toward the copper electrode. Positive and negative terminals correspond with the positive and negative ionic charges.



Source: DOE-HDBK-1011/2-92

Figure 42. Basic chemical production of electrical power

b. Describe the hazards associated with storage batteries.

Short circuits cause a great reduction in battery capacity. To prevent short circuits in a battery, overcharging and over-discharging should be avoided at all costs.

If gassing occurs and the gases are allowed to collect, an explosive mixture of hydrogen and oxygen can be readily produced. To reduce the amount of gassing, charging voltages above 2.30 volts per cell should be minimized.

Higher temperatures will give some additional capacity, but they will eventually reduce the life of the battery. Very high temperatures, 125°F and higher, can actually do damage to the battery and cause early failure.

Low temperatures will lower battery capacity but also prolong battery life under floating (i.e., slightly charging) operation or storage. Extremely low temperatures can freeze the electrolyte, but only if the battery is low in specific gravity.

c. Define the following terms:

- **Voltaic cell**
- **Battery**
- **Electrode**
- **Electrolyte**
- **Specific gravity**
- **Ampere-hour**
- **Electrolysis**
- **Equalizing charge**
- **Float charge**
- **Pilot cell**

All of these definitions are taken from DOE-HDBK-1011/2-92 except as follows. Electrolysis, equalizing charge and float charge are taken from DOE-HDBK-1084-95, and pilot cell is taken from DOE-SPEC-3019-96.

Voltaic Cell

The term “voltaic cell” is defined as a combination of materials used to convert chemical energy into electrical energy. A voltaic or chemical cell consists of two electrodes made of different types of metals or metallic compounds placed in an electrolyte solution.

Battery

A battery is a group of two or more connected voltaic cells.

Electrode

An electrode is a metallic compound, or metal, that has an abundance of electrons (negative electrode) or an abundance of positive charges (positive electrode).

Electrolyte

An electrolyte is a solution that is capable of conducting an electric current. The electrolyte of a cell may be a liquid or a paste. If the electrolyte is a paste, the cell is referred to as a *dry cell*; if the electrolyte is a liquid, it is called a *wet cell*.

Specific Gravity

Specific gravity is defined as the ratio comparing the weight of any liquid to the weight of an equal volume of water. The specific gravity of pure water is 1.000. Lead-acid batteries use an electrolyte that contains sulfuric acid. Pure sulfuric acid has a specific gravity of 1.835; it weighs 1.835 times as much as pure water per unit volume.

Since the electrolyte of a lead-acid battery consists of a mixture of water and sulfuric acid, the specific gravity of the electrolyte will fall between 1.000 and 1.835. Normally, the electrolyte for a battery is mixed such that the specific gravity is less than 1.350.

Specific gravity is measured with a hydrometer. A simple hydrometer consists of a glass float inside a glass tube. The hydrometer float is weighted at one end and sealed at both ends. A scale calibrated in specific gravity is positioned lengthwise along the body of the float. The float is placed inside the glass tube, and the fluid to be tested is drawn into the tube. As the fluid is drawn into the tube, the hydrometer float will sink to a certain level in the fluid. The extent to which the hydrometer float protrudes above the level of the fluid depends on the specific gravity of the fluid. The reading on the float scale at the surface of the fluid is the specific gravity of the fluid.

Ampere-Hour

An ampere-hour is defined as a current of one ampere flowing for 1 hour. If the current in amperes is multiplied by the time of flow in hours, the result is the total number of ampere-hours. Ampere-hours are normally used to indicate the amount of energy a storage battery can deliver.

Electrolysis

Electrolysis is the chemical dissociation of water into hydrogen and oxygen gas caused by passage of an electrical current.

Equalizing charge

Equalizing charge is the charge applied to a battery which is greater than the normal float charge and is used to completely restore the active materials in the cell, bringing the cell float voltage and the specific gravity of the individual cells back to “equal” values.

Float Charge

Float charge is the method of charging in which a secondary cell is continuously connected to a constant-voltage supply that maintains the cell in a fully charged condition.

Pilot Cell

A pilot cell is a selected cell whose condition is assumed to indicate the condition of the entire battery string. The pilot cell is usually selected for representative measurements for a select period of time. Once this time period has elapsed, another cell from the battery string is selected in turn to be the pilot cell.

d. Describe the operation of a simple voltaic cell.

The information for KSAs ‘d’ through ‘i’ is taken from DOE-HDBK-1011/2-92.

A voltaic cell consists of two electrodes of different types of metals or metallic compounds and an electrolyte solution that is capable of conducting an electric current. A good example of a voltaic cell is one that contains zinc and copper electrodes. The zinc electrode contains an abundance of negatively charged atoms, and the copper electrode contains an abundance of positively charged atoms. When these electrodes are immersed in an electrolyte, chemical action begins. The zinc electrode will accumulate a much larger negative charge because it dissolves into the electrolyte. The atoms, which leave the zinc electrode, are positively charged and are attracted by the negatively charged ions of the electrolyte; the atoms repel the positively charged ions of the electrolyte toward the copper electrode.

e. Explain the relationship between specific gravity and state of charge of a lead-acid battery.

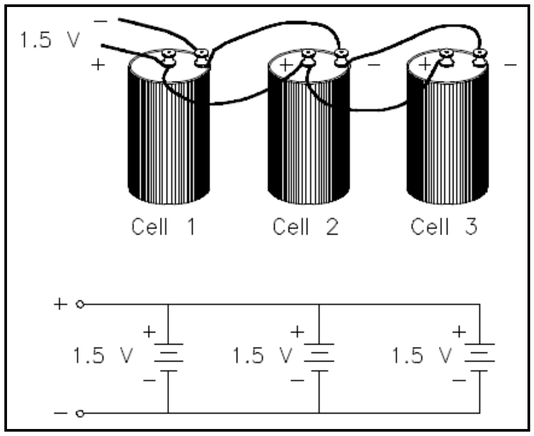
The decrease in specific gravity on discharge is proportional to the ampere-hours discharged. While charging a lead-acid battery, the rise in specific gravity is not uniform, or proportional, to the amount of ampere-hours charged. The electrolyte in a lead-acid battery plays a direct role in the chemical reaction. The specific gravity decreases as the battery discharges and increases to its normal, original value as it is charged. Since specific gravity of a lead-acid battery decreases proportionally during discharge, the value of specific gravity at any given time is an approximate indication of the battery’s state of charge. To determine the state of charge, compare the specific gravity, as read using a hydrometer, with the full charge value and the manufacturer’s published specific gravity drop, which is the decrease from full to nominal charge value.

f. Describe the relationship between total battery voltage and individual cell voltage for a series-connected battery.

When several cells are connected in series, the total voltage output of the battery is equal to the sum of the individual cell voltages. When cells are connected in series, the positive terminal of one cell is connected to the negative terminal of the next cell. The current flow through a battery connected in series is the same as for one cell.

g. Explain the advantage of connecting a battery in parallel with respect to current-carrying capability.

Cells connected in parallel, as in figure 43, give the battery a greater current capacity. When cells are connected in parallel, all the positive terminals are connected together, and all the negative terminals are connected together. The total voltage output of a battery connected in parallel is the same as that of a single cell. Cells connected in parallel have the same effect as increasing the size of the electrodes and electrolyte in a single cell. The advantage of connecting cells in parallel is the increase in current-carrying capability of the battery.



Source: DOE-HDBK-1011/2-92

Figure 43. Cells connected in parallel

h. Describe the difference between primary and secondary cells with respect to recharge capability.

Cells that cannot be returned to good condition or recharged after their voltage output has dropped to a value that is not usable are called *primary cells*. Dry cells that are used in flashlights and transistor radios (e.g., AA cells, C cells) are examples of primary cells.

Cells that can be recharged to nearly their original condition are called *secondary cells*. The most common example of a secondary, or rechargeable cell, is the lead-acid automobile battery.

i. State the advantages of each of the following types of batteries:

- **Carbon-zinc cell**
- **Alkaline cell**
- **Nickel-cadmium cell**
- **Edison cell**
- **Mercury cell**

Carbon-Zinc Cell

The carbon-zinc cell is one of the oldest and most widely used types of dry cells. The carbon in the battery is in the form of a rod, in the center of the cell, that acts as the positive terminal. The case is made from zinc and acts as the negative electrode. The electrolyte for this type of cell is a chemical paste-like mixture that is housed between the carbon electrode and the zinc case. The cell is then sealed to prevent any of the liquid in the paste from evaporating. The advantage of a carbon-zinc battery is that it is durable and very inexpensive to produce. The cell voltage for this type of cell is about 1.5 volts.

Alkaline Cell

The alkaline cell is so called because it has an alkaline electrolyte of potassium hydroxide. The negative electrode is made from zinc, and the positive electrode is made of manganese dioxide. The alkaline cell has the advantage of an extended life over that of a carbon-zinc cell of the same size; however, it is usually more expensive. The typical alkaline cell generates 1.5 volts.

Nickel-Cadmium Cell

The nickel-cadmium cell is a secondary cell, and the electrolyte is potassium hydroxide. The negative electrode is made of nickel hydroxide, and the positive electrode is made of cadmium hydroxide. The nickel-cadmium battery has the advantage of being a dry cell that is a true storage battery with a reversible chemical reaction (i.e., it can be recharged). It is a rugged, dependable battery that gives dependable service under extreme conditions of temperature, shock, and vibration. Due to its dependability, it is ideally suited for use in portable communications equipment. The nominal voltage of a nickel-cadmium cell is 1.25 volts.

Edison Cell

In an Edison cell the positive plate consists of nickel and nickel hydrate, and the negative plate is made of iron. The electrolyte is alkaline. The Edison cell has the advantage of being a lighter and more rugged secondary cell than a lead-acid storage battery. Typical voltage output is 1.4 volts, and it should be recharged when it reaches 1.0 volts.

Mercury Cell

Mercury cells come in two types: (1) flat cell that is shaped like a button and (2) cylindrical cell that looks like a regular flashlight battery. These cells are very rugged and have a relatively long shelf life. The mercury cell has the advantage of maintaining a fairly constant output under varying load conditions. For this reason, they are used in products such as electric watches, hearing aids, cameras, and test instruments. Each cell produces about 1.35 volts.

j. Explain how gas generation is minimized for a lead-acid battery and list the steps to prevent hydrogen buildup.

The following 3 paragraphs are taken from DOE-HDBK-1011/2-92.

A lead-acid battery cannot absorb all the energy from the charging source when the battery is nearing the completion of the charge. This excess energy dissociates water by way of electrolysis into hydrogen and oxygen. Oxygen is produced by the positive plate, and hydrogen is produced by the negative plate. This process is known as *gassing*.

Gassing is first noticed when cell voltage reaches 2.30–2.35 volts per cell and increases as the charge progresses. At full charge, the amount of hydrogen produced is about one cubic foot per cell for each 63 ampere-hours input. If gassing occurs and the gases are allowed to collect, an explosive mixture of hydrogen and oxygen can be readily produced. It is necessary, therefore, to ensure that the area is well ventilated and that it remains free of any open flames or spark-producing equipment.

As long as battery voltage is greater than 2.30 volts per cell, gassing will occur and cannot be prevented entirely. To reduce the amount of gassing, charging voltages above 2.30 volts per cell should be minimized (e.g., 13.8 volts for a 12 volt battery).

The following paragraph is taken from DOE-HDBK-1084-95.

With good air circulation around a battery, hydrogen accumulation is normally not a problem. However, if relatively large batteries are confined in small rooms, exhaust fans should be installed to vent the room constantly or to be turned on automatically when hydrogen accumulation exceeds 20% of the lower explosive limit. Battery boxes should also be vented to the atmosphere. Sparks or flame can ignite these hydrogen mixtures above the LEL. To prevent ignition, electrical sources of arcs, sparks, or flame should be mounted in explosion-proof metal boxes. Flooded batteries can similarly be equipped with flame arrestors in the vents to prevent outside sparks from igniting explosive gases inside the cell cases. It is mandatory to refrain from smoking, using open flames, or creating sparks in the vicinity of the battery.

k. Explain how heat is generated in a lead-acid battery.

The following is taken from DOE-HDBK-1011/2-92.

Whenever a lead-acid battery is charged, the current flowing through the battery will cause heat to be generated by the electrolysis of water. The current flowing through the battery (I) will also cause heat to be generated (P) during charge and discharge as it passes through the internal resistance (R_i), as illustrated in the following formula:

$$P = I^2 R_i$$

l. Describe the various uses of battery banks in DOE facilities.

The following is taken from Renewable Energy Resource Center, *Solar Electric Basics.*

A battery bank, comprising several batteries linked together, collects and stores energy for periods when power is not available, when a surplus of power is desired, or when there is an outage.

Several factors can be used to help determine the size of the battery bank. These include the electric load, the duration of required reserve power, and the availability of a source of backup power (grid or generator). A good quality, lead-acid battery bank will last from 500 to 1,000 charge-discharge cycles depending on depth of discharge and attention to maintenance considerations. A battery box is needed to enclose the battery bank. The box contains potential acid spills, keeps out unfamiliar persons, and keeps objects from falling on the batteries, possibly damaging or shorting battery terminals.

m. Describe how batteries are tested.

The following is taken from DOE-HDBK-1084-95.

Batteries should be tested at regular intervals to (a) determine whether the battery meets its specification or the manufacturer's rating, or both; (b) periodically determine whether the performance of the battery, as found, is within acceptable limits, and (c) if required, determine whether the battery as found meets the design requirements of the system to which it is connected. The schedule and procedure for battery capacity tests should be performed according to the requirements of ANSI/IEEE 450, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations*.

For an acceptance or performance test, use the following equation to determine battery capacity:

$$\% \text{ capacity at } 25^{\circ}\text{C } (77^{\circ}\text{F}) = \text{Ta/Ts} \bullet 100$$

where:
Ta = actual time of test to specified terminal voltage
Ts = rated time to specified terminal voltage.

ANSI/IEEE 450 recommends replacement of a battery if its capacity as determined from the equation above is less than 80% manufacturer's rating. A capacity of 80% shows that the battery rate of deterioration is increasing even if there is ample capacity to meet load requirements. If individual cells are required to be replaced, they should be compatible with existing cells and tested prior to installation. It is recommended that when one or more cells/jars are replaced the entire battery string be replaced in order to prevent large differences in cell impedance. If uncorrected, this may result in unequal charging of the battery string.

II. ELECTRICAL ISSUE IDENTIFICATION & REPORTING

15. Electrical personnel shall demonstrate a working level knowledge of surveillance and assessment techniques, reporting, and follow up actions for electrical systems and programmatic elements of an electrical safety program, such as management systems, problem remediation and trends processes, inspection programs, training and qualification programs, and oversight of contractor assurance systems.

a. Describe the role of electrical personnel in performance oversight of Government-owned, Contractor-operated (GOCO) facilities.

The information for KSAs 'a' and 'b' is taken from DOE-O-226.1.A.

Periodically, a company should perform a self-assessment to determine how well their written electrical safety program is actually being implemented. To be of value, the assessment should be very objective, without trying to blame people. The goal is to improve the safety performance, not to punish employees. Besides, if the program is not being carried out effectively, a significant part of the blame belongs to management. Occasionally, it is also prudent to have the company's safety organization, or even an outside-contracted safety auditor, perform an electrical safety audit. This way, a set of eyes that is not so familiar with the facility, and does not have a fear of retaliation from local management, can discover things that self-assessors might overlook.

The electrical safety program should contain a requirement that the written program itself be occasionally audited. The auditing should be designed to identify new or revised requirements, as well as weaknesses in the system. Attention should be paid not only to the written work practices and procedural requirements, but also to how well personnel appear to understand and implement these requirements.

Whenever electrical safety-related incidents or accidents occur, there should be a thorough investigation to determine the root cause and contributing factors. As a result of the investigation, actions should be taken to prevent a recurrence of the incident. Lessons-learned information should be distributed to all personnel who could get involved in, or influence decisions about, similar future situations.

Additionally, an effective oversight process enables contractors to incorporate the following as appropriate:

Federal Responsibility and Accountability for Activities

DOE line management will require that contracts adequately delineate contractor responsibilities for programs, management systems, and assurance programs. Contractors will be responsible under their contracts to provide these assurances. DOE line management and contractors may perform some assessments jointly to increase efficiency and promote common understanding of processes and results. However, DOE line management is responsible and accountable for understanding and accepting the hazards and risks associated with activities. To accomplish this, DOE has the right and responsibility to perform oversight at the level necessary to understand the hazards and risks, to ensure compliance with applicable requirements, to pursue excellence through continuous improvement, to ensure timely identification and correction of deficient conditions, and to verify the effectiveness of completed corrective actions.

Program Plan

Documented program plans need to identify the program areas to be reviewed, the periodicity of reviews, the reviews necessary to maintain the baseline oversight program, the qualifications of review personnel, and the source of review criteria. Documented program plans need to describe the various oversight methods used, how they are used, and how the results of the various methods are integrated and considered as a whole to give an accurate oversight picture.

Continuous Improvement

Assurance systems and oversight processes will identify ways to make programs more effective and efficient through improved performance and report such opportunities to line managers for their consideration. Line managers at all levels are responsible for using the results of DOE line and independent oversight processes and assurance systems. These results are to be used to make informed decisions about corrective actions that will improve the effectiveness and efficiency of their programs and operations and about the acceptability of residual risks. The use of external, nationally recognized experts should be considered to carry out independent risk and vulnerability studies and to validate that contractor management systems meet applicable standards. DOE sites and DOE line management must have effective processes for communicating issues up the management chain to senior management using a graded approach that considers hazards and risks. The processes must provide sufficient technical basis to allow managers to make informed decisions. Processes for resolving disputes about oversight findings and other significant issues shall also be implemented and include provisions for independent technical reviews of significant issues.

Requirements and Performance Objectives

DOE oversight programs and assurance systems will evaluate performance against requirements and performance objectives, which may include laws, regulations, national standards, DOE directives, DOE-approved plans and program documents (e.g., security plans, authorization basis documents, and QA plans), site-specific procedures/manuals, criteria review and DOE P 226.1A, *Department of Energy Oversight Policy,* approach documents, other contractually mandated requirements, and contractual performance objectives. Requirements and performance objectives are established and interpreted through approved processes so that they are relevant to the site and mission.

Personnel Competence

Personnel responsible for managing and performing assurance and oversight functions will possess experience, knowledge, skills, and abilities commensurate with their responsibilities. Line managers are responsible for ensuring that their personnel with oversight responsibilities meet applicable qualifications standards. Continuing training and professional development activities are encouraged to supplement individual experience and provide a means to maintain awareness of changes and advances in the various fields of expertise.

Baseline Oversight Program and Priorities

Line management is responsible and accountable for establishing and implementing a baseline oversight program that provides for an adequate assessment of programs, management systems, and assurance systems. Clear and unambiguous lines of authority and responsibility for performing line management oversight functions will be established and maintained. Line management will provide its oversight processes with sufficient resources and access to conduct an effective oversight program. Site assurance systems and DOE oversight processes will be tailored to be effective and efficient and will take into account hazards and risks (including risks associated with potentially hazardous activities and risks to DOE missions, including schedule, cost, and scope uncertainties). Oversight priorities are to be based on a systematic analysis of hazards, risks, and past performance of organizations, programs, and facilities, including previous assessment results. Higher hazard or risk activities (e.g., facilities with a higher nuclear material attractiveness level) and less mature programs will be assessed more frequently and/or in more depth. The scope and results of reviews by external regulators (e.g., the Environmental Protection Agency) and organizations (e.g., the Defense Nuclear Facilities Safety Board [DNFSB]) are important factors in determining oversight priorities but are not a substitute for effective line management oversight.

DOE Headquarters and field element line management regularly assess site assurance systems to determine the appropriate level of overlap and redundancy of DOE Headquarters and field element line management oversight. Accordingly, DOE line management organizations may increase their frequency and/or depth based on performance deficiencies or events or may decrease the frequency and/or depth of line management oversight assessments to reflect sustained, effective site performance. Although external organization reviews and the effectiveness of assurance systems are considered in determining DOE line management oversight priorities and the scope and frequency of oversight activities, DOE line management must always maintain an adequate minimum baseline oversight program that enables DOE line management to understand the hazards and risks of activities.

Performance Indicators and Measures

Performance indicators and measures will be used as one mechanism to help line management identify adverse trends and promote improvements. This data is considered in a variety of DOE P 226.1A management decisions, such as allocating resources, establishing goals, identifying performance trends, identifying potential problems, and applying lessons learned and good practices. Site performance criteria will focus on results and system-based metrics to drive improvements in site programs and management systems at DOE sites.

Self-Assessments of Line Management Functions

Line management must perform self-assessments of its activities, including its oversight activities and activities necessary to support site assurance and mission activities. Headquarters, field element, and contractor management organizations are responsible for establishing effective management assessments and line management oversight processes and to address shortcomings, identified through self-assessments, in their oversight programs.

b. Describe the assessment requirements and limitations associated with the interface of electrical personnel and contractor employees.

A rigorous and credible assessment program is the cornerstone of effective, efficient management of programs such as environment, safety, and health (EH&S); safeguards and security; cyber security; and emergency management. Contractors will be responsible for developing, implementing, and performing comprehensive assessments of all facilities, systems, and organizational elements, including subcontractors, on a recurring basis. The scope and frequency of assessments must be specified in site plans and program documents (e.g., the QA program [QAP]) and must ensure that assessments required by applicable DOE directives are being performed; the effectiveness of safety management programs, including programs that are credited in the safety basis for nuclear facilities, are being assessed adequately; deficiencies are being self-identified; and corrective actions are being taken in a timely and effective manner. External peers or subject matter experts may be utilized to support assessment activities.

Self-assessment is used to periodically evaluate performance at all levels and to determine the effectiveness of policies, requirements, and standards and the implementation status (see also DOE O 414.1C, *Quality Assurance,* criterion 9, “Management Assessment”). Management self-assessments (also called management assessments) are performed by contractor management, and are developed (scope and review criteria) based on the nature of the facility/activity being assessed and the hazards and risks to be controlled. Self-assessments, which focus on hands-on work and the implementation of administrative processes, involve workers, supervisors, and managers to encourage identification and resolution of deficiencies at the lowest level practicable (e.g., workplace inspections and post-job reviews). Support organizations will perform self-assessments of their performance and the adequacy of their processes. Contractors, at all levels, will assess the implementation and adequacy of their processes, including analysis of the collective results of lower-level self-assessments. Self-assessment results will be documented commensurate with the significance of and risks associated with activities being evaluated. Deficiencies will be accurately described and documented for evaluation and correction using formal issues management processes.

Internal independent assessments will be performed by contractor organizations or personnel that have authority and independence from line management, to support unbiased evaluations (see also DOE O 414.1C, criterion 10, "Independent Assessment"). The assessments will be formally planned and scheduled based on the risk, hazards, and complexity of the processes and activities to be evaluated. Independent evaluators will be appropriately trained and qualified and have knowledge of the areas assessed. Reviewers will be dedicated contractor staff, members of external organizations, or both. Although independent assessments are applied to individual activities and processes, they will typically focus on entire facilities or projects, and programs and management processes that are used by multiple organizations. Internal independent assessments will concentrate on performance and observation of work activities and the results of process implementation.

c. Describe how planning, observations, interviews, and document research are used during an assessment.

The following is taken from DOE G 414.1-1B.

Planning

Planning management assessments is an organization-specific effort that should be integrated with other assessment processes. No single method is appropriate for every situation. Either quantitative or qualitative assessment methods may be used as appropriate for the assessment scope. Managers are challenged to make the assessment a value-added process that will lead to improvement in organizational performance, safety, meeting customer expectations, and achieving mission goals in full compliance with regulatory and DOE requirements. It is important to remember that while management assessments have some commonalities with audits, they should focus on evaluating organizational performance and identifying barriers that hinder improved performance.

Observation

Observation, the viewing of actual work activities, is often considered the most effective technique for determining whether performance is in accordance with requirements. Assessors should understand the effect their presence has on the person being observed and convey an attitude that is helpful, constructive, positive, and unbiased. The primary goal during observation is to obtain the most complete picture possible of the performance, which should then be put into perspective relative to the overall program, system, or process.

Interviews

Interviews provide the means of verifying the results of observation, document review, inspection, and performance testing; allow the responsible person to explain and clarify those results; help to eliminate misunderstandings about program implementation; and provide a venue where apparent conflicts or recent changes can be discussed and organization and program expectations can be described.

Document Research

Document reviews provide the objective evidence to substantiate compliance with applicable requirements. A drawback is that the accuracy of the records cannot be ascertained by review alone. This technique should be combined with interviews, observation, inspection, and/or performance testing to complete the performance picture. Records and documents should be selected carefully to ensure that they adequately characterize the program, system, or process being assessed.

d. Explain the essential elements of a performance-based assessment, including investigation, fact-finding, and reporting. Include a discussion of the essential elements and processes of the following assessment activities:

- **Exit interviews**
- **Closure process**
- **Tracking to closure**
- **Follow-up**
- **Contractor corrective action implementation**

The following information through 'Exit Interviews' is taken from DOE G 414.1-1B.

Performance-based assessments take the approach of focusing first on the adequacy of the process that produced a product or service, and then on the product itself. If problems are found in the product or work processes, the assessor evaluates the methods and procedures used to implement the applicable requirements in an effort to find the failure that led to the problems. The assessor is expected to determine whether a non-compliance or series of non-compliances with procedures could result in a failure to satisfy top-level requirements. Results of prior compliance assessments may help the assessor in determining the focus areas for planning performance-based assessments.

Investigation and Fact-Finding

In performance-based assessments, great emphasis is placed on getting the full story on a problem before coming to a conclusion. If an assessor sees a problem with the execution of a welding process, the next step should determine the extent of the problem. Is it limited to one welder? Is it limited to one process? Can the problem be traced to the qualification program for the welder or to the qualification program for the welding process? Or is there a problem with the weld material itself, indicating a problem such as engineering or procurement?

While the assessor should be familiar with requirements and procedures, in performance-based assessments the assessor's experience and knowledge play an integral part in determining whether requirements are satisfied. Therefore, participants in performance-based assessments should be technically competent in the areas they are assessing. For example, if an assessor is evaluating a welding process, the assessor relies heavily on his or her knowledge of welding codes, welding processes, and metallurgy, rather than just verifying simple procedure compliance.

Performance-based assessments usually provide the most useful information to management; however, it requires a much higher level of competence on the part of the assessment team.

Results of performance-based assessments may provide useful insight for management's pursuit of excellence.

Reporting

Assessment reports are required for documentation of assessment results. Assessment team leaders have the overall responsibility for preparing the report and obtaining appropriate approval for its release as applicable. The report may be formal (e.g., distributed by memorandum) or informal (e.g., letter to file or email), depending on the level of assessment performed, but should provide a clear picture of the results in terms of the programs, systems, and processes assessed. The assessment report should be clear, concise, accurate, and easy to understand, and should include only facts that directly relate to assessment observations and results. It should include sufficient information to enable the assessed organization to develop and implement appropriate improvement plans.

Specific report formats may vary considerably from one organization to the next. An independent assessment report usually includes the following sections:

- Executive summary
- Assessment scope
- Identification of team members
- Identification of personnel contacted
- Documents reviewed
- Work performance observed
- Assessment process and criteria (e.g., criteria review and assessment documents)
- Results of the assessment, including identification of areas for improvement, and/or strengths

A management assessment report may not require all of the listed sections and may only require an executive summary.

Exit Interviews

An exit interview meeting is used primarily by the assessment team to present the assessment summary.

Reasonable time should be allowed to discuss any concerns, but this meeting should not be used to argue the assessment findings or methodology. There should be no surprises during the exit meeting since the assessment team should have taken every effort possible during the conduct of the assessment to ensure that the assessed organization was aware of the team's findings and concerns. Prior to the exit meeting the assessment team should consider combining related findings into a small number of well-supported findings to help focus management's opportunities for improvement.

Objective evidence needs to be available to substantiate assessment findings. Additionally, performance metrics should reflect the assessment process itself, not individuals. There should be a clear linkage between identified findings and how they impact the mission/goals of the organization.

Closure Process

The information for 'Closure Process' and 'Tracking to Closure' is taken from DOE O 226.1A.

In the closure process, contractors send a letter to the directives management group (DMG) requesting closure and stating that the corrective actions in the implementation plan have been completed. The DMG coordinates approval of the closure with the appropriate division of primary interest and the contracting officer's representative.

Tracking to Closure

DOE line management requires that findings be tracked and resolved through structured and formal processes, including provisions for review of corrective action plans.

The following are integral tracking elements:

- Determining the risk, significance, and priority of deficiencies
- Evaluating the scope and extent of the condition or deficiency (e.g., applicability to other equipment, activities, facilities, or organizations)
- Determining event reportability under applicable requirements (e.g., Price-Anderson Amendments Act, Occurrence Reporting and Processing System, security incident reporting)
- Identifying root causes (applied to all items using a graded approach based on risk)
- Identifying and documenting suitable corrective actions and recurrence controls, based on analyses, to correct the conditions and prevent recurrence
- Identifying individuals/organizations responsible for implementing corrective actions
- Establishing appropriate milestones for completion of corrective actions, including consideration of significance and risk
- Tracking progress toward milestones such that responsible individuals and managers can ensure timely completion of actions and resolution of issues

The following information through the end of this KSA is taken from DOE G 414.1-1B.

Information systems comprise a wide range of different forms and formats, and can be useful tracking tools. In their simplest form they may include the weekly and monthly laboratory or organizational performance reports that may be used to alert the organization to potential assessment areas. In more complex form, these systems may include computerized databases that link performance to specific performance objectives or track actions to resolve programmatic weaknesses. In any case, information systems are important tools for assessors, providing much of the necessary data to focus assessment activities.

Follow-Up

A follow-up assessment with special focus may be performed and should be completed in accordance with applicable corrective action documents. Particularly, this follow-up assessment should evaluate the effectiveness of corrective actions. A reasonable subset of corrective actions should be reviewed for effectiveness.

Contractor Corrective Action Implementation

Managers responsible for the activities assessed are also responsible for the development of effective corrective actions for the problem areas/deficiencies discovered during the assessment. At a minimum, these corrective actions should include the following:

- Measures to correct each deficiency
- Identification of all root causes for significant deficiencies
- Determination of the existence of similar deficiencies or underlying causes (i.e., extent of condition, extent of cause)
- Actions to preclude recurrence of like or similar deficiencies
- Assignment of corrective action responsibility; and completion dates for each corrective action

Managers should verify that corrective actions are likely to fully address the identified deficiency and when actions are completed, validate that the actions have corrected the deficiency.

e. Describe the actions to be taken if the contractor challenges the assessment findings and explain how such challenges can be avoided.

The following is taken from DOE G 414.1-5.

Disputes between assessed and assessing employees or organizations concerning corrective action program (CAP) development, implementation, or completion should be resolved at the lowest possible organizational level. If informal discussions successfully resolve the dispute, the resolution should be documented in a mutually agreeable way. If the dispute cannot be resolved in informal discussions, it should be elevated to the minimum extent necessary to reach resolution through the organizational level of management hierarchy.

If problem findings identified in the assessment/event report and/or corrective actions to be addressed involve multiple sites/organizations, it may be feasible to designate a lead manager to coordinate and approve a single comprehensive CAP by mutual agreement of all applicable senior managers. Other sites/organizations would forward their portions of the CAP and status of corrective action activities to the designated lead manager for consolidation.

f. Describe the methods by which noncompliance is determined and communicated to the contractor and Departmental management.

The following is taken from DOE G 414.1-1B.

Site/facility protocols should be followed for what to do if an imminent danger situation or a reportable noncompliance or violation is encountered during the course of an assessment. Any assessment schedules or specific protocols established during the pre-assessment meeting are used to ensure that the assessment is conducted effectively and safely. Assessors should keep their points of contact informed of their activities to preclude surprises during the post-assessment conference. This may include requests for additional assistance or the communication of concerns that require immediate action on the part of the assessed organization. Timely communication, oral and written, will allow the assessed organization to verify the accuracy of observations and provide relevant facts and background on the issues. One way to accomplish this is to meet periodically (daily or every other day) with the organization being assessed to convey questions/concerns and provide a status update.

Daily team meetings may be helpful in ensuring continuity and overall focus by providing assessment team leaders with information about the completion status of the assessment checklists, and offering the opportunity for inquiry into issues requiring additional action (e.g., clearances, access, requests for personnel or material, and impasse resolution). These meetings also provide the setting for advising other team members of issues that may be of interest in their assigned scope, or for integrating data gathered by the various assessors. The meetings should be brief so that they do not significantly reduce the team members' field time with the processes they are to assess and the people they are to interview.

It is important that sufficient information be gathered during the assessment to determine whether an activity meets the performance criteria established. The assessor should be able to state clearly the criterion impacted by the activity and whether identified findings impact the mission/goals of the organization. To accomplish this, the assessor may deviate from the assessment schedule to determine the extent and significance of an issue. Deviations that affect the assessor's ability to complete the assessment team's interview schedule should immediately be made known to the organization being assessed and the team leader.

g. Describe the role of electrical personnel in the contractor performance evaluation process.

The following is from DOE electrical subject matter experts SMEs.

Electrical personnel may be asked to provide written records of work completed and work inprocess. They may be interviewed or observed so as to provide an assessor with important job-task data. Additionally, they may be asked to engage in a performance test so as to provide response data that may normally only be available during a crisis and not when the assessor is visiting.

h. Participate in the evaluation of a contractor's performance.

Elements 'h' through 'k' are performance-based KSAs. The Qualifying Official will evaluate their completion.

i. Conduct an interview as part of an evaluation of an occurrence.

j. **Develop an assessment report.**

k. **Participate in formal meetings between Departmental management and senior contractor management to discuss the results of electrical assessments.**

16. Electrical personnel shall demonstrate the ability to communicate technical issues (both orally and written) when working or interacting with the contractor, stakeholders, and other internal and external organizations.

Elements 'a' through 'c' are performance-based KSAs. The Qualifying Official will evaluate their completion.

a. **Identify the various internal and external groups with whom electrical personnel must interface in the performance of their duties.**

b. **Apply written communication skills in the development of:**
   - **Assessment reports**
   - **Technical reports**
   - **Technical papers**

c. **Apply effective and appropriate communications skills when interfacing with the contractor.**

17. Electrical personnel shall demonstrate a familiarity level knowledge of the Environmental Safety and Health (ES&H) reporting requirements as noted in DOE M 231.1-1A, Environment, Safety and Health Reporting Manual.

a. **Using an occurrence report related to an electrical system or component and using DOE M 231.1-2 as a reference, identify the following:**
   - **Causes**
   - **Corrective actions**
   - **Lessons learned**
   - **Whether corrective actions have been completed**

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

b. **State the purpose of DOE Order (O) 231.1A and DOE M 231.1-2.**

DOE O 231.1A, Environment, Safety, and Health Reporting

The purpose of DOE O 231.1A is to ensure timely collection, reporting, analysis, and dissemination of information on EH&S issues as required by law or regulations or as needed to ensure that DOE and NNSA are kept fully informed on a timely basis about events that could adversely affect the health and safety of the public or the workers, the environment, the intended purpose of DOE facilities, or the credibility of the Department.

DOE M 231.1-2, Occurrence Reporting and Processing of Operations Information

The purpose of DOE M 231.1-2 is to provide detailed requirements to supplement DOE O 231.1A, *Environment, Safety, and Health Reporting*. It is approved for use by all DOE Elements and their contractors.

c. Define the following terms:

- **Event**
- **Condition**
- **Facility**
- **Notification report**
- **Occurrence report**
- **Reportable occurrence**
- **Near miss**
- **Hazardous energy control**

The following is taken from DOE M 231.1-2.

Event

An event is something significant and real-time that happens (e.g., pipe break, valve failure, loss of power, environmental spill, earthquake, tornado, flood).

Condition

A condition is any as-found state, whether or not resulting from an event, that may have adverse safety, health, QA, operational or environmental implications. A condition is usually programmatic in nature, for example, errors in analysis or calculation, anomalies associated with design or performance, or items indicating a weakness in the management process are all conditions.

Facility

A facility is any equipment, structure, system, process, or activity that fulfills a specific purpose. Examples include accelerators, storage areas, fusion research devices, nuclear reactors, production or processing plants, coal conversion plants, magnetohydrodynamic experiments, windmills, radioactive waste disposal systems and burial grounds, environmental restoration activities, testing laboratories, research laboratories, transportation activities, and accommodations for analytical examinations of irradiated and unirradiated components.

Notification Report

A notification report is the initial documented report, to the Department, of an event or condition that meets the reporting criteria defined in DOE M 231.1-2, *Occurrence Reporting and Processing of Operations Information*.

Occurrence Report

An occurrence report is a documented evaluation of an event or condition that is prepared in sufficient detail to enable the reader to assess its significance, consequences, or implications and to evaluate the actions being proposed or employed to correct the condition or to avoid recurrence.

Reportable Occurrence

A reportable occurrence is an occurrence to be reported in accordance with the criteria defined in DOE M 231.1-2.

Near Miss

A near miss is a situation where no barrier or only one barrier prevented an event from having a reportable consequence.

Hazardous Energy Control

Hazardous energy control may include a control process (e.g., lockout/tagout [LOTO]) or focus on mitigating a disturbance of a previously unknown or mislocated hazardous energy source (e.g., live electrical power circuit, steam line, pressurized gas) resulting in a person contacting (burn, shock, etc.) hazardous energy.

d. Discuss the Department's policy regarding the reporting of occurrences as outlined in the Order and Manual.

Refer to sections 4 through 11 in DOE M 231.1-2 for in-depth coverage of the Department's occurrence reporting policy. DOE O 231.1A covers the same in less detail.

e. State the different categories of reportable occurrences and discuss each.

The following is taken from DOE M 231.1-2.

Operational Emergency Occurrences

Operational Emergency Occurrences are the most serious occurrences and require an increased alert status for onsite personnel and in specified cases, for offsite authorities. (Operational emergencies are defined in DOE O 151.1A, *Comprehensive Emergency Management System*. The prompt notification requirements, definitions, criteria, and classifications of operational emergencies and appropriate responses are provided in DOE O 151.1A, as well.) Written occurrence reports, however, must be completed in accordance with the DOE M 231.1-2 contractor requirements document.

Significance Category 1

Occurrences in this category are those that are not Operational Emergencies and that have a significant impact on safe facility operations, worker or public safety and health, regulatory compliance, or public/business interests.

Significance Category R

Occurrences in this category are those identified as recurring, as determined from the periodic performance analysis of occurrences across a site.

Significance Category 2

Occurrences in this category are those that are not Operational Emergencies and that have a moderate impact on safe facility operations, worker or public safety and health, regulatory compliance, or public/business interests.

Significance Category 3

Occurrences in this category are those that are not Operational Emergencies and that have a minor impact on safe facility operations, worker or public safety and health, regulatory compliance, or public/business interests.

Significance Category 4

Occurrences in this category are those that are not Operational Emergencies and that have some impact on safe facility operations, worker or public safety and health, public/business interests.

f. Review a sample of Occurrence Reports and Operating Experience Weekly Reports for issues on electrical safety and discuss the lessons learned.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

18. Electrical personnel shall demonstrate a working level knowledge of problem analysis principles and the ability to apply the techniques necessary to identify problems, determine potential causes of problems, and identify corrective action(s).

a. Describe and explain the application of problem analysis techniques, including the following:

- **Root cause analysis**
- **Causal factor analysis**
- **Change analysis**
- **Barrier analysis**
- **Management oversight risk tree (MORT) analysis**

The information for KSAs ‘a’ and ‘b’ is taken from DOE G 225.1A-1.

Root Cause Analysis

Root cause analysis is used in accident investigations to identify those deficiencies, including management system factors that, if corrected, would prevent recurrence of the accident (i.e., the root cause[s] of an accident). Root causes of an accident can be determined using numerous automated and manual techniques. A manual version of root cause analysis—such as compliance/noncompliance or tier diagramming—is acceptable. Commercially available automated techniques are widely used in the DOE complex. Whatever technique is used, investigators should assure that actual root causes are determined, not just contributing causes. The contributing causes are important; however, the need to find concise and justified root causes should be the main intent of using these analytical techniques.

Causal Factor Analysis

Identifying systemic causal factors requires understanding the sequence of events over time and the interaction of those events and their causal factors. This sequence proceeds from an initiating event through the final loss-producing occurrence. A meticulous tracing of, for example, unwanted energy transfers and their relationships to each other and to the people, plant, procedures, and controls involved in an accident will usually reveal a definable sequence for an accident.

Two basic principles are helpful in defining and understanding these sequences of events, causal factors, and energy transfers: (1) accidents result from a set of successive events that produce unintentional harm (i.e., personal injury, property damage), and (2) the accident sequence occurs during the conduct of some work activity (i.e., a series of events directed toward some anticipated or intended outcome other than injury or damage).

Event and causal factor charting is an integral and important part of the DOE accident investigation process. It is used in conjunction with other key tools (such as root cause analysis, change analysis, and barrier analysis) to achieve optimal analytical results in accident investigation.

An event and causal factor chart is a graphic representation that produces a picture of the accident: both the sequence of events that led to the accident and the conditions that were causal factors. Event and causal factor analysis is an effective means of integrating other analytical techniques into a concise and complete investigative summary. Event and causal factor analysis depicts, in logical sequence, the necessary and sufficient events and conditions for accident occurrence. It provides a systematic accident analysis tool to aid in collecting, organizing, and depicting accident information; validating information from other analytical techniques; writing and illustrating the accident investigation report; and briefing management on the results of the investigation.

Change Analysis

Change analysis is a systematic approach to problem-solving that can help identify accident causes. Change analysis is a simple, straightforward process that is relatively quick and easy to learn and apply.

Change is a necessary ingredient for progress; however, changes to systems and their impact also contribute to errors, loss of control, and accidents. The purpose of change analysis is to identify and examine all changes systematically and to determine the significance or impact of the changes. The use of this technique in accident investigation is particularly well-suited for finding quick answers and identifying causal factors that are not otherwise obvious.

It has been demonstrated that when problems arise for any functional system that has been operating satisfactorily (i.e., up to some standard), changes and differences associated with personnel, plant and hardware, or procedures and managerial controls are actual causal factors in creating these problems. Change can be thought of as stress on a system that was previously in a state of dynamic equilibrium. Change can also be viewed as anything that disturbs the planned or normal functioning of a system.

Accident investigators need to carefully evaluate all the changes identified during the investigation. Did the change really cause the result, or did the change merely bring an existing system deficiency to light? The investigation must focus on the systemic deficiencies that allowed the accident to happen and not just accept the changes identified as being the sole cause of the accident. Often, change analysis will lead to further insight into areas that must be explored by other analytical techniques.

Barrier Analysis

The basic premise of barrier analysis is that there is energy flow associated with all accidents. This energy may be kinetic, potential, electromagnetic, thermal, steam, other pressurized gases or liquids, or a myriad of other types of energy. It is the isolation, shielding, and control (barriers) of this energy (hazard) from people, property, or the environment (targets) that prevent accidents. Generally, barriers can be grouped in the following categories: equipment, design, administrative (procedures and work processes), supervisory/ management, warning devices, knowledge and skills, and physical. Therefore, identifying the energy sources and the failed or deficient barriers and controls in an accident investigation provides the means for identifying the causal factors of the accident.

If barriers were installed and one failed partially or totally, an investigator would examine the secondary safety systems, if any, that were in place to mitigate the failure. The investigator would also determine what events led up to and through the failure sequence, paying particular attention to changes made in the system. To accomplish this, the entire sequence of events can be broken down into a logical flow from the beginning to the end of an accident. Questions are asked about the practicality of the barriers and controls selected, why they failed, or why none were selected for use.

The principal benefits of barrier analysis are that it identifies safety system elements that failed, and the results can be succinctly presented. Another benefit of barrier analysis is that the results can easily be presented graphically. A graphical flowchart (diagram) can clearly and concisely portray the energy flows and failed or unused barriers that led to the accident. Thus, barrier analysis is valuable in understanding the accident and the sequence of events that led to it.

Management Oversight Risk Tree (MORT) Analysis

For complex accidents, more rigorous techniques such as MORT analysis may be employed. MORT analysis involves complicated analytical trees that may be necessary to ensure that accident causation is identified.

There are many acceptable equivalent methods of using analytical trees, such as fault trees (computerized and manual versions). Additional information on the application of analytical trees to accident investigations can be found in section 7.4 of the DOE workbook *Conducting Accident Investigations*.

b. Describe and explain the application of the following root cause analysis processes in the performance of occurrence investigations:

- **Event and causal factors charting**
- **Root cause coding**
- **Recommendation generation**

Events and Causal Factors Charting

The events and causal factors (E&CF) chart (or diagram) depicts in logical sequence the necessary and sufficient E&CF for accident occurrence. It can be used not only to analyze the accident and evaluate the evidence during investigation, but also can help validate the accuracy of pre-accident systems analyses. The E&CF sequence charting technique is an integral and important part of the MORT-based DOE accident investigation process. It is used in conjunction with other key MORT tools, such as MORT analysis, change analysis, and energy trace and barrier analysis, to achieve optimum results in accident investigation. E&CF charting has been used successfully as a focal point of analysis on several DOE accident and incident investigations with excellent results.

Root Cause Coding
Root cause coding is a useful tool that enables an investigator to visualize the various root causes, as well as contributing causes. The coding system is broken down into seven main categories: (1) equipment/material problem, (2) procedure problem, (3) personnel error, (4) design problem, (5) training deficiency, (6) management problem, and (7) external phenomenon.

Recommendation Generation
Recommendation generation provides for valuable input to program management that should lead to improved safety practices, with the ultimate goal of avoiding future similar occurrences and accidents. Based on the review of an occurrence's facts and environment, sound analysis, using a graded approach, should provide an avenue to achieve that goal.

Recommendations are generated through coordination with the accident investigation program manager, as outlined in DOE G 225.1-1A, and DOE O 225.1A.

c. Using event and/or occurrence data, apply problem analysis techniques and identify the problems and how they could have been avoided.

Elements 'c' through 'e' are performance-based KSAs. The Qualifying Official will evaluate their completion.

d. Participate in at least one contractor or Department problem analysis and critique the results.

e. Using data, interpret two fault tree analyses.

19. Electrical personnel shall demonstrate the ability to perform electrical safety and system walkdowns, and observe and report nonconformance to OSHA 29 CFR 1910, 29 CFR 1926, NFPA-70 (National Electrical Code), NFPA-70E, and IEEE C2- NESC.

Elements 'a' and 'b' are performance-based KSAs. The Qualifying Official will evaluate their completion.

a. **Coordinate and conduct two or more electrical safety and system walkdowns of applicable contractor facilities and document issues in a report.**

b. **For each report finding (if any), cite noncompliance to one or more of the above mentioned requirements documents, describe the "as found" condition, and explain how it is not in compliance with the cited requirement(s).**

SPECIFIC TECHNICAL COMPETENCIES

III. SAFETY & HEALTH RELATED TO ELECTRICAL SYSTEMS AND COMPONENTS

This section is optional and should be used by the program and/or field offices to assist them with specific technical qualifications for that office.

20. Electrical personnel shall demonstrate a working level knowledge of how electrical hazards are addressed via the Integrated Safety Management System (ISMS) process, including applicable site contractor(s) job planning (job hazard analysis and identification and integration of hazard controls within work package) and application of hazard controls during the work control process.

a. **Describe and explain how the ISMS process addresses and controls electrical hazards.**

The following is taken from DOE P 450.4.

The objective of an ISMS is to incorporate safety into management and work practices at all levels, addressing all types of work and all types of hazards to ensure safety for the workers, the public, and the environment. To achieve this objective, DOE has established guiding principles and core safety management functions.

The following three guiding principles relate to responsibilities intrinsic in all ISMS core functions:

- Line management responsibility for safety
- Clear roles and responsibilities
- Competence commensurate with responsibilities

These interrelated guiding principles help ensure that the management structure has personnel who focus on the safe accomplishment of mission, understand their assignments, and can carry out the core safety management functions correctly and efficiently.

See DOE G 450.4-1B, *Integrated Safety Management System Guide for Use with Safety Management System Policies (DOE P 450.4, DOE P 450.5, and DOE P 450.6)*; the *Functions, Responsibilities, and Authorities Manual*; and the Department of Energy Acquisition Regulation for in-depth treatment of all core principles and functions related to ISMS.

b. **Describe and explain the contractors' electrical work control process in the following areas:**
   - **Work planning**

- **Hazard identification via hazard analysis**
- **Hazard controls**
- **Work performance**
- **Work feedback**

The information on work planning and hazard identification via hazard analysis is taken from DOE G 151.1-2. The information on the remaining terms of this KSA is taken from DOE G 414.1-2A.

Work Planning

Facility guidance that describes safety preplanning requirements for all operational activities should exist. The guidance should explain the role of safety analysis reviews, job safety analyses, and the handling of safety matters. All operations personnel should understand the safety planning requirements.

See DEAR 970.5223-1, "Integration of Environment, Safety, and Health into Work Planning and Execution," for detailed information.

Hazard Identification via Hazard Analysis

The hazards survey is an effective method of identifying and analyzing hazards in a facility or site. The hazards survey document should be a distinct document and should contain, or incorporate by reference, the information specified in DOE G 151.1-2, *Technical Planning Basis: Emergency Management Guide*. A tabular/matrix presentation can be used to efficiently summarize and document the survey information.

The recommended steps in the hazards survey process are as follows:

1. Briefly describe each facility and identify its hazards.
2. Screen hazardous materials to determine the need for further analyses in a facility-specific quantitative emergency planning hazard assessment.
3. Identify the generic types of emergency events and conditions that apply to each facility.
4. Qualitatively describe the potential health, safety, environmental, or national security impacts of the applicable emergencies.
5. Identify and document the applicable Base Program planning and preparedness requirements.

A hazards survey may address one or more facilities. A single hazards survey document may even cover an entire site.

Each facility or activity covered by the hazards survey should be identified and a brief description of its operations provided. Any detailed descriptive information should be included by reference. Sufficient information to provide a general understanding of the facility and its associated hazards can be adequately presented in a table or matrix. This information should include

- a general characterization of the facility and its operations (e.g., office building, laboratory, warehouse);
- the number of workers normally assigned;

- any special designations, such as nuclear facility, radiological facility, hazardous waste site, treatment, storage, or disposal facility, etc.;
- whether hazardous materials, other than standard office products and cleaning supplies, are used or stored in the facility.

Hazard Controls

A graded approach is used to identify proper hazard controls. The first step in the grading process is to identify the hazards, and for the facility level, their consequences and probability of a failure, before work begins. The second step is to identify the specific requirements and controls to be applied. The third step is to determine the depth, extent, and degree of rigor necessary in the application of the requirements and controls. The final step is to communicate and implement the selected requirements and controls and their degree of rigor by means of documented work processes (procedures, instructions, specifications, and controls).

The logic, method of implementation, and basis for grading should be documented in the quality management system, periodically reviewed in light of changes that may have occurred, and if appropriate, revised to reflect those changes.

The graded approach must not be used to "grade QA criterion to zero," which has the effect of eliminating all verifications of the requirement ("to get out of work"). Even in the least stringent application, compliance with applicable portions of stated requirements is mandatory unless an exemption is approved through an appropriate process.

When considering the use of grading of an item or activity, it is important to consider the impact of safety on personnel, the public, and the environment. The safety class or safety significance of the item or activity is critical to the number of controls imposed to assure the requisite or desired quality.

Risk is a fundamental consideration in determining the extent to which controls should be applied at the facility level. The varying degrees of the controls applied should be dependent upon function, complexity, consequence of failure, reliability, repeatability of results, and economic considerations.

These controls are documented and communicated to facility/activity personnel to ensure appropriate application. The documentation should take the form of written procedures, practices, requirements manuals, policy statements, standing orders, or other written and controlled means as deemed appropriate by facility/activity management. The level of approval of this documentation is also based on the hazards, complexity, and/or relative risk.

Work Performance

Managers are responsible for ensuring that personnel under their supervision have the training, skills (including knowledge and understanding of the capabilities of the processes being used), equipment, work process documents, and resources needed to accomplish their work. Line management and workers should cooperate to identify processes that can be improved based on feedback prior to and following implementation of the work process.

Management should ensure that the following are clearly identified and conveyed to workers before they begin work:

- Customer and data requirements for the work and final product
- Hazards associated with the work
- Safety, administrative, technical, environmental, and QCs to be used during the work
- Technical standards applicable to the work and final product
- Acceptance criteria applicable to the work and final product
- Procedures for verification of the completed work using established criteria

Procedures, work instructions, or other appropriate means used to define work processes should be documented and controlled. The scope and detail of documentation should be commensurate with the complexity and importance of the work, the skills required to perform the work, the hazards and risks or consequences of quality problems in the product, process, or service, and the need to meet regulatory and contract requirements. Control of processes, skills, hazards, and equipment should be clearly specified, understood, and fully documented. This serves as the point of integration for Integrated Safety Management and QA into an integrated management approach. See DOE P 450.4 and DOE Order 5480.19 for details and additional requirements.

Workers are responsible for the quality of their work. Workers should do their work correctly the first time, in accordance with established procedures and work instructions. Because workers are the best resource for contributing ideas for improving work processes, products, and services, they should be involved in work process design, process evaluation (pre-job briefing), and providing the feedback necessary for improvement.

Operating problems should be documented and evaluated. Based on assessments of these problems, corrective actions should be taken to improve the performance of the operations department. Additionally, frequent, direct observation of operations activities by supervisors and managers is essential to the monitoring of operations. Safety, environment, and operating goals should be used as a management tool for involving cognizant groups or individuals in improving operating performance and for measuring operating effectiveness.

Work Feedback

Work activities and management systems can be continuously improved through assessment and feedback processes. Effective feedback from multiple sources is the foundation for processes designed to prevent, identify, and correct problems. The least desirable form of feedback results from accidents or unplanned events that self-disclose a quality problem. The process should include the use of lessons learned from the local organization and other organizations. Identified improvement actions should also be shared with other organizations. Management should track the actions to closure and ensure the actions are effective in providing the anticipated improvements. Quality improvement processes will support safety management system policy feedback and improvement core function, and the Department’s commitment to develop corrective action plans for safety issues (findings) reported by the Office of Independent Oversight and Performance Assurance, or for judgments of need resulting from Type A accident investigations. These findings will be tracked using the DOE Corrective Action Tracking System.

21. Electrical personnel shall demonstrate a working level knowledge of 29 CFR 1910. 331–335; 29 CFR 1910.269; and NFPA 70E, Article 110, Electrical Safety-Related Work Practices.

[Note: The 2004 version of NFPA 70E has been superseded by the 2009 revision and is archived but still available. Because the 2009 revision was drastically reduced in scope it is not used as a reference in this guide.]

The information for this competency statement is taken from DOE HDBK 1092-2004.

a. Describe and explain electrical training and qualification programs.

Only qualified workers shall perform work on electrical systems. It is dangerous for unqualified personnel to attempt to do electrical work. There should be an employee training program implemented to qualify workers in the safety-related work practices that pertain to their respective job assignments.

Management should establish formal training and qualifications for qualified workers before they are permitted to perform electrical work. Refresher training is recommended at intervals not to exceed three years to provide an update on new regulations and electrical safety criteria. The training shall be on-the-job and/or classroom type. The degree of training provided shall be determined by the risk to the employee. This training shall be documented. Qualified employees shall be trained and familiar with, but not be limited to, the following:

- Safety-related work practices, including proper selection and use of PPE, that pertain to their respective job assignments
- Skills and techniques necessary to distinguish exposed live parts from other parts of electrical equipment
- Skills and techniques necessary to determine the nominal voltage of exposed live parts, clearance distances, and the corresponding voltages to which the qualified person will be exposed
- Procedures on how to perform their jobs safely and properly
- How to LOTO energized electrical circuits and equipment safely. Other types of training recommended for electrical workers include the following:
  - National Electrical Code (NFPA 70) (2002)
  - National Electrical Safety Code (ANSI C2) (2002)
  - Use of personal protective grounds
  - Use of testing and measuring equipment
  - Work permit and work authorization procedures
  - Use and care of PPE
  - Proper clothing required for arc flash or arc blast protection
  - First-aid and CPR refresher training is recommended at intervals not to exceed 3 years
  - Standard for Electrical Safety in the Workplace (NFPA 70E) (2004)

29 CFR 1910.269(a) and 1910.332 also require training for persons other than qualified workers if their job assignments bring them close enough to exposed parts of electrical circuits operating at 50 V or more to ground for a hazard to exist.

b. Describe and explain electrical safety program elements.

The six basic elements of an effective Electrical Safety Program are listed below:

1. Management must have complete commitment to the program;
2. Effective training for all degrees of hazard and a baseline for training must be established;
3. Effective and complete safe electrical work practices must be established;
4. Documentation must be kept for all activities;
5. Electrical safety engineering support must be made; and
6. Oversight for the electrical safety program must be established also.

Management commitment

Management ensures that the Electrical Safety Program is integrated into an overall ES&H program, selects the Electrical Safety Committee Chair, and approves the committee's charter.

Effective training

- Establish qualification requirements, training programs and certifications where appropriate for all personnel.
- Prior to performing electrical work, personnel must be qualified to perform job-related electrical tasks as required by 29 CFR 1910.332.
- Personnel exposed to the presence of voltages of 50 V or more will have formal electrical safety awareness training. This training can be in a classroom or on the job.
- All training must be documented.
  - Instructors must provide course outlines.
  - Proof of successful completion must be maintained in appropriate files.

- Minimum training requirements should include
  - electrical safety awareness;
  - electrical safety theory;
  - applicable codes, DOE orders, regulations, and standards;
  - demonstrations and hands-on practice;
  - use and care of PPE;
  - job-specific safe electrical work practices; and
  - electrical requirements of safe operating procedures and operating procedures.
  - Personnel working with high voltage (greater than 600 V) must have specialized electrical awareness training.
  - Periodic training refresher courses are required to maintain and update skills and code requirements.

- Management and supervision who oversee electrical work must have completed Electrical Safety Awareness Training at a level commensurate with the level of work being performed.

Safe electrical work practices

- Provide general and job-specific training in safe electrical work practices as required in 29 CFR 1910, Subpart S.

- All safety-related electrical work practices covered by the provisions in 29 CFR 1910.331 through .335 shall be followed.
- Develop and implement safe operating procedures to ensure safe electrical work practices that mitigate the risks of electrical hazards.

Documentation

- Document all results of any inspection.
- Documentation should be developed to substantiate the acceptance of any equipment. Such documentation should include but not be limited to:
  - Tests performed
  - Conditions of acceptability
  - Applicable standards to which the equipment was evaluated
  - Limitations of approved use, if any
- Establish measurement criteria and documentation for self-assessment of the Electrical Safety Program.
- Document work experience, on-the-job, and offsite formal training to verify understanding and retention of minimum knowledge, skills, and abilities.

Electrical safety engineering support

Management must ensure that any necessary engineering support is provided.

Program oversight

- ES&H managers provide oversight for implementing the Electrical Safety Program.
- Safety managers provide oversight and customer liaison for electrical safety for the departments. They also provide cognizant electrical safety professionals trained in the application of the National Electrical Code (NEC), OSHA, etc.
- Qualified QA personnel will participate in the QA process and provide design input and oversight as follows:
  - Review electrical plans for all new, or modifications to, facilities and research and development projects.
  - Review safe operating procedures for Electrical Safety Program compliance.
  - Periodically inspect wiring materials, connections, and components of existing facilities and R&D projects.
  - Review drawings, specifications, and manufacturer’s installation operation instructions for all electrical equipment prior to connection and operations.

22. Electrical personnel shall demonstrate a working level knowledge of the site contractor's procedure/work control program, how electrical work performed by the site contractor is within planned controls, and the specific work control requirements for each job observed. The level of rigor of these jobs should allow the candidate to review the functional areas, requirements, and workscope for compliance with 29 CFR 1910, 29 CFR 1926, and NFPA 70E.

[Note: The 2004 version of NFPA 70E has been superseded by the 2009 revision and is archived but still available. Because the 2009 revision was drastically reduced in scope it is not used as a reference in this guide.]

Note: To safely observe electrical work on or near energized electrical conductors, the candidate must be previously trained to the appropriate requirements. Candidates are not to cross any shock or arc flash boundary without the appropriate training and understanding of the potential hazards.

The information for KSAs 'a' through 'f' is taken from NFPA 70E.

a. Describe and explain electrical safety-related work practices and the establishment of electrically safe work conditions (29 CFR 1910.147, 29 CFR 1910.331–335, and NFPA 70E, Article 120) including, but not limited to, Lockout/Tagout (LOTO), de-energization requirements, zero-energy checks, and the electrically-safe-work-condition verification process.

Lockout/Tagout

- Each person who could be exposed directly or indirectly to a source of electrical energy shall be involved in the LOTO process.
- All persons who could be exposed shall be trained to understand the established procedure to control the energy and their responsibility in executing the procedure. New (or reassigned) employees shall be trained (or retrained) to understand the LOTO procedure as related to their new assignment.
- A plan shall be developed on the basis of the existing electrical equipment and system and shall utilize up-to-date diagrammatic drawing representation(s).
- All sources of electrical energy shall be controlled in such a way as to minimize employee exposure to electrical hazards.
- The LOTO device shall be unique and readily identifiable as a LOTO device.
- Voltage shall be removed and absence of voltage verified.
- The established electrical LOTO procedure shall be coordinated with all of the employer's procedures associated with LOTO of other energy sources. The LOTO procedure shall be audited for execution and completeness on an annual basis.
- The employer shall establish LOTO procedures for the organization, provide training to employees, provide equipment necessary to execute the details of the procedure, audit execution of the procedures to ensure employee understanding/compliance, and audit the procedure for improvement opportunity and completeness.

De-energization Requirements

De-energization should always be accompanied by approved positive lockout or LOTO procedures to ensure against an unexpected re-energization and resulting hazard to personnel or equipment. De-energization should be immediately followed by a test to ensure that the equipment is de-energized. The equipment should be grounded prior to the start of any work.

Each employer shall identify, document, and implement LOTO procedures conforming to Article 120 to safeguard employees from exposure to electrical hazards while they are working on or near de-energized electrical conductors or circuit parts that are likely to result in injury from inadvertent or accidental contact or equipment failure. The LOTO procedure shall be appropriate for the experience and training of the employees and conditions as they exist in the workplace.

A complex LOTO plan shall be permitted where one or more of the following exist:

- Multiple energy sources
- Multiple crews
- Multiple crafts
- Multiple locations
- Multiple employers
- Different disconnecting means
- Particular sequences
- A job or task that continues for more than one work period

Zero-Energy Checks

In addition to the processes and procedures associated with the practices described above, all sources of electrical energy shall be controlled in such a way as to minimize employee exposure to electrical hazards. Voltage shall be removed and the absence of voltage verified.

Electrically Safe Work Condition Verification Process

An electrically safe work condition shall be achieved when work is performed in accordance with the procedures of NFPA 70E, Article 120.2, and verified by the following process:

- Determine all possible sources of electrical supply to the specific equipment. Check applicable up-to-date drawings, diagrams, and identification tags.
- After properly interrupting the load current, open the disconnecting device(s) for each source.
- Wherever possible, visually verify that all blades of the disconnecting devices are fully open or that drawout-type circuit breakers are withdrawn to the fully disconnected position.
- Apply LOTO devices in accordance with a documented and established policy.
- Use an adequately rated voltage detector to test each phase conductor or circuit part to verify they are de-energized. Test each phase conductor or circuit part both phase-to-phase and phase-to-ground. Before and after each test, determine that the voltage detector is operating satisfactorily.
- Where the possibility of induced voltages or stored electrical energy exists, ground the phase conductors or circuit parts before touching them. Where it could be reasonably anticipated that the conductors or circuit parts being de-energized could contact other exposed energized conductors or circuit parts, apply ground connecting devices rated for the available fault duty.

b. Describe and explain the electrical hazards/risk identification and classification processes (29 CFR 1910, 29 CFR 1926, and NFPA 70E, Article 130).

The DOE uses two general electrical hazard/risk identification and classification processes. One process is used for the identification and analysis of electrical risks/hazards for the purpose of determining appropriate controls and PPE required for particular work activities. The other process is used for standardizing events for the occurrence and reporting process.

Work controls (procedures, boundaries, permits, etc.) and PPE are directly related to, and determined by the particular risk/hazard of the work activity. Specifically, a relationship is established wherein

Work controls and PPE = F (hazards)

NFPA 70E, Article 130 provides a general approach in which approach boundaries for shock protection (controls) are determined from phase-to-phase voltages (hazards), and arc-flash risks are categorized by the potential incidental energy releases for particular combinations of voltages and work activities. The results of these approach boundaries and incidental energy estimates are then used to develop work permits, procedures, and drive tool and protective equipment requirements.

The second process is used for electrical event categorization and performance measurement of occurrence reporting and processing of electrical operations information. This process establishes an "electrical severity" measure for an accident or event that is calculated from several factors (the electrical hazard, environmental conditions, shock, arc-flash, and thermal proximities, and an injury factor). Hazard classification charts are used to consider several factors (voltage, power, waveform, equipment, frequency, etc.) in determining the electrical hazard factor.

Once electrical severity is calculated, it is then used to establish an electrical-severity-index performance measure for normalization of site events versus organizational work hours that can be trended and used for occurrence reporting.

A shock hazard analysis shall determine the voltage to which personnel will be exposed, boundary requirements, and the PPE necessary in order to minimize the possibility of electric shock to personnel.

The shock protection boundaries identified as Limited, Restricted, and Prohibited Approach Boundaries are applicable to the situation in which approaching personnel are exposed to live parts. See table 4 for the distances associated with various system voltages.

Table 4. Approach boundaries to live parts for shock protection

(1)	(2)	(3)	(4)	(5)
	Limited Approach Boundary[1]			
Nominal System Voltage Range, Phase to Phase	Exposed Movable Conductor	Exposed Fixed Circuit Part	Restricted Approach Boundary[1]; Includes Inadvertent Movement Adder	Prohibited Approach Boundary[1]

(1) Nominal System Voltage Range, Phase to Phase	(2) Limited Approach Boundary[1] Exposed Movable Conductor	(3) Limited Approach Boundary[1] Exposed Fixed Circuit Part	(4) Restricted Approach Boundary[1]; Includes Inadvertent Movement Adder	(5) Prohibited Approach Boundary[1]
Less than 50	Not specified	Not specified	Not specified	Not specified
50 to 300	3.05 m (10 ft 0 in.)	1.07 m (3 ft 6 in.)	Avoid contact	Avoid contact
301 to 750	3.05 m (10 ft 0 in.)	1.07 m (3 ft 6 in.)	304.8 mm (1 ft 0 in.)	25.4 (0 ft 1 in.)
751 to 15 kV	3.05 m (10 ft 0 in.)	1.53 m (5 ft 0 in.)	660.4 mm (2 ft 2 in.)	177.8 mm (0 ft 7 in.)
15.1 kV to 36 kV	3.05 m (10 ft 0 in.)	1.83 m (6 ft 0 in.)	787.4 mm (2 ft 7 in.)	254 mm (0 ft 10 in.)
36.1 kV to 46 kV	3.05 m (10 ft 0 in.)	2.44 m (8 ft 0 in.)	838.2 mm (2 ft 9 in.)	431.8 mm (1 ft 5 in.)
46.1 kV to 72.5 kV	3.05 m (10 ft 0 in.)	2.44 m (8 ft 0 in.)	965.2 mm (3 ft 2 in.)	635 mm (2 ft 1 in.)
72.6 kV to 121 kV	3.25 m (10 ft 8 in.)	2.44 m (8 ft 0 in.)	991 mm (3 ft 3 in.)	812.8 mm (2 ft 8 in.)
138 kV to 145 kV	3.36 m (11 ft 0 in.)	3.05 m (10 ft 0 in.)	1.093 m (3 ft 7 in.)	939.8 mm (3 ft 1 in.)
161 kV to 169 kV	3.56 m (11 ft 8 in.)	3.56 m (11 ft 8 in.)	1.22 m (4 ft 0 in.)	1.07 m (3 ft 6 in.)
230 kV to 242 kV	3.97 m (13 ft 0 in.)	3.97 m (13 ft 0 in.)	1.6 m (5 ft 3 in.)	1.45 m (4 ft 9 in.)
345 kV to 362 kV	4.68 m (15 ft 4 in.)	4.68 m (15 ft 4 in.)	2.59 m (8 ft 6 in.)	2.44 m (8 ft 0 in.)
500 kV to 550 kV	5.8 m (19 ft 0 in.)	5.8 m (19 ft 0 in.)	3.43 m (11 ft 3 in.)	3.28 m (10 ft 9 in.)
765 kV to 800 kV	7.24 m (23 ft 9 in.)	7.24 m (23 ft 9 in.)	4.55 m (14 ft 11 in.)	4.4 m (14 ft 5 in.)

Note: For Flash Protection Boundary, see 130.3(A).

[1]See definition in Article 100 and text in 130.2(D)(2) and Annex C for elaboration.

Source: NFPA 70E

c. Describe and explain how to conduct electrical work on or near live parts, including, but not limited to, energized electrical work permits (elements and exemptions), shock and arc-flash hazard analyses, arc flash calculation methodology, arc flash reduction techniques, approach boundaries, and associated Personal Protective Equipment (PPE) (NFPA 70E, Article 130; IEEE Std 1584; etc.).

Energized Electrical Work Permits

If live parts are not placed in an electrically safe work condition (i.e., for the reasons of increased or additional hazards or infeasibility per NFPA 70E, 130.1), work to be performed shall be considered energized electrical work and shall be performed by written permit only.

The energized electrical work permit shall include, but not be limited to, the following items:

- A description of the circuit and equipment to be worked on and their location
- Justification for why the work must be performed in an energized condition
- A description of the safe work practices to be employed
- Results of the shock hazard analysis
- Determination of shock protection boundaries
- Results of the flash hazard analysis
- The flash protection boundary
- The necessary PPE to safely perform the assigned task
- Means employed to restrict the access of unqualified persons from the work area

- Evidence of completion of a job briefing, including a discussion of any job-specific hazards
- Energized work approval (authorizing or responsible management, safety officer, or owner, etc.) signature(s)

Work performed on or near live parts by qualified persons related to tasks such as testing, troubleshooting, voltage measuring, etc., shall be permitted to be performed without an energized electrical work permit, provided appropriate safe work practices and PPE are provided and used.

Shock and Arc-Flash Hazard Analyses

A shock hazard analysis shall determine the voltage to which personnel will be exposed, boundary requirements, and the PPE necessary in order to minimize the possibility of electric shock to personnel. The shock protection boundaries identified as Limited, Restricted, and Prohibited Approach Boundaries are applicable to the situation in which approaching personnel are exposed to live parts. See table 4 for the distances associated with various system voltages.

A flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc flash. The analysis shall determine the flash protection boundary and the PPE that people within the flash protection boundary shall use. For systems that are 600 volts or less, the flash protection boundary shall be 4.0 feet, based on the product of clearing times of 6 cycles (0.1 second) and the available bolted fault current of 50 kiloamperes (kA) or any combination not exceeding 300 kA cycles (5,000 ampere-seconds). For clearing times and bolted fault currents other than 300 kA cycles, or under engineering supervision, the flash protection boundary shall alternatively be permitted to be calculated in accordance with the following general formula:

$$D_c = [2.65 \times MVA_{bf} \times t]^{1/2}$$

or

$$D_c = [53 \times MVA \times t]^{1/2}$$

where:

D_c = distance in feet from an arc source for a second-degree burn

MVA_{bf} = bolted fault capacity available at point involved (in megavolt-amperes)

MVA = capacity rating of transformer (megavolt-amperes). For transformers with *MVA* ratings below 0.75 MVA, multiply the transformer *MVA* rating by 1.25

t = time of arc exposure (in seconds)

At voltage levels above 600 volts, the flash protection boundary is the distance at which the incident energy equals 5 J/cm^2(1.2 calorie [cal] /cm^2). For situations where fault-clearing time is 0.1 second (or faster), the flash protection boundary is the distance at which the incident energy level equals 6.24 J/cm^2(1.5 cal/cm^2).

Arc-Flash Calculation Methodology

See above formula.

Arc-Flash Reduction Techniques

Shock and arc-flash hazard analyses, proper PPE, and noting limited approach to boundaries are methods by which arc flashes may be reduced and altogether avoided.

Approach Boundaries

See table 4 and associated boundary explanations.

Personal Protective Equipment

Personal Protective Equipment requirements are directly derived from the identified hazards and risks for the particular work activity. Where it has been determined that work will be performed within the flash protection boundary, the flash hazard analysis shall determine, and the employer shall document, the incident energy exposure of the worker (in calories per square centimeter). The incident energy exposure level shall be based on the working distance of the employee's face and chest areas from a prospective arc source for the specific task to be performed. Flame-resistant clothing and PPE shall be used by the employee based on the incident energy exposure associated with the specific task. Recognizing that incident energy increases as the distance from the arc flash decreases, additional PPE shall be used for any parts of the body that are closer than the distance at which the incident energy was determined. As an alternative, the PPE requirements of NFPA 70E 130.7(C)(9) shall be permitted to be used in lieu of the detailed flash hazard analysis approach described in NFPA 70E 130.3(A).

When flame-resistant clothing is worn to protect an employee, it shall cover all ignitable clothing and shall allow for movement and visibility. Employees shall wear nonconductive head protection wherever there is a danger of head injury from electric shock or burns due to contact with live parts or from flying objects resulting from electrical explosion. Employees shall wear nonconductive protective equipment for the face, neck, and chin whenever there is a danger of injury from exposure to electric arcs or flashes or from flying objects resulting from electrical explosion. Employees shall wear protective equipment for the eyes whenever there is danger of injury from electric arcs, flashes, or from flying objects resulting from electrical explosion. Employees shall wear flame-resistant clothing wherever there is possible exposure to an electric arc flash above the threshold incident-energy level for a second-degree burn.

Employees shall wear rubber insulating gloves where there is danger of hand and arm injury from electric shock due to contact with live parts. Hand and arm protection shall be worn where there is possible exposure to arc flash burn. Where insulated footwear is used as protection against step and touch potential, dielectric overshoes shall be required. Insulated soles shall not be used as primary electrical protection.

d. Describe and explain safety-related maintenance requirements, including grounding and bonding, safety equipment, clear space requirements, substations, switchgear, panels, motor control centers, premises wiring, controller equipment, fuses and circuit breakers, rotating equipment, hazardous locations, batteries and battery rooms, portable electric tools and equipment, and personal safety and protective equipment (NFPA 70E, Chapter 2; IEEE Std-450; etc.).

Grounding and Bonding

Equipment, raceways, cable trays, and enclosure bonding and grounding shall be maintained to ensure electrical continuity.

Safety Equipment

Locks, interlocks, and other safety equipment shall be maintained in proper working condition to accomplish the control purpose.

Clear Space Requirements

Access to working space and escape passages shall be kept clear and unobstructed.

Substations, Switchgear, Panels, Motor Control Centers (MCCS).

Enclosures shall be kept free of material that would create a hazard.

Fences, physical protection, enclosures, or other protective means, where required to guard against unauthorized access or accidental contact with exposed live parts, shall be maintained.

Current-carrying conductors (buses, switches, disconnects, joints, and terminations) and bracing shall be maintained to

- conduct rated current without overheating, and
- withstand available fault current.

Insulation integrity shall be maintained to support the voltage impressed.

Protective devices shall be maintained to adequately withstand or interrupt available fault current.

Premises Wiring

Covers for wiring system components shall be in place with all associated hardware, and there shall be no unprotected openings.

Open wiring protection, such as location or barriers, shall be maintained to prevent accidental contact.

Raceways and cable trays shall be maintained to provide physical protection and support for conductors.

Controller Equipment

The following shall apply to controllers, including electrical equipment that governs the starting, stopping, direction of motion, acceleration, speed, and protection of rotating equipment and other power utilization apparatus in the workplace: protection and control circuitry used to guard against accidental contact with live parts and to prevent other electrical or mechanical hazards shall be maintained.

Fuses and Circuit Breakers

Fuses shall be maintained free of breaks or cracks in fuse cases, ferrules, and insulators. Fuse clips shall be maintained to provide adequate contact with fuses.

Molded-case circuit breakers shall be maintained free of cracks in cases and cracked or broken operating handles.

Circuit breakers that interrupt faults approaching their ratings shall be inspected and tested in accordance with the manufacturer’s instructions.

Rotating Equipment

Terminal chambers, enclosures, and terminal boxes shall be maintained to guard against accidental contact with live parts and other electrical hazards.

Guards, barriers, and access plates shall be maintained to prevent employees from contacting moving or energized parts.

Hazardous Locations

Equipment and installations in hazardous locations shall be maintained such that the following apply:

- No energized parts are exposed. Exception: intrinsically safe and non-incendive circuits.
- There are no breaks in conduit systems, fittings, or enclosures from damage, corrosion, or other causes.
- All bonding jumpers are securely fastened and intact.
- All fittings, boxes, and enclosures with bolted covers have all bolts installed and bolted tight.
- All threaded conduit shall be wrench-tight, and enclosure covers shall be tightened in accordance with the manufacturer’s instructions.
- There are no open entries into fittings, boxes, or enclosures that would compromise the protection characteristics.
- All close-up plugs, breathers, seals, and drains are securely in place.
- Marking of luminaires (lighting fixtures) for maximum lamp wattage and temperature rating is legible and not exceeded.
- Required markings are secure and legible.

Batteries and Battery Rooms

Ventilation systems, forced or natural, shall be maintained to prevent buildup of explosive mixtures. This maintenance shall include a functional test of any associated detection and alarm systems.

Eye and body wash apparatus shall be maintained in operable condition.

Battery cell ventilation openings shall be unobstructed, and cell flame arresters shall be maintained.

Portable Electric Tools and Equipment

Attachment plugs, receptacles, cover plates, and cord connectors shall be maintained such that the following apply:

- There are no breaks, damage, or cracks exposing live parts.
- There are no missing cover plates.
- Terminations have no stray strands or loose terminals.
- There are no missing, loose, altered, or damaged blades, pins, or contacts.
- Polarity is correct.

Personal Safety and Protective Equipment

Personal safety and protective equipment such as the following shall be maintained in a safe working condition:

- Grounding equipment
- Hot sticks
- Rubber gloves, sleeves, and leather protectors
- Voltage test indicators
- Blanket and similar insulating equipment
- Insulating mats and similar insulating equipment
- Protective barriers
- External circuit breaker rack-out devices
- Portable lighting units
- Safety grounding equipment
- Dielectric footwear
- Protective clothing

e. Describe and explain the safety requirements for special equipment such as Research and Development (R&D) electrical safety requirements and work practices for such R&D equipment, i.e., laser operations and power electronic equipment, etc. (NFPA 70E, Article 400; American National Standards Institute (ANSI); etc.).

Laser Operations

Employees shall be provided with eye protection as required by Federal regulation. Warning signs shall be posted at the entrances to areas or protective enclosures containing laser products. High-power laser equipment shall include a key-operated master control. High-power laser equipment shall include a fail-safe laser radiation emission audible and visible warning when it is switched on or the capacitor banks are charged. Beam shutters or caps shall be utilized, or the laser switched off, when laser transmission is not required. The laser shall be switched off when unattended for 30 minutes or more. Laser beams shall not be aimed at employees. Laser equipment shall bear a label indicating its maximum output.

Personnel protective equipment shall be provided for users and operators of high-power laser equipment.

Employees shall be responsible for the following:
- Obtaining authorization for laser use
- Obtaining authorization for being in a laser operating area
- Observing safety rules
- Reporting laser equipment failures and accidents to the employer

Power Electronic Equipment

The employee and employer responsibilities listed below shall apply to safety-related work practices around power electronic equipment, including the following:
- Electric arc welding equipment
- High-power radio, radar, and television transmitting towers and antennae
- Industrial dielectric and RF induction heaters
- Shortwave or RF diathermy devices
- Process equipment that includes rectifiers and inverters such as the following:
  - Motor drives
  - Uninterruptible power supply (UPS) systems
  - Lighting controllers

The employer shall be responsible for the following:
- Proper training and supervision by properly qualified personnel, including the following:
  - The nature of the associated hazard
  - Strategies to minimize the hazard
  - Methods of avoiding or protecting against the hazard
  - The necessity of reporting any hazardous incident
- Properly installed equipment
- Proper access to the equipment
- Availability of the correct tools for operation and maintenance
- Proper identification and guarding of dangerous equipment
- Provision of complete and accurate circuit diagrams and other published information to the employee prior to the employee starting work. The circuit diagrams should be marked to indicate the hazardous components
- Maintenance of clear and clean work areas around the equipment to be worked
- Provision of adequate and proper illumination of the work area

The employee is responsible for the following:
- Being continuously alert and aware of the possible hazards
- Using the proper tools and procedures for the work
- Informing the employer of malfunctioning protective measures, such as faulty or inoperable enclosures and locking schemes

- Examining all documents provided by the employer relevant to the work, especially those documents indicating the hazardous component's location
- Maintaining good housekeeping around the equipment and work space
- Reporting any hazardous incident

f. Describe and explain the installation safety requirements for power systems protection; flash protection; guarding of live parts; wiring design and protection; wiring methods, components, and equipment; specific purpose equipment and installations [cranes and hoists, elevators, Heating, Ventilating and Air-conditioning (HVAC), X-ray equipment, motor controllers, etc.]; and hazardous locations (NFPA 70 and NFPA 70E, Chapter 4).

Power Systems Protection

The requirements contained in Chapter 4 of NFPA 70E shall be based on the provisions of NFPA 70, *National Electrical Code*. Where installations of electric conductors and equipment have been found to conform with the safety requirements of the NEC in use at the time of installation by governmental bodies or agencies having legal jurisdiction for enforcement of the NEC, this conformance shall be prima facie evidence that such installations were adequately designed and installed.

The chapter is divided into six articles. Article 400, 410, and 420 apply generally. Article 430 applies to specific-purpose equipment installations. Articles 440 and 450 apply to hazardous (classified) locations and special systems. Articles 430, 440, and 450 supplement or modify the general rules, and 450.5 covers communications systems and is independent of the other paragraphs and chapters except where specifically referenced. Articles 400, 410, and 420 apply except as amended by Articles 430, 440, and 450 for the particular condition.

Flash Protection

Switchboards, panelboards, industrial control panels, and MCCs that are in other than dwelling occupancies and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc-flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

Guarding of Live Parts

Except as elsewhere required or permitted, live parts of electric equipment operating at 50 volts or more shall be guarded against accidental contact by approved enclosures or by any of the following means:

- Location in a room, vault, or similar enclosure that is accessible only to qualified persons
- Suitable permanent, substantial partitions or screens arranged so that only qualified persons have access to the space within reach of the live parts. Any openings in such partitions or screens shall be sized and located so that persons are not likely to come into accidental contact with the live parts or to bring conducting objects into contact with them
- Location on a suitable balcony, gallery, or platform elevated and arranged so as to exclude unqualified persons

- Elevation of 2.5 m (8 ft) or more above the floor or other working surface

In locations where electric equipment is likely to be exposed to physical damage, enclosures or guards shall be so arranged and of such strength as to prevent such damage. Entrances to rooms and other guarded locations that contain exposed live parts operating at 50 volts or more shall be marked with conspicuous warning signs forbidding unqualified persons to enter.

Wiring Design and Protection

A conductor used as a grounded conductor shall be identifiable and distinguishable from all other conductors. No grounded conductor shall be attached to any terminal or lead so as to reverse designated polarity.

A lengthy description of wiring and design protection is available in NFPA 70E, Article 410.

Wiring Methods, Components, and Equipment

The provisions of the following paragraph are not intended to apply to the conductors that form an integral part of equipment, such as motors, controllers, MCCs, factory assembled control equipment, or listed utilization equipment.

Metal raceways, cable trays, cable armor, cable sheath, enclosures, frames, fittings, and other metal non-current-carrying parts that are to serve as grounding conductors, with or without the use of supplementary equipment grounding conductors, shall be effectively bonded where necessary to ensure electrical continuity and the capacity to conduct safely any fault current likely to be imposed on them. Any nonconductive paint, enamel, or similar coating shall be removed at threads, contact points, and contact surfaces or be connected by means of fittings designed so as to make such removal unnecessary.

A lengthy description of wiring methods, components, and equipment is available in NFPA 70E, Article 420.

Specific Purpose Equipment and Installations—Cranes and Hoists, Elevators, Heating, Ventilating and Air-Conditioning, X-ray Equipment, Motor Controllers, etc.

A lengthy description of specific purpose equipment and installations is available in NFPA 70E, Article 430.

Hazardous Locations

NFPA 70E, Article 440 applies to the requirements for electric equipment and wiring in locations that are classified, depending on the properties of the flammable vapors, liquids, or gases or combustible dusts or fibers that might be present therein and the likelihood that a flammable or combustible concentration or quantity is present. Hazardous (classified) locations can be found in occupancies such as, but not limited to, aircraft hangars, gasoline dispensing and service stations, bulk storage plants for gasoline or other volatile flammable liquids, paint-finishing process plants, health care facilities, agricultural or other facilities where excessive combustible dusts might be present, marinas, boat yards, and petroleum and chemical processing plants. Each room, section, or area shall be considered individually in determining its classification.

A lengthy description of specific purpose equipment and installations is available in NFPA 70E, Article 440.

23. From the jobs observed in Competency 22 above, electrical personnel shall demonstrate the ability to assess how well contractor management systems (lessons learned and other feedback processes) are integrated with the work planning and ISMS process and how lessons learned are addressed by each contractor's ISMS feedback process (DOE P 450.4, Safety Management System Policy).

The information for all of the KSAs in this competency statement is taken from DOE O 226.1A.

a. Describe and explain the contractors' lessons learned program.

Formal programs must be established to communicate lessons learned during work activities, process reviews, and event analyses to potential users and applied to future work activities. Contractors must identify, apply, and exchange lessons learned with the rest of the DOE complex.

b. Describe and explain how electrical lessons learned are integrated into the contractors' work planning process.

Contractors must review and apply lessons learned identified by other DOE organizations and external sources to prevent similar occurrences (see also DOE O 414.1C, criterion 3, "Quality Improvement").

c. Describe and explain how feedback from the workers who have completed an electrical job is integrated into the contractors' work planning process.

In addition to structured assessments, DOE contractors will establish and implement processes to solicit feedback from workers and work activities. Common feedback mechanisms are described in site plans/program documents and include the following: employee concerns programs, telephone or intranet "hotline" processes for reporting concerns or questions, pre-job briefs, job hazard walk-downs by workers prior to work, post-job reviews, employee suggestion forms, safety meetings, employee participation in committees and working groups, and labor organization input.

24. Electrical personnel shall demonstrate a working level knowledge of 29 CFR 1910; 29 CFR 1926; and NFPA 70E, Article 420 requirements.

[Note: The 2004 version of NFPA 70E has been superseded by the 2009 revision and is archived but still available. Because the 2009 revision was drastically reduced in scope it is not used as a reference in this guide.]

a. Describe and explain wiring methods, bonding of enclosures, temporary wiring, and permitted use of cable trays.

The information for KSAs 'a' through 'f' and 'h' is taken from NFPA 70E.

Wiring Methods

These provisions are not intended to apply to the conductors that form an integral part of equipment, such as motors, controllers, MCCs, factory assembled control equipment, or listed utilization equipment.

Bonding of Enclosures

Metal raceways, cable trays, cable armor, cable sheath, enclosures, frames, fittings, and other metal non-current-carrying parts that are to serve as grounding conductors, with or without the use of supplementary equipment grounding conductors, shall be effectively bonded where necessary to ensure electrical continuity and the capacity to conduct safely any fault current likely to be imposed on them. Any nonconductive paint, enamel, or similar coating shall be removed at threads, contact points, and contact surfaces or be connected by means of fittings designed so as to make such removal unnecessary.

Where required for the reduction of electrical noise (EMI) of the grounding circuit, an equipment enclosure supplied by a branch circuit shall be permitted to be isolated from a raceway containing circuits that supply only that equipment by one or more listed nonmetallic raceway fittings located at the point of attachment of the raceway to the equipment enclosure. The metal raceway shall comply with provisions of this standard and shall be supplemented by an internal insulated equipment grounding conductor installed to ground the equipment enclosure.

No wiring systems of any type shall be installed in ducts used to transport dust, loose stock, or flammable vapors. No wiring system of any type shall be installed in any duct, or any shaft containing only such ducts, used for vapor removal or for ventilation of commercial-type cooking equipment.

Temporary Wiring

Temporary electrical power and lighting wiring methods may be of a class less than would be required for a permanent installation. Except as specifically modified in sections 420.1(B)(1)(a) through 420.1(B)(1)(d), all other requirements of NFPA 70E for permanent wiring shall apply to temporary wiring installations.

Feeders shall be protected as provided in Article 410.9. They shall originate in an approved distribution center. Conductors shall be permitted within cable assemblies or within multiconductor cords or cables of a type identified for hard usage or extra-hard usage. For the purpose of this section, type NM (nonmetallic) and type NMC (nonmetallic, corrosion-resistant) cables shall be permitted to be used in any dwelling, building, or structure without any height limitation.

Single insulated conductors shall be permitted where installed for the purpose(s) specified in Article 420.1(B)(3)(c) where accessible only to qualified persons.

All branch circuits shall originate in an approved power outlet or panelboard. Conductors shall be permitted within cable assemblies or within multiconductor cord or cable of a type identified for hard usage or extra-hard usage. All conductors shall be protected as provided in

Article 410.9. For the purpose of this section, type NM and NMC cables shall be permitted to be used in any dwelling, building, or structure without any height limitation.

Branch circuits installed for the purposes specified in sections 420.1(B)(3)(b) or 420.1(B)(3)(c) shall be permitted to be run as single insulated conductors. Where the wiring is installed in accordance with Article 420.1(B)(1)(c), the voltage to ground shall not exceed 150 volts, the wiring shall not be subject to physical damage, and the conductors shall be supported on insulators at intervals so that excessive strain is not transmitted to the lampholders.

All receptacles shall be of the grounding type. Unless installed in a continuous grounded metal raceway or metal-covered cable, all branch circuits shall contain a separate equipment grounding conductor, and all receptacles shall be electrically connected to the equipment grounding conductors. Receptacles on construction sites shall not be installed on branch circuits that supply temporary lighting. Receptacles shall not be connected to the same ungrounded conductor of multiwire circuits that supply temporary lighting. Suitable disconnecting switches or plug connectors shall be installed to permit the disconnection of all ungrounded conductors of each temporary circuit. Multiwire branch circuits shall be provided with a means to disconnect simultaneously all ungrounded conductors at the power outlet or panelboard where the branch circuit originated. Approved handle ties shall be permitted. All lamps for general illumination shall be protected from accidental contact or breakage by a suitable fixture or lampholder with a guard. Brass shell, paper-lined sockets, or other metal-cased sockets shall not be used unless the shell is grounded. On construction sites, a box shall not be required for splices or junction connections where the circuit conductors are multiconductor cord or cable assemblies, provided that the equipment grounding continuity is maintained with or without the box. A box, conduit body, or terminal fitting having a separately bushed hole for each conductor shall be used wherever a change is made to a conduit or tubing system or a metal-sheathed cable system.

Flexible cords and cables shall be protected from accidental damage. Sharp corners and projections shall be avoided. Where passing through doorways or other pinch points, protection shall be provided to avoid damage. Flexible cords and cables entering enclosures containing devices requiring termination shall be secured to the box with fittings designed for the purpose. Cable assemblies and flexible cords and cables shall be supported in place at intervals that ensure that they will be protected from physical damage. Support shall be in the form of staples, cable ties, straps, or similar type fittings installed so as not to cause damage. Vegetation shall not be used for support of overhead spans of branch circuits or feeders.

Permitted Use of Cable Trays

Cable tray shall be permitted to be used as a support system for services, feeders, branch circuits, communications circuits, control circuits, and signaling circuits. Cable tray installations shall not be limited to industrial establishments. Where exposed to direct rays of the sun, insulated conductors and jacketed cables shall be identified as being sunlight resistant. Cable trays and their associated fittings shall be identified for the intended use.

The following wiring methods shall be permitted to be installed in cable tray systems: armored cable; communication raceways; electrical metallic tubing; electrical nonmetallic tubing; fire alarm cables; flexible metal conduit; flexible metallic tubing; instrumentation tray cable; intermediate metal conduit; liquidtight flexible metal conduit and liquidtight flexible nonmetallic conduit; metal-clad cable; mineral-insulated, metal-sheathed cable; multiconductor service-entrance cable; multiconductor underground feeder and branch-circuit cable; multipurpose and communications cables; nonmetallic-sheathed cable; power and control tray cable; power-limited tray cable; optical fiber cables; optical fiber raceways; other factory-assembled, multiconductor control, signal, or power cables that are specifically approved for installation in cable trays; rigid metal conduit; and rigid nonmetallic conduit.

The wiring methods in Article 420.1(C)(2) shall be permitted to be used in any industrial establishment under the conditions described in their respective articles. In industrial establishments only, where conditions of maintenance and supervision ensure that only qualified persons service the installed cable tray system, any of the cables in sections 420.1(C)(2)(a) and 420.1(C)(2)(b) shall be permitted to be installed in ladder, ventilated trough, solid bottom, or ventilated channel cable trays. Single conductor cables shall be permitted to be installed in accordance with the following: single conductor cable shall be 1/0 American wire gauge (AWG) or larger and shall be of a type listed and marked on the surface for use in cable trays. Where 1/0 AWG through 4/0 AWG single conductor cables are installed in ladder cable tray, the maximum allowable run spacing for the ladder cable tray shall be 230 mm (9 in.). Welding cables shall be installed in dedicated cable trays, as permitted. Single conductors used as equipment grounding conductors shall be insulated, covered, or bare, and they shall be 4 AWG or larger. Single- and multi-conductor medium voltage cables shall be type MV cable. Single conductors shall be installed in accordance with Article 420.1(C)(1).

Metallic cable trays shall be permitted to be used as equipment grounding conductors where continuous maintenance and supervision ensure that qualified persons service the installed cable tray system. Hazardous (classified) locations as permitted. Nonmetallic cable tray shall be permitted in corrosive areas and in areas requiring voltage isolation.

Cable tray systems shall not be used in hoistways or where subject to severe physical damage. Cable tray systems shall not be used in environmental airspaces, except as permitted in Article 420.1(A)(2) to support wiring methods recognized for use in such spaces.

b. Describe and explain safety positioning and connection of switches.

Safety Positioning

Single-throw knife switches shall be placed so that gravity will not tend to close them. Single-throw knife switches approved for use in the inverted position shall be provided with a locking device that ensures that the blades remain in the open position when so set.

Double-throw knife switches shall be permitted to be mounted so that the throw is either vertical or horizontal. Where the throw is vertical, a locking device shall be provided to hold the blades in the open position when so set.

Connection of Switches

Single-throw knife switches and switches with butt contacts shall be connected so that their blades are de-energized when the switch is in the open position. Bolted pressure contact switches shall have barriers that prevent inadvertent contact with energized blades. Single-throw knife switches, bolted pressure contact switches, molded-case switches, switches with butt contacts, and circuit breakers used as switches shall be connected so that the terminals supplying the load are de-energized when the switch is in the open position.

The blades and terminals supplying the load of a switch shall be permitted to be energized when the switch is in the open position where the switch is connected to circuits or equipment inherently capable of providing a backfeed source of power. For such installations, a permanent sign shall be installed on the switch enclosure or immediately adjacent to open switches with the following words or equivalent:

WARNING
LOAD SIDE TERMINALS MAY BE ENERGIZED
BY BACKFEED

c. Describe and explain switch/panelboard location and access requirements.

Switchboards that have any exposed live parts operating at 50 volts or more shall be located in permanently dry locations and then only where under competent supervision and accessible only to qualified persons. Switchboards shall be located so that the probability of damage from equipment or processes is reduced to a minimum. Panelboards shall be mounted in cabinets, cutout boxes, or enclosures designed for the purpose and shall be dead front. Panelboards other than of the dead-front, externally operable type shall be permitted where accessible only to qualified persons.

d. Describe and explain enclosures for damp and wet locations.

In damp or wet locations, surface-type enclosures within the scope of this standard shall be placed or equipped so as to prevent moisture or water from entering and accumulating within the cabinet or cutout box, and shall be mounted so there is at least a 6-mm (¼-in.) airspace between the enclosure and the wall or other supporting surface. Enclosures installed in wet locations shall be weatherproof. Nonmetallic enclosures shall be permitted to be installed without the airspace on a concrete, masonry, tile, or similar surface.

Switchboards or panelboards in a wet location or outside of a building shall be enclosed in a weatherproof enclosure or cabinet that shall comply with Article 420.5(A).

e. Describe and explain conductor identification requirements.

Insulated or covered grounded conductors shall be identified in accordance with NFPA 70E, Article 420. Equipment grounding conductors shall be identified in accordance with this standard. Conductors that are intended for use as ungrounded conductors, whether used as a single conductor or in multiconductor cables, shall be finished to be clearly distinguishable from grounded and grounding conductors. Distinguishing markings shall not conflict in any manner with the surface markings.

f. Describe and explain permitted and non-permitted use of flexible cords and cables.

Permitted Use

Flexible cords and cables shall be used only for the following:

- Pendants
- Wiring on luminaires (fixtures)
- Connection of portable lamps, portable and mobile signs, or appliances
- Elevator cables
- Wiring on cranes and hoists
- Connection of utilization equipment to facilitate frequent interchange
- Prevention of the transmission of noise or vibration
- Appliances where the fastening means and mechanical connections are specifically designed to permit ready removal for maintenance and repair, and the appliance is intended or identified for flexible cord connection
- Data processing cables
- Connection of moving parts
- Temporary wiring

Where used as permitted in NFPA 70E, Article 420.7(B)(1)(3), (9), and (11), each flexible cord shall be equipped with an attachment plug and shall be energized from a receptacle outlet.

Non-permitted Use

Unless specifically permitted in Article 420.7(B), flexible cords and cables shall not be used for the following:

- As a substitute for the fixed wiring of a structure
- Where run through holes in walls, structural ceilings, suspended ceilings, dropped ceilings, or floors
- Where run through doorways, windows, or similar openings
- Where attached to building surfaces (exception would be that flexible cord and cable shall be permitted to be attached to building surfaces in accordance with the provisions of NEC Article 368.8)
- Where concealed by walls, floors, or ceilings or where located above suspended or dropped ceilings
- Where installed in raceways, except as otherwise permitted in this standard

g. Describe and explain portable cables over 600 volts.

The following is taken from 29 CFR 1910.305.

- The conductors shall be 8 AWG copper or larger and shall employ flexible stranding.
- The size of the insulated ground-check conductor of type G-GC cables shall be not smaller than 10 AWG.
- Cables operated at over 2,000 volts shall be shielded. Shielding shall be for the purpose of confining the voltage stresses to the insulation.

- An equipment grounding conductor(s) shall be provided. The total area shall not be less than that of the size of the equipment grounding conductor required in NFPA 70E, Article 420.
- All shields shall be grounded.
- Grounding conductors shall be connected in accordance with NFPA 70E, Article 420.
- The minimum bending radii for portable cables during installation and handling in service shall be adequate to prevent damage to the cable.
- Connectors used to connect lengths of cable in a run shall be of a type that locks firmly together. Provisions shall be made to prevent opening or closing these connectors while energized. Suitable means shall be used to eliminate tension at connectors and terminations.
- Portable cables shall not contain splices unless the splices are of the permanent molded, vulcanized types in accordance with this standard. Terminations on portable cables rated over 600 volts, nominal, shall be accessible only to authorized and qualified personnel.

h. Describe and explain motor, transformer, and capacitor general use equipment.

Motor

Where one piece of equipment shall be "in sight from," "within sight from," or "within sight," and so forth, of another piece of equipment, the specified equipment is to be visible and not more than 15 m (50 ft) distant from the other.

An individual disconnecting means shall be provided for each controller and shall disconnect the controller. The disconnecting means shall be located in sight from the controller location.

For motor circuits over 600 volts, nominal, a controller disconnecting means capable of being locked in the open position shall be permitted to be out of sight of the controller, provided the controller is marked with a warning label giving the location of the disconnecting means. A single disconnecting means shall be permitted for a group of coordinated controllers that drive several parts of a single machine or piece of apparatus. The disconnecting means shall be located in sight from the controllers, and both the disconnecting means and the controllers shall be located in sight from the machine or apparatus.

A separate disconnecting means shall be located in sight from the motor location and the driven machinery location. The disconnecting means required in accordance with NFPA 70E, Article 420.10(E)(1), shall be permitted to serve as the disconnecting means for the motor if it is located in sight from the motor location and the driven machinery location.

The disconnecting means shall not be required to be in sight from the motor and the driven machinery location under either condition (a) or (b), provided the disconnecting means required in accordance with Article 420.10(E)(2) is individually capable of being locked in the open position. The provision for locking or adding a lock to the disconnecting means shall be permanently installed on or at the switch or circuit breaker used as the disconnecting means.

(a) Where such a location of the disconnecting means is impracticable or introduces additional or increased hazard to persons or property.

(b) In industrial installations, with written safety procedures, where conditions of maintenance and supervision ensure that only qualified persons service the equipment.

Some examples of increased or additional hazards include, but are not limited to, motors rated in excess of 100 hp, multimotor equipment, submersible motors, motors associated with variable frequency drives, and motors located in hazardous (classified) locations. The disconnecting means shall plainly indicate whether it is in the open (off) or closed (on) position. At least one of the disconnecting means shall be readily accessible.

Each motor shall be provided with an individual disconnecting means. A single disconnecting means shall be permitted to serve a group of motors under any one of the following conditions:

- Where a number of motors drive several parts of a single machine or piece of apparatus, such as metal and woodworking machines, cranes, and hoists
- Where a group of motors is under the protection of one set of branch-circuit protective devices
- Where a group of motors is in a single room within sight from the location of the disconnecting means
- Overload devices are intended to protect motors, motor-control apparatus, and motor branch-circuit conductors against excessive heating due to motor overloads and failure to start. Overload in electrical apparatus is an operating overcurrent that, when it persists for a sufficient length of time, would cause damage or dangerous overheating of the apparatus. It does include short circuits or ground faults. These provisions shall not be interpreted as requiring overload protection where it might introduce additional or increased hazards, as in the case of fire pumps.
- Exposed live parts of motors and controllers operating at 50 volts or more shall be guarded against accidental contact by enclosures or by location as follows: by installation in a room or enclosure that is accessible only to qualified persons; by installation on a suitable balcony, gallery, or platform elevated and arranged so as to exclude unqualified persons; by elevation 2.5 m (8 ft) or more above the floor. The only exception is that live parts of motors operating at more than 50 volts between terminals shall not require additional guarding for stationary motors that have commutators, collectors, and brush rigging located inside of motor-end brackets and not conductively connected to supply circuits operating at more than 150 volts to ground.
- Where live parts of motors or controllers operating at over 150 volts to ground are guarded against accidental contact only by location, and where adjustment or other attendance might be necessary during the operation of the apparatus, suitable insulating mats or platforms shall be provided so that the attendant cannot readily touch live parts unless standing on the mats or platforms

Transformer

Sections 420.10(F)(2) through 420.10(F)(8) of NFPA 70E, Article 420 cover the installation of all transformers. The following transformers are not covered by 420.10(F):

- Current transformers

- Dry-type transformers that constitute a component part of other apparatus and comply with requirements for such apparatus
- Transformers that are an integral part of an X-ray, high-frequency, or electrostatic-coating apparatus
- Transformers used with Class 2 and Class 3 circuits
- Transformers for sign and outline lighting
- Transformers for electric-discharge lighting
- Transformers used for power-limited fire alarm circuits
- Transformers used for research, development, or testing, where effective arrangements are provided to safeguard persons from contacting energized parts

The operating voltage of exposed live parts operating at 50 volts or more of transformer installations shall be indicated by signs or visible markings on the equipment or structures.

Dry-type transformers installed indoors and rated over 35 kV shall be installed in a vault.

Oil-insulated transformers installed indoors shall be installed in a vault. Combustible material, combustible buildings, and parts of buildings, fire escapes, and door and window openings shall be safeguarded from fires originating in oil-insulated transformers installed on roofs, attached to or adjacent to a building or combustible material. Vault doorways shall be protected in accordance with sections 420.10(F)(6)(a), 420.10(F)(6)(b), and 420.10(F)(6)(c):

- Each doorway leading into a vault from the building interior shall be provided with a tight-fitting door that has a minimum fire rating of 3 hours. The authority having jurisdiction (AHJ) shall be permitted to require such a door for an exterior wall opening where conditions warrant. The exception is that where transformers are protected with automatic sprinklers, water spray, carbon dioxide, or halon, construction of 1-hour rating shall be permitted.
- A door sill or curb that is of sufficient height to confine the oil from the largest transformer within the vault shall be provided, and in no case shall the height be less than 100 mm (4 in.).
- Doors shall be equipped with locks, and doors shall be kept locked, access being allowed only to qualified persons. Personnel doors shall swing out and be equipped with panic bars, pressure plates, or other devices that are normally latched but open under simple pressure.

Any pipe or duct system foreign to the electrical installation shall not enter or pass through a transformer vault. Piping or other facilities provided for vault fire protection, or for transformer cooling, shall not be considered foreign to the electrical installation.

Materials shall not be stored in transformer vaults.

Capacitor

Group-operated switches shall be used for capacitor switching and shall be capable of the following:

- Carrying continuously not less than 135 percent of the rated current of the capacitor installation

- Interrupting the maximum continuous load current of each capacitor, capacitor bank, or capacitor installation that will be switched as a unit
- Withstanding the maximum inrush current, including contributions from adjacent capacitor installations
- Carrying currents due to faults on capacitor side of switch

A means shall be installed to isolate from all sources of voltage each capacitor, capacitor bank, or capacitor installation that will be removed from service as a unit. The isolating means shall provide a visible gap in the electrical circuit adequate for the operating voltage.

Isolating or disconnecting switches (with no interrupting rating) shall be interlocked with the load-interrupting device or shall be provided with prominently displayed caution signs to prevent switching load current.

The proper switching sequence shall be ensured by use of one of the following:

- Mechanically sequenced isolating and bypass switches
- Interlocks
- Switching procedure prominently displayed at the switching location

25. Electrical personnel shall demonstrate a working level knowledge of the safety requirements in DOE-HDBK-1092-2004, Electrical Safety Handbook.

a. Describe and explain hazards identification, classification, PPE, and associated work practices.

Hazards Identification and Classification

The DOE uses two general electrical hazard/risk identification and classification processes. The first process, which is used for the identification and analysis of electrical risks/hazards for the purpose of determining appropriate controls and PPE required for particular work activities, is covered in NFPA 70E, Article 130.

Work controls (procedures, boundaries, permits, etc.) and PPE are directly related to and determined by the particular risk/hazard of the work activity. Specifically, a relationship is established wherein:

Work controls and PPE = F (hazards)

NFPA 70E, Article 130 provides a general approach in which approach boundaries for shock protection (controls) are determined from phase-to-phase voltages (hazards), and arc-flash risks are categorized by the potential incidental energy releases for particular combinations of voltages and work activities. The results of these approach boundaries and incidental energy estimates are then used to develop work permits, procedures, and drive tool and protective equipment requirements.

The second process, outlined in DOE G 231.1-x (under development) is used for electrical event categorization and performance measurement of occurrence reporting and processing of electrical operations information. This process establishes an “electrical severity” measure for an accident or event that is calculated from several factors (the electrical hazard, environmental conditions, shock, arc-flash, and thermal proximities, and an injury factor). Hazard classification charts are used to consider several factors (voltage, power, waveform, equipment, frequency, etc.) in determining the electrical hazard factor. Once electrical severity is calculated, it is then used to establish an electrical-severity-index performance measure for normalization of site events versus organizational work hours that can be trended and used for occurrence reporting.

Employees who are exposed or potentially exposed must be able to recognize when and how they are exposed. Management has the responsibility to provide training to deal with each known hazard, as required.

Hazardous areas and locations are classified by group, class, and division. These classifications are determined by the atmospheric mixtures of various gases, vapors, dust, and other materials present. The intensity of the explosion that can occur depends on concentrations, temperatures, and many other factors that are listed in NFPA codes.

Hazardous locations must be well understood by anyone designing, installing, working on, or inspecting electrical equipment and wiring in such areas. Such locations carry a threat of flammable or combustible gases, vapors, or dusts being present some or all of the time.

Information in this section will assist in classifying areas or locations with respect to hazardous conditions, whether from atmospheric concentrations of hazardous gases, vapors, and deposits, or from accumulations of readily ignitable materials.

Section 5.0 of DOE-HDBK-1092-2004 covers the requirements for electrical equipment and wiring in locations that are classified according to the properties of the flammable vapors, liquids, or gases or combustible dusts that may be present and the likelihood that a flammable or combustible concentration is present. The hazardous (classified) locations are assigned the following designations:

- Class I Division 1
- Class I Division 2
- Class II Division 1
- Class II Division 2
- Class I, Zone 0, Zone 1, Zone 2

A detailed description of hazards identification and classification can be reviewed in section 5.0 of DOE-HDBK-1092-2004.

PPE

Qualified workers are responsible for avoiding and preventing accidents while performing electrical work, repairs, or troubleshooting electrical equipment. Personnel shall wear or use PPE and protective clothing that is appropriate for safe performance of work. Qualified workers need to use appropriate arc-fault PPE whenever they work near electrical equipment that could create an arc flash hazard.

Managers shall ensure that appropriate PPE is provided and ensure that employees using PPE are trained in their proper use. Furthermore, managers shall ensure that employees use the appropriate PPE for their assigned task.

A detailed description of hazards identification and classification can be reviewed in sections 2.0 and 7.0 of DOE-HDBK-1092-2004.

Associated Work Practices

The following is taken from DOE-HDBK-1092-2002,

> NFPA 70E covers electrical safety-related work practices and procedures for qualified and unqualified employees who work on or near exposed energized electrical conductors or circuit parts in workplaces. This information provides a foundation for establishing an electrically safe working environment. NFPA 70E has embedded four basic strategies in the document. These strategies are:
>
> 1. establish an electrically safe work condition,
> 2. training,
> 3. planning the work, and
> 4. PPE.
>
> NFPA 70E is updated on a 3-year cycle in compliance with ANSI requirements. This schedule allows for the latest acceptable technology and experience to be integrated into the document.

There are several topics under these strategies that provide specific guidance.

b. Describe and explain equipment configuration and operational practices.

Chapter 4 of DOE-STD-1039-93, *Guide to Good Practices for Control of Equipment and System Status*, contains ten specific areas of good practices. The topics are as follows:

- 4.1, Status Change Authorization and Reporting
- 4.2, Equipment and System Alignment
- 4.3, Equipment Locking and Tagging
- 4.4, Operational Limits Compliance
- 4.5, Alarm Status
- 4.6, Equipment Deficiency Identification and Documentation
- 4.7, Work Authorization and Documentation
- 4.8, Equipment Post-Maintenance Testing and Return to Service
- 4.9, Temporary Modification and Control
- 4.10, Distribution and Control of Equipment and System Documents

Additional information on the specific topics can be found in the referenced Standard.

c. Describe and explain training and qualifications requirements.

According to DOE-HDBK-1092-2004, “effective training for all degrees of hazard” is one of the six basic elements of an effective electrical safety program. Training programs must be established in accordance with 29 CFR 1910.331-335.

Facility engineering managers are responsible for ensuring that their personnel receive training in accordance with general and job-specific safe electrical work practices as required in 29 CFR 1910, subpart S, as well as training in NFPA, IEEE, and ANSI codes and standards.

Construction managers are responsible for implementing and enforcing the requirements of NFPA 70, IEEE C2, and Occupational Safety and Health Administration (OSHA) 29 CFR 1926 during construction of all facilities by providing AHJ-approved certification for electrical inspectors. They also ensure that the inspectors receive training in NFPA 70, 29 CFR 1926, IEEE C2, and electrical safety awareness.

Safety managers provide oversight and customer liaison for electrical safety for the departments. They also provide cognizant electrical safety professionals trained in the application of NEC, Occupational Safety and Health Act (OSH Act), etc.

Department managers are responsible for ensuring that personnel receive electrical systems and safety awareness training and other task-specific electrical safety training as required by 29 CFR 1910.332.

All employees and onsite contractors are responsible for attending appropriate electrical systems and safety awareness training and other equivalent job-specific training as required by 29 CFR 1910.332.

ES&H training managers are responsible for developing and overseeing electrical safety training courses, including any site-specific electrical safety training courses, as required by the Electrical Safety Committee and the Electrical Safety Program.

26. Electrical personnel shall demonstrate a working level knowledge of the requirements related to safe work practices for laser operations (NFPA 70E, Chapter 3, etc.).

> **[Note: The 2004 version of NFPA 70E has been superseded by the 2009 revision and is archived but still available. Because the 2009 revision was drastically reduced in scope it is not used as a reference in this guide.]**

The information for KSAs ‘a’ and ‘c’ through ‘e’ is taken from NFPA 70E.

a. Describe and explain fail-safe interlocks.

A fail-safe interlock is an interlock that in the failure mode does not defeat the purpose of the interlock, for example, an interlock that is positively driven into the off position as soon as a hinged cover begins to open, or before a detachable cover is removed, and that is positively held in the off position until the hinged cover is closed or the detachable cover is locked in the closed position.

Though fail-safe interlocks do not apply to Class 1 lasers due to their application, ANSI Z136.1 defines the item as:

> “…protective housings which enclose embedded Class 3a, Class 3b, or Class 4 lasers or laser systems [which] shall be provided with an interlock system

which is activated when the protective housing is intended to be opened during operation and maintenance. The interlock or interlock system shall be designed to prevent access to laser radiation above the applicable MPE (maximum permissible exposure). The interlock may, for example, be electrically or mechanically interfaced to a shutter which interrupts the beam when the protective housing is removed."

b. Describe and explain controlled areas.

The following is taken from 10 CFR 835.602.

A controlled area is an area where the occupancy and activity of those within are subject to control and supervision for the purpose of protection from radiation hazards.

Each access point to a controlled area (as defined at § 835.2) shall be posted whenever radiological areas or radioactive material areas exist in the area. Individuals who enter only controlled areas without entering radiological areas or radioactive material areas are not expected to receive a total effective dose of more than 0.1 rem (0.001 sievert) in a year. Signs used for this purpose may be selected by the contractor to avoid conflict with local security requirements

c. Describe and explain laser characteristics.

A laser is any device that can be made to produce or amplify electromagnetic radiation in the wavelength range from 100 nm to 1 mm primarily by the process of controlled stimulated emission. Important key concepts related to lasers are as follows:

- Laser energy source—any device intended for use in conjunction with a laser to supply energy for the excitation of electrons, ions, or molecules. General energy sources, such as electrical supply services or batteries, shall not be considered to constitute laser energy sources.
- Laser fiber optic transmission system—a system consisting of one or more laser transmitters and associated fiber optic cable.
- Laser hazard area—the area within which the beam irradiance or radiant exposure exceeds the appropriate corneal maximum permissible exposure, including the possibility of accidental misdirection of the beam.
- Laser product—any product or assembly of components that constitutes, incorporates, or is intended to incorporate a laser or laser system.
- Laser radiation—all electromagnetic radiation emitted by a laser product between 100 nm and 1 mm that is produced as a result of a controlled stimulated emission.
- Laser system—a laser in combination with an appropriate laser energy source with or without additional incorporated components.

d. Describe and explain safety training and qualifications.

Training includes, but is not limited to, the following:

- Familiarization with laser principles of operation, laser types, and laser emissions
- Laser safety, including the following:
  - System operating procedures

- Hazard control procedures
- The need for personnel protection
- Accident reporting procedures
- Biological effects of the laser upon the eye and the skin
- Electrical and other hazards associated with the laser equipment, including the following:
  - High voltages (>1 kV) and stored energy in the capacitor banks
  - Circuit components, such as electron tubes, with anode voltages greater than 5 kV emitting X-rays
  - Capacitor bank explosions
  - Production of ionizing radiation
  - Poisoning from the solvent or dye switching liquids or laser media
  - High sound intensity levels from pulsed lasers

Proof of qualification of the laser equipment operator shall be available and in possession of the operator at all times.

e. Describe and explain safeguarding of personnel.

Employees shall be provided with eye protection as required by Federal regulation. Warning signs shall be posted at the entrances to areas or protective enclosures containing laser products. High-power laser equipment shall include a key-operated master control. High-power laser equipment shall include a fail-safe laser radiation emission audible and visible warning when it is switched on or if the capacitor banks are charged. Beam shutters or caps shall be utilized, or the laser switched off, when laser transmission is not required. The laser shall be switched off when unattended for 30 minutes or more. Laser beams shall not be aimed at employees. Laser equipment shall bear a label indicating its maximum output. PPE shall be provided for users and operators of high-power laser equipment.

IV. ELECTRICAL MAINTENANCE MANAGEMENT FOR NUCLEAR AND NON-NUCLEAR FACILITIES

This section is optional and should be used by the program and/or field offices to assist them with specific technical qualifications for that office.

27. Electrical personnel shall demonstrate a familiarity level knowledge of the DOE maintenance management requirements as defined in DOE O 433.1A, Maintenance Management Program for DOE Nuclear Facilities, and DOE Guide 433.1-1, Nuclear Facility Maintenance Management Program Guide for Use with DOE O 433.1 (IEEE Yellow Book; reference IEEE Std-902).

a. Define each of the following maintenance-related terms and explain their relationship to each other:

- **Corrective**
- **Planned**
- **Preventive**
- **Reliability centered**
- **Predictive**

The information for KSAs ‘a‘ through ‘c’ is taken from DOE G 433.1-1.

Corrective Maintenance

Corrective maintenance is the repair of failed or malfunctioning equipment, system, or facilities to restore the intended function or design condition. This maintenance does not result in a significant extension of the expected useful life.

Planned Maintenance

Planned maintenance is preventive or seasonal maintenance activities performed before SSC failure that may be initiated by predictive or periodic maintenance results, through vendor recommendations, or by experience/lessons learned. These include actions such as scheduled cold weather protection, valve repacking, replacement of bearings as indicated from vibration analysis, major or minor overhauls based on experience factors or vendor recommendations, and replacement of known life-span components. For example, repacking a valve because of packing leakage would be corrective maintenance, but scheduled repacking before leakage would be planned maintenance.

Preventive Maintenance

This type of maintenance includes all those planned, systematic, periodic, and seasonal maintenance actions taken to prevent SSC or facility failures, to maintain designed-in operating conditions, and to extend operating life. The PM process takes into account the inevitability of failures in any simple or complex piece of equipment, although the consequences of failures can be controlled by careful design and effective maintenance. The reason for the failure incident can be apparent if basic differences between expected behaviors and the actual behaviors of SSCs are considered. These differences can be translated into possible failure modes. PM identifies any differences between actual and expected behavior of SSCs. Generally, regulatory and code requirements, DOE technical safety requirements (TSRs) for surveillances, in-service inspection and testing, vendor recommendations, and other forms of maintenance action and frequency selection based on engineering judgment or analytical methods are the pursuit of proactive planned maintenance.

Reliability-Centered Maintenance (RCM)

Reliability-centered maintenance is a proactive systematic decision logic tree approach to identify or revise PM tasks or plans to preserve or promptly restore operability, reliability and availability of facility SSCs; or to prevent failures and reduce risk through types of maintenance action and frequency selection to ensure high performance. Reliability centered maintenance is the performance of scheduled maintenance for complex equipment, quantified by the relationship of PM to reliability and the benefits of reliability to safety and cost reduction through the optimization of maintenance task/frequency intervals. The concept relies on empirical maintenance task/frequency intervals to make determinations about real applicable data suggesting an effective interval for task accomplishment. The approach taken to establish a logical path for each functional failure is that each functional failure, failure effect, and failure cause be processed through the logic so that a judgment can be made as to the necessity of the task, and includes (1) reporting PM activities, plans, and schedules; (2) optimizing/calculating the PM interval by balancing availability, reliability, and cost; (3)

ranking PM tasks; (4) accessing PM information from piping and instrumentation drawings; (5) accessing PM and other maintenance data; (6) listing recurring failure modes/parts, including failure to start and failure to run; (7) calculating and monitoring SSC availability; (8) accessing PM procedures, and (9) keeping track of PM cost.

Implementing an RCM program involves taking an existing electrical preventive maintenance program and modifying it to align with the critical path or mission of the facility. In a data center, that would include everything that is necessary to keep the computers running, which includes the UPS as well as the air conditioning system. All the systems in the critical path would receive priority, while the remaining nonessential support systems would receive much less attention.

Predictive Maintenance

Predictive maintenance is the actions necessary to monitor; find trends; and analyze parameters, properties, and performance characteristics or signatures associated with SSCs, facilities, or pieces of equipment to discern whether a state or condition may be approaching that is indicative of deteriorating performance or impending failure, where the intended function of the SSCs, facilities, or pieces of equipment may be compromised. Predictive maintenance activities involve continuous or periodic monitoring and diagnosis to forecast component degradation so that "as-needed" planned maintenance can be initiated before failure. Not all SSC, facility, or equipment conditions and failure modes can be monitored and diagnosed in advance; therefore, predictive maintenance should be selectively applied. To the extent that predictive maintenance can be relied on without large uncertainties, it is normally preferable to activities such as periodic internal inspection or equipment overhauls.

b. Discuss the importance of maintaining a proper balance of preventive and corrective maintenance.

A proper balance of corrective maintenance and PM should be used to provide a high degree of confidence that degradation of facility equipment is identified and corrected, that life of equipment is optimized, and that the maintenance program is cost-effective. The maintenance program includes preventive, predictive, and corrective maintenance.

c. Identify typical maintenance performance indicators, and discuss their importance.

A program should be in place to regularly provide management with accurate information regarding key maintenance performance indicators. Such information should be measurable and used to assess maintenance performance and identify areas requiring management attention. Overall indicators relevant to maintenance performance, indicators to measure progress in achieving goals and objectives, and specific indicators for monitoring current performance problems and performance in specific functional areas should be selected. Information should be presented in a systematic way that provides ready recognition of trends and comparison of actual versus expected results and, where appropriate, clearly indicates corrective action and the results of these actions.

The results of maintenance performance indicators, goals and objectives, and other related information should be developed, trended, and reported to provide feedback. This feedback should be used by senior management in progress and feedback reviews. Section 4.14.2 of DOE G 433.1-1 discusses the development of performance indicators, goals, and objectives for maintenance. Reports should include trends of the performance indicators, goals, and objectives; a brief explanation for trends that appear unusual (positively or negatively); and intended corrective measures where warranted.

d. Discuss the relationship between maintenance and conduct of operations, quality assurance, and configuration management.

Conduct of Operations

The following is taken from DOE O 5480.19.

Conduct of operations in electrical-related maintenance efforts should reflect high operating standards by management; by communicating operating standards to the working level; by providing sufficient resources to the operations department; by ensuring personnel are well trained; by closely monitoring performance in operations; and by holding workers and their supervisors accountable for their performance in conducting activities.

Quality Assurance

The following is taken from DOE O 414.1C.

Quality assurance as related to electrical maintenance involves all those actions that provide confidence that quality is achieved. This includes development of a management program, a personnel training and qualification program, quality improvement processes, a document and records management program, clearly identified work processes, designed items and interfaces validated/verified according to engineering/scientific principles and appropriate standards, established procurement processes, established inspection and acceptance testing processes, management assessments, and independent assessments.

Configuration Management

The following is taken from DOE-STD-1073-2003.

Configuration management (CM) includes processes that involve identifying and defining the configuration items in an electrical system, controlling the release and change of these items throughout the system’s life cycle, and recording and reporting the status of configuration items and change requests.

e. Discuss the requirements for receiving and inspecting parts, materials, and equipment.

The information for KSAs ‘e’ through ‘g’ is taken from DOE G 433.1.1.

Many personnel at a facility are involved in some portion of the stores operation. They should be aware of the correct process to receive, inspect, handle, and store facility material and equipment so that it is easily retrievable and usable when issued. Therefore, policies should be established that address these functions. These policies must be understood by stores personnel and other organizations that interface with them, such as purchasing, QA, quality control (QC), engineering, radiological protection, operations, safety, and maintenance. Procedures should be prepared that specifically describe the responsibilities and the techniques for receiving, inspecting, handling, storing, retrieving, and issuing material from stores. QA/QC aspects of the stores function should be incorporated into these procedures.

When parts, materials, and equipment are received, stores personnel should inspect them before they are accepted for storage or are used. This inspection is conducted to verify that the items delivered agree with the approved purchase documentation, are packaged in accordance with purchase order specifications, have necessary product control requirements furnished by the vendor (such as special storage or shelf-life information), and appear to be in good condition. In the case of safety items and designated critical items important to reliable facility operations, stores personnel should inspect them to ensure that the vendor has supplied what was ordered, that the necessary formal documentation has accompanied the shipment or is otherwise on hand, and that items have been received in an acceptable condition. Technical staff and maintenance personnel may be needed to assist in the inspection of more complicated parts, materials, and equipment.

Technical staff and QC personnel should approve any deviation from design specifications of material or equipment received before the item is accepted into the stores system. They should also approve any upgrade of material or equipment from a nonsafety to a safety category. An acceptance tag or label placed on the received material may be used to signify that the receiving inspection was performed and that the applicable requirements have been met.

A separate receiving and inspection area, as well as a separate holding area, should be provided. The latter area is used to hold material and equipment that has not been officially received into the stores system because of nonconformance. Nonconforming material must also be clearly tagged or labeled to prevent its inadvertently being issued. A tracking or follow-up method should be established to ensure that problems with nonconforming items are promptly resolved.

During receipt inspection, the designated organization should ensure that special storage instructions have been addressed. Before final acceptance of an item, the designated organization should ensure that the necessary purchase order instructions and requirements are completed, such as the following:

- The tickler file has been updated.
- Appropriate items have been added to the PM program.
- Appropriate inspection instructions are clearly defined.

Inspection and test activities should be selectively and judiciously applied to new, repaired, and replacement items, on the basis of risk to safety and/or importance to reliable capacity, to ensure items will perform as expected.

Plant Engineering should develop a process for providing data sheets that form the basis for procurement of SC items and other major purchases (e.g., equipment and construction projects). These data sheets should provide

- procurement information,
- critical parameters and their acceptance criteria,
- unique or special testing requirements/methods,
- reorder instructions, and
- suspect/counterfeit parts information.

Items or parameter values that do not satisfy established acceptance criteria should be rejected; Plant Engineering approval should be required for other disposition. Nonconforming items should be

- clearly identified,
- segregated from normal items to prevent inadvertent use,
- documented on a nonconformance report and/or a defective or substandard material report, and
- tracked and dispositioned as soon as practical by the applicable authority.

Routine inspections performed by appropriate personnel should ensure that:

- packaging is appropriate (as designated on the purchase order when specified), is undamaged, and/or has not deteriorated;
- color, count, shape, size, part number, model number, manufacturer/vendor name, etc., are as specified on the purchase order;
- shelf-life and other time-environment requirements have not been violated;
- date and time of receipt are logged for regular follow-up review during the storage period; and
- specified vendor documentation, in the quantities required by the purchase order, exists.

Special inspections should be performed on SC items, safety-significant SSCs, and other items when designated by the requisitioner.

- Special inspections should be performed by the organization specified on the requisition.
- Special inspection requirements for items not involving Engineering data sheets should be defined by the requisitioner.
- Special inspections normally require formal quality records of all measured data, formal date the inspection was performed, identification of the individual and the organization performing the inspection, accept/reject status identification, and signature of the applicable authority to approve the status.

Items receiving special inspection (especially SC items and safety-significant SSCs) should be appropriately identified and segregated from normal stock to indicate status and ensure proper application.

Before becoming available for use or restock, materials and equipment that have been repaired and/or stored in the plant should require the same inspection defined for the original purchase and/or appropriate for its intended application as specified by engineering.

Stored items that are affected by time-environment should be regularly checked by designated personnel; expired or otherwise jeopardized items should be removed from normal storage until dispositioned by the proper authority.

An "acceptance tag" should be placed on the item after satisfactory receipt inspection. The tag should be legibly marked to indicate whether an item has any type of special storage requirements. This provides the user, requestor, or storeroom personnel with an easy method to ensure special storage control requirements are satisfied. The tag may cross-reference a particular entry in a file system (tickler file) for further instructions.

A method should be developed to accept material that has been repaired or reworked by the facility maintenance organization. Whenever materials or parts are repaired or reworked, suitable testing and inspection requirements should be specified by design engineering to ensure that the materials or parts perform acceptably when placed in service. This method should also address material that has been issued and is sent back to stores for reissuance.

Warehouse documents should be updated to reflect receipt of the material and any shelf-life or PM requirements.

f. Describe the difference between temporary and permanent repairs/work and the requirements and controls in place to prevent inadvertent modifications.

DOE G 433.1-1, *Nuclear Facility Maintenance Management Program Guide for Use with DOE O 433.1*, guidelines suggests that temporary modifications be installed or removed using an approved work request and/or work order.

Temporary repairs should be tracked after their completion for consideration of permanent repairs, and permanent corrective action should be taken as soon as practicable. Temporary repairs are recorded and controlled by the facility temporary modification program, and permanent repairs are scheduled when facility conditions permit. Because temporary repairs often precede permanent repairs, it is important to note several requirements and controls necessary for the prevention of inadvertent modifications.

Temporary modifications should be controlled to ensure necessary personnel are aware of all changes and the expected duration of temporary modifications and that temporary alterations made to facility SSCs do not unacceptably alter or degrade the original design, facility safety, or reliability. The number and duration of temporary modifications should be minimized. Use of this guideline should control temporary modifications by requiring them to be adequately identified, reviewed, approved, documented, and periodically reassessed for continued applicability.

A temporary modification is any short-term alteration made to facility SSCs that does not conform with approved drawings or other design documents. The following are examples of temporary modifications: lifted leads, electrical jumpers, pulled circuit boards, disabled annunciators/alarms, mechanical jumpers/bypasses, temporary setpoint changes, installed or removed blank flanges, disabled relief or safety valves, installed or removed filters or strainers, plugged floor drains, and temporary pipe supports.

A facility program to control temporary modifications should include the following elements:

- Owner/operator approval of temporary modifications before installation or removal
- Positive identification of electrical temporary modifications with independent verification before installation
- Independent verification or functional test of all temporary modifications after they are installed or removed
- Record of all installed temporary modifications
- Assurance that operators and supervisors are trained on installed temporary modifications and their impact on system/component operation before returning the system to service
- Safety reviews of temporary modifications installed on in-service (operable) equipment to ensure that the modified equipment should continue to perform as intended and not adversely affect plant or personnel safety
- Assurance of the quality of work and suitability of materials used for temporary modifications
- Method to review the temporary modifications periodically for errors and continued need
- Method of clearly identifying installed temporary modifications
- Method to provide operators with instructions for operating temporarily modified equipment and/or guidance regarding the periodic monitoring of its operation (e.g., drawings and procedures should be marked up or annotated to reflect the new configuration before returning the system to operation)

g. Discuss the importance and methods of establishing acceptance criteria for inspection and testing.

Equipment that is important to safe and reliable facility operation should be tested in accordance with approved procedures. Post maintenance test procedures should contain acceptance criteria that aid in measuring the performance of repaired equipment. Baseline data should be provided, if applicable.

If a surveillance test, calibration, or special procedure does not exist to test particular equipment following maintenance, a special test procedure may be written, or the test may be performed in accordance with instructions written for the work request or work order. With any of these procedure methods, the required and actual testing performed should be described, data recorded, acceptance criteria specified, and appropriate reviews and approvals performed and documented. If special test procedures are written to perform post maintenance tests, the appropriate safety and technical reviews should be performed in accordance with facility procedures.

Test instructions should include details such as initial conditions and prerequisites, hold points, cautions, personnel qualification requirements, personnel safety requirements, clear acceptance criteria, and post-test restoration.

Test instructions should be as specific as possible and should avoid using vague criteria such as “verify proper operation” or “check for excessive temperature.”

28. Electrical personnel shall demonstrate a familiarity level knowledge of the safety requirements for electrical equipment maintenance as defined by NFPA 70B, manufacturers' requirements, American Society for Testing and Materials (ASTM), ANSI, etc.

a. Describe and explain electrical preventive maintenance program elements.

The following is taken from DOE-HDBK-1092-2004. Additional detail is available from that document.

The EPM program should include the essential elements described in NFPA 70B, Chapter 5, *What is an Effective EPM Program?* This includes planning, identifying the main parts, and utilizing available support services for a program. For example:

- assigning qualified personnel
- surveying and analyzing equipment maintenance requirements
- performing routine inspections and tests
- analyzing inspection and test reports
- prescribing corrective measures
- performing necessary work
- preparing appropriate records

b. Describe and explain training requirements; special precautions relating to electronic equipment, e.g., equipment de-energization; zero-energy checks; prevention of shock; and grounding requirements for maintenance actions.

The information for all of the items in this KSA is taken from NFPA 70B, except for 'Prevention of Shock', which is taken from NFPA 70E.

Training Requirements

Maintenance should be performed only by qualified personnel who are trained in safe maintenance practices. These individuals should be familiar with the requirements for safe electrical installations. A person does not have to be fully trained in all categories so long as the specific task information provided and the safety-related information provided are adequate and the employee has demonstrated he/she understands the procedure. Specific training should be determined by the needs of the employee.

Equipment De-energization

Live parts to which an employee may be exposed shall be de-energized before the employee works on or near them, unless the employer can demonstrate that de-energizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations. Live parts that operate less than 50 volts to ground need not be de-energized if there will be no increased exposure to electrical burns or to explosions due to electric arcs.

Each employer shall identify, document, and implement LOTO procedures to safeguard employees from exposure to electrical hazards while they are working on or near de-energized electrical conductors.

Zero-Energy Checks

Use an adequately rated voltage detector to test each phase conductor or circuit part to verify they are de-energized. Test each phase conductor or circuit part both phase-to-phase and phase-to-ground. Before and after each test, determine whether the voltage detector is operating satisfactorily.

Prevention of Shock

Shock prevention is best ensured within an electrically safe work condition. NFPA 70E delineates six steps for achieving an electrically safe work condition, summarized as follows:

1. Determine all possible sources of electrical supply to the specific equipment.
2. After properly interrupting the load current, open the disconnecting device(s) for each source.
3. Wherever possible, visually verify that all blades of the disconnecting devices are fully open or that the drawout-type circuit breakers are withdrawn to the fully disconnected position.
4. Apply LOTO devices in accordance with a documented and established policy.
5. Use an adequately rated voltage detector to test each phase conductor or circuit part to verify they are de-energized.
6. Where the possibility of induced voltages or stored electrical energy exists, ground the phase conductors or circuit parts before touching them.

Grounding Requirements for Maintenance Operations

If any vehicle or mechanical equipment capable of having parts of its structure elevated near energized overhead lines is intentionally grounded, employees working on the ground near the point of grounding shall not stand at the grounding location whenever there is a possibility of overhead line contact. Additional precautions, such as the use of barricades or insulation, shall be taken to protect employees from hazardous ground potentials (step and touch potential), which can develop within a few feet or more outward from the grounded point.

c. Describe and explain Ground Fault Circuit Interrupter (GFCI) and Ground-Fault Protection for Equipment (GFPE) maintenance requirements, e.g., trip tests, records keeping, and approved listing of test equipment.

The following is taken from NFPA 70B, chapter 15. Key points are noted below.

A GFCI is designed to protect a person from electrocution when contact between a live part of the protected circuit and ground causes current to flow through a person's body. GFPE is intended for two uses: where there might be excessive ground-fault leakage current from equipment, and where equipment and conductors are to be protected from damage in the event of a higher-level ground fault (either solid or arcing). These types of protective equipment are only for use on AC, grounded circuits and cause the circuit to be disconnected when a current equal to or higher than its pickup setting or rating flows to ground.

Trip Tests

Standard molded-case circuit breakers generally are not equipped with ground-fault sensing and protection devices and, therefore, will not normally trip and clear low-level ground faults, which can do immense damage. Special ground-fault sensing and protection devices should be specified to achieve this type of equipment protection where necessary. GFCIs are equipped with an integral test means for checking the tripping operation, and should be used according to the frequency recommended by the manufacturer. When a separate GFCI test instrument is used, if the tester indicates “no trip” and the GFCI integral test button indicates “trip” the following mis-wiring scenarios should be investigated: line and load wires transposed, reverse polarity, open ground.

Records Keeping

Results and dates of tests should be recorded on the test record label or card supplied with each permanently installed GFCI unit. A copy of test reports (e.g., acceptance testing) should be forwarded to the plant engineer for the maintenance records.

Approved Listing of Test Equipment

Circuit-breaker-type GFCIs, receptacle-type GFCIs, portable-type GFCIs, and permanently mounted-type GFCIs require particular maintenance, which is explained in detail in NFPA 70B, chapter 15.

d. Describe and explain testing and test methods, precautions and safety, qualifications of test operators, test equipment, and protective device testing.

The following is taken from NFPA 70B, chapter 21.

Testing

Data obtained from electrical power tests assist in determining whether any corrective maintenance or replacement is necessary or desirable, ascertaining the ability of the element to continue to perform its desired function adequately, as well as charting the gradual deterioration of the equipment over its service life.

Test Methods

The most common tests are acceptance tests, routine maintenance tests, special maintenance tests, as-found tests, as-left tests, and insulation testing (e.g., direct-current testing, alternating-current testing, step-current testing, transformer testing, circuit breaker testing, etc.).

Precautions and Safety

Adequate safety rules should be implemented and practiced to prevent injury to personnel. Also, test procedures should be designed to ensure that no intentional damage to equipment results from the testing process.

Regarding equipment, over-potential or high-potential testing is intended to stress the insulation structure above that of normal system voltage. However, some insulation might break down with no warning; therefore, plans for coping with this possibility should be included in the test schedule. Low-voltage insulation testing can generally be done at the beginning of a planned maintenance shutdown. In the event of an insulation failure under test, maximum time would be available for repair prior to the scheduled plant start-up.

Equipment found in wet or dirty condition should be cleaned and dried before high-potential testing is done, since a breakdown could damage the equipment.

Qualifications of Test Operators

The test operator should be thoroughly acquainted with the equipment being used in the type of test to be performed and also should be sufficiently experienced to be able to detect any equipment abnormalities or questionable data during the performance of the tests.

Test Equipment

Only proper equipment may be used to perform the required tests. In general, any test equipment used for the calibration of other equipment should have an accuracy that is at least twice the accuracy of the equipment under test. All test equipment should be calibrated at regular intervals to ensure the validity of the data obtained. In order to get valid test results, it might be necessary to regulate the power input to the test equipment for proper waveform and frequency and to eliminate voltage surges.

Protective Device Testing

Chapter 21 of NFPA 70B covers the tests ordinarily used in the field to determine the condition of various elements of an electrical power distribution system. The data obtained in these tests provide information that is used as follows:

- To determine whether any corrective maintenance or replacement is necessary or desirable
- To ascertain the ability of the element to continue to perform its design function adequately
- To chart the gradual deterioration of the equipment over its service life

e. Describe and explain de-energizing and grounding of equipment to provide protection for electrical maintenance personnel, such as grounding requirements and symptoms and causes of inadequate grounding.

The following is taken from NFPA 70E, Article 130.

Grounding equipment consists mainly of several heavy-duty clamps that are connected to cables of adequate capacity for the system fault current. This current, which might well be in excess of 100,000 amperes, will flow until the circuit overcurrent protective devices operate to de-energize the conductors. The grounding equipment should not be larger than necessary because bulkiness and weight hinder personnel connecting them to the conductors, especially when they are working with hot-line sticks. Selection of grounding clamps and grounding procedures are explained in detail in NFPA 70B, chapter 7.

Common reasons for grounding electrical systems and equipment are to limit the voltage imposed by lightning, line surges (transients), or unintentional contact with higher voltages; to stabilize the voltage to earth under normal operation; and to establish an effective path for fault current.

There are several symptoms and causes of inadequate grounding. Common mode noise voltages can develop when the equipment-grounding conductor and the grounded conductor are not effectively bonded. Common mode noise can be produced in wiring without an equipment grounding conductor and without electrically continuous raceway. Ground loops can be undesirable because they create a path for noise currents to flow. Undesirable touch potentials can result from contacting metallic surfaces that are improperly grounded. Equipment misoperation due to unequal ground potentials results in improper data communication or improper readings of transducers. Shutdown or damage of electronic equipment can be due to electrostatic discharge (ESD). Non-operation or malfunction of protective circuit devices or voltage sag can be due to high-impedance ground fault paths.

Damage, non-operation, or misoperation of electronic components can be caused by poor connections in the grounding path. Damage or destruction of the neutral conductor or cable shields can result from improper sizing of a high-impedance neutral grounding device.

Voltage can be present on de-energized circuits during testing of these conductors.

Destruction of equipment and surge protection devices can follow a voltage transient, such as a lightning strike.

In spite of all precautions, de-energized circuits can be inadvertently reenergized. When this occurs, adequate grounding is the only protection for personnel working on those circuits. For this reason, it is especially important that adequate grounding procedures be established and rigidly enforced.

f. Describe and explain grounding system inspection, testing and monitoring, and solutions for inadequate grounding.

The information for KSAs ‘f’ and ‘g’ is taken from NFPA 70B.

Grounding System Inspection, Testing, and Monitoring

A visual and physical inspection should be made to verify the integrity of the grounding and bonding conductors and associated connections. The integrity of the grounding electrode system and substation grids should be checked on a periodic basis.

The electrical connection to earth can be measured using one of several available methods and technologies. A ground loop impedance test should be performed on the equipment-grounding path with a four-lead, low-resistance ohmmeter such as a Wheatstone bridge, a Kelvin bridge, or a digital low-resistance ohmmeter. Impedances should be appropriate for the type, length, and size of the path.

Measure the voltage between the equipment-grounding conductor and the grounded conductor at multiple locations throughout the system, as applicable. At the bonding jumper, the voltage normally should be less than 0.1 volt AC. It is normal to find voltage downstream from the main bonding jumper in energized circuits, due to current flow in the grounded conductor. Readings in excess of 3 volts AC or less than 0.5 volt AC at locations remote from the bonding jumper should be investigated to determine if this represents a problem for the system.

The current on the equipment-grounding conductor should be measured for objectionable levels, which will depend on the location and type of the facility. The source of currents on equipment-grounding conductors should be determined and corrected. Use of a true RMS ammeter is recommended. The voltage from the chassis of equipment and an external ground point should be measured. Differences should be less than 2 volts.

Continuous monitoring of ground and neutral currents in information technology areas is recommended. In the absence of any specifications, when ESD systems are being examined, the leakage resistance should not exceed 1 megohm from any conductor to ground.

Testing of the ground integrity of data communication cable shields might require special instrumentation and expertise. If a result of testing indicates that changes to a substation grounding system are necessary or required, reference should be made to IEEE 80-2000, *Guide for Safety in AC Substation Grounding*, for appropriate design requirements.

Solutions for Inadequate Grounding

To minimize the resistance between the grounding electrode system and the earth, the following should be done:

- Clean and tighten and test connections as needed, using appropriate safety precautions.
- Replace or repair damaged or corroded components.
- Size the grounding electrode conductor in accordance with Article 250 of NFPA 70, *National Electrical Code*.
- Use soil enhancement material as necessary.

The grounded conductor should be connected to the equipment-grounding conductor only as permitted by Article 250 of NFPA 70, *National Electrical Code*. The grounded conductor and the equipment-grounding conductor should be sized in accordance with NFPA 70.

Many of the grounding electrode corrosion problems are caused by galvanic action. This problem can be minimized by using a system of cathodic protection (active or passive). The use of dissimilar metals should be avoided.

An isolation transformer has separate primary and secondary windings. The bonding jumper between the equipment-grounding conductor and the secondary grounded conductor provides protection from common mode electrical noise. It is recommended that a shielded isolation transformer be used. It contains an electrostatic shield between the primary and secondary windings that is connected to the equipment-grounding terminal.

One solution is to install an isolated ground receptacle (identified by orange color and/or orange triangle) in which the equipment-grounding terminal is insulated from the mounting strap. An insulated equipment-grounding conductor is then connected in accordance with NFPA 70. The insulated equipment-grounding conductor is connected to the applicable derived system or service grounding terminal.

g. **Describe and explain maintenance and servicing of transformers, cables, breakers, and motors.**

Transformers

Power and distribution transformers require regular maintenance if they are to have a normal service life. The extent and frequency of maintenance should be based not only on size or voltage but also on the relative importance of the transformer in the system. The failure of a small distribution transformer serving a critical load can have more impact on an operation than the failure of a larger or higher-voltage unit. Also, on some smaller systems, the failure of a distribution transformer can result in an outage of the complete system. When the level of maintenance on a transformer is being planned, consideration should also be given to other factors, such as replacement lead time.

Transformers can be divided into two general categories, according to their insulating medium and construction: liquid filled and dry type. Each has several variations listed under the specific maintenance recommendations, and each requires different maintenance techniques. In general, insulation tests, such as power-factor testing and insulation-resistance testing, and diagnostic tests, such as turns-ratio testing and exciting-current testing, are the major maintenance tests for all transformers. In addition, liquid-filled transformers should be tested to determine the quality of the insulating liquid.

Cables

Cables in manholes should be inspected for sharp bends, physical damage, excessive tension, oil leaks, pits, cable movement, insulation swelling, soft spots, cracked jackets in nonlead cables, damaged fireproofing, poor ground connections, deterioration of metallic sheath bonding, as well as corroded and weakened cable supports and the continuity of any main grounding system. Terminations and splices of nonlead cables should be squeezed in search of soft spots and inspected for tracking or signs of corona. The ground braid should be inspected for corrosion and tight connections. The bottom surface of the cable should be inspected for wear or scraping, due to movement, at the point of entrance into the manhole and also where it rests on the cable supports.

The manhole should be inspected for spalling concrete or deterioration of the aboveground portion. In some instances, the manhole can be equipped with drains, which might require cleaning. In some instances, it might be necessary to pump water from the manhole prior to entrance. A manhole should not be entered unless a test for dangerous gas has been made and adequate ventilation is provided. The inspection crew should always consist of two or more persons with at least one remaining outside the manhole.

Potheads should be inspected for oil or compound leaks and cracked or chipped porcelain. The porcelain surfaces should be cleaned and, if the connections are exposed, their tightness should be checked.

Cable identification tags or marking should be checked.

Because inspection intervals normally are 1 year or more, comprehensive records are an important part of any maintenance program. Comprehensive records should be arranged to facilitate comparison from year to year.

Aerial cable installations should be inspected for mechanical damage due to vibration, deteriorating supports, or suspension systems. Special attention should be given to the dead-end supports to ensure that the cable insulation is not abraded, pinched, or bent too sharply. Terminations should be inspected as covered in NFPA 70B, chapter 11.

Because the raceway is the primary mechanical support for the cable, it should be inspected for signs of deterioration, mechanical damage, cable jacket abrasion, or mechanically caused damage. In many installations, the raceway serves as a part of the ground-fault current circuit. Joints should be inspected for signs of looseness or corrosion that could result in a high resistance. The recommendations for splices and terminations covered in NFPA 70B, chapter 11 also apply in this section.

The two most commonly used tests for cable insulation are insulation-resistance testing and DC over-potential testing.

Breakers

Breakers are an integral feature of substations, the maintenance of which is summarized below. Substations in an electrical system perform the functions of voltage transformation, system protection, power factor correction metering, and circuit switching. They are comprised of electrical power products, such as transformers, regulators, air switches, circuit breakers, capacitors, and lightning arresters.

Circuit interrupters in switchgear assemblies are either circuit breakers or interrupter switches.

The general rules for maintaining contacts on all types of breakers are as follows:

- They should be kept clean, smooth, and in good alignment.
- The pressure should be kept normal, as prescribed in the manufacturers’ literature.

Concerning air circuit breakers, prior to any maintenance work, the manufacturers’ instruction manuals should be obtained and read carefully. If the breaker is a drawout type, it should be removed from its cubicle and placed in a secure, convenient location for maintenance. A stored-energy-type circuit breaker or its mechanism never should be worked on while its closing spring is charged.

The principal difference between vacuum circuit breakers and air circuit breakers is in the main contact and interrupter equipment. In the vacuum circuit breaker, these components are in the vacuum bottle and are not available for cleaning, repair, or adjustment. Contact-wear indicators are available for measuring contact wear. Vacuum integrity is checked by application of test voltage across the open contacts of the bottle. This test should be performed strictly in accordance with the manufacturer’s instructions.

In replacing the oil, only the oil recommended by the manufacturer should be used, and it should have been stored in sealed containers. In addition, the oil should be given a dielectric breakdown test immediately prior to use and to avoid air entrapment when it is added. An oil pump or other means should be used, to avoid aeration. In the event entrapment of air cannot be avoided, the entrapped air should be removed by application of vacuum, or the equipment should be allowed to stand for 8 to 12 hours prior to being energized. The main contacts of an oil circuit breaker are not readily accessible for routine inspection. Contact resistance should be measured. Contact engagement can be measured by measuring the travel of the lift rod from the start of contact opening to the point where contacts separate, as indicated by an ohmmeter. More extensive maintenance on main contacts might require removal of the oil and lowering the tank and should therefore be performed less frequently than routine maintenance.

The frequency should be determined by the severity of the breaker duty, for example, the number of operations and operating current levels. Any time the breaker has interrupted a fault current at or near its maximum rating, this type of maintenance should be performed. The contacts should be inspected for erosion or pitting. Contact pressures and alignment should be checked. All bolted connections and contact springs should be inspected for looseness.

Motors

Motor control equipment should be inspected and serviced at the same time as the motors. As a general rule, overhaul procedures for control equipment are less involved than motor overhauling. Most repairs can be made onsite. Motor starters represent one area in which manufacturers have emphasized simplicity of construction and wiring. Improvements have resulted in starters that are simple to install, maintain, and operate. Connections are readily accessible. Some parts are the plug-in type and can be replaced easily. Coils are often encapsulated in epoxy compounds and are less likely to burn out. Practically all newer starters have provisions for adding several auxiliary contacts with very little effort. Spare parts for starters are usually available from local suppliers. Spare starters, as well as spare parts, for the most used types and sizes should be stocked in the regular shop supply channels.

29. Electrical personnel shall demonstrate a familiarity level knowledge of safety-related maintenance requirements as defined in 29 CFR 1910.269 and NFPA 70E, Chapter 2.

[Note: The 2004 version of NFPA 70E has been superseded by the 2009 revision and is archived but still available. Because the 2009 revision was drastically reduced in scope it is not used as a reference in this guide.]

a. Describe and explain grounding and bonding.

The following is taken from 29CFR1910.269.

Grounding and Bonding

For the employee to work lines or equipment as de-energized, the lines or equipment shall be de-energized under the provisions of paragraph (m) of 29 CFR 1910.269 and shall be grounded as specified in paragraphs (n)(3) through (n)(9). However, if the employer can demonstrate that installation of a ground is impracticable or that the conditions resulting from the installation of a ground would present greater hazards than working without grounds, the lines and equipment may be treated as de-energized provided all of the following conditions are met:

- The lines and equipment have been de-energized under the provisions of paragraph (m) of 29 CFR 1910.269.
- There is no possibility of contact with another energized source.
- The hazard of induced voltage is not present.

Temporary protective grounds shall be placed at such locations and arranged in such a manner as to prevent each employee from being exposed to hazardous differences in electrical potential. Protective grounding equipment shall be capable of conducting the maximum fault current that could flow at the point of grounding for the time necessary to clear the fault. This equipment shall have an ampacity greater than or equal to that of no. 2 AWG copper. Protective grounds shall have an impedance low enough to cause immediate operation of protective devices in case of accidental energizing of the lines or equipment.

Before any ground is installed, lines and equipment shall be tested and found absent of nominal voltage, unless a previously installed ground is present.

When a ground is to be attached to a line or to equipment, the ground-end connection shall be attached first, and then the other end shall be attached by means of a live-line tool.

When a ground is to be removed, the grounding device shall be removed from the line or equipment using a live-line tool before the ground-end connection is removed.

When work is performed on a cable at a location remote from the cable terminal, the cable may not be grounded at the cable terminal if there is a possibility of hazardous transfer of potential should a fault occur.

Grounds may be removed temporarily during tests. During the test procedure, the employer shall ensure that each employee uses insulating equipment and is isolated from any hazards involved, and the employer shall institute any additional measures as may be necessary to protect each exposed employee in case the previously grounded lines and equipment become energized.

A bond is the electrical interconnection of conductive parts designed to maintain a common electrical potential. While an employee is approaching, leaving, or bonding to an energized circuit, the minimum approach distances shall be maintained between the employee and any grounded parts.

b. Describe and explain safety equipment and clear space requirements.

The following is taken from NFPA 70E.

Safety Equipment

Locks, interlocks, and other safety equipment shall be maintained in proper working condition to accomplish the control purpose.

Safe work practice training shall include techniques to prevent bypassing the protection of safety equipment. Clothing may bypass protective equipment if the clothing is wet. Trouser legs should be kept at appropriate length, and shirt sleeves should be a good fit so as not to drape while reaching. Jewelry and other metal accessories that may bypass protective equipment shall not be worn while working in the cell line working zone.

Clear Space Requirements

Access to working space and escape passages shall be kept clear and unobstructed.

Working space required by NFPA 70E shall not be used for storage. When normally enclosed live parts operating at 50 volts or more are exposed for inspection or servicing, the working space, if in a passageway or general open space, shall be suitably guarded. Except as elsewhere required or permitted in this standard, the minimum clear working space in the direction of access to live parts of electric equipment shall be not less than specified in table 5. Distances shall be measured from the live parts if such are exposed or from the enclosure front or opening if such are enclosed.

Table 5. Minimum depth of clear working space at electrical equipment

Nominal Voltage to Ground	Minimum Clear Distance					
	Condition 1		Condition 2		Condition 3	
	m	ft	m	ft	m	ft
601–2500 V	0.9	3	1.2	4	1.5	5
2501–9000 V	1.2	4	1.5	5	1.8	6
9001–25,000 V	1.5	5	1.8	6	2.8	9
25,001–75 kV	1.8	6	2.5	8	3.0	10
Above 75 kV	2.5	8	3.0	10	3.7	12

Source: NFPA 70E

c. Describe and explain electrical systems and components.

This element reflects a broad topic, and can be best addressed by reviewing the balance of this reference guide. Electrical systems and components are discussed in other elements of the Qualification Standard, and are referenced accordingly.

d. Describe and explain hazardous locations.

The following is taken from NFPA 70.

Hazardous locations must be well understood by anyone designing, installing, working on, or inspecting electrical equipment and wiring in such areas. Such locations carry a threat of flammable or combustible gases, vapors, or dusts being present some or all of the time.

Hazardous areas and locations are classified by group, class, and division. These classifications are determined by the atmospheric mixtures of various gases, vapors, dust, and other materials present. The intensity of the explosion that can occur depends on concentrations, temperatures, and many other factors that are listed in NFPA codes.

Information in section 5.3 of DOE-HDBK-1092-2004, *DOE Handbook: Electrical Safety,* assists in classifying areas or locations with respect to hazardous conditions, whether from atmospheric concentrations of hazardous gases, vapors, and deposits, or from accumulations of readily ignitable materials. This section covers the requirements for electrical equipment and wiring in locations that are classified according to the properties of the flammable vapors, liquids, or gases or combustible dusts that may be present and the likelihood that a flammable or combustible concentration is present. The hazardous (classified) locations are assigned the following designations:

1. Class I Division 1
2. Class I Division 2
3. Class I, Zone 0, Zone 1, Zone 2
4. Class II Division 1
5. Class II Division 2

Class III fibers and flyings are not covered in this section.

Class I

Class I locations are identified in the NEC as those in which flammable gases or vapors are or may be present in the air in amounts sufficient to create explosive or ignitable mixtures. Gases or vapors may be continuously or intermittently present. However, if a gas or vapor is present, there is a potential that a flammable mixture will be present.

From an engineering standpoint, greater precautions are needed if a particular set of conditions is likely to occur (e.g., the presence of a flammable mixture within the explosive range) than if it is unlikely. This is the reason for dividing hazardous locations into two divisions.

Division 1

NEC 500.5 defines Class I, Division 1 hazardous locations as those in which

1. ignitable concentrations of flammable gases, liquids, or vapors can exist under normal operating conditions;
2. ignitable concentrations of such gases or vapors may exist frequently because of repair or maintenance operations or because of leakage; or
3. breakdown or faulty operation of equipment or processes might release ignitable concentrations of flammable gases, liquids, or vapors and might also cause simultaneous failure of electrical equipment.

Note: In each case, ignitable concentrations are mentioned. This means concentrations between the lower and upper flammable or explosion limits.

Division 2

NEC 500.5(B)(2) defines Class I, Division 2 locations as those

1. in which flammable liquids or gases are handled, processed, or used, but where such materials are normally confined in closed containers or closed systems from which they can escape only in case of accidental rupture or breakdown of such containers or systems or in case of abnormal equipment operation.
2. in which gases or vapors are normally prevented, by positive mechanical ventilation, from forming ignitable concentrations and which might become hazardous through failure or abnormal operation of the ventilating equipment.
3. that are adjacent to a Class I Division 1 location and to which ignitable concentrations of gases or vapors might occasionally be transmitted unless such transmittal is prevented by adequate positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided.

NEC 500.5 describes a number of areas and occupancies normally classified as Class I, Division 1 and Class I, Division 2 locations.

Zone 0

Class I, Zone 0. A Class I, Zone 0 location is a location in which

1. ignitable concentrations of flammable gases or vapors are present continuously, or
2. ignitable concentrations of flammable gases or vapors are present for long periods of time.

Zone 1

A Class I, Zone 1 location is a location

1. in which ignitable concentrations of flammable gases or vapors are likely to exist under normal operating conditions; or
2. in which ignitable concentrations of flammable gases or vapors may exist frequently because of repair or maintenance operations or because of leakage; or
3. in which equipment is operated or processes are carried on, of such a nature that equipment breakdown or faulty operations could result in the release of ignitable concentrations of flammable gases or vapors and also cause simultaneous failure of electrical equipment in a mode to cause the electrical equipment to become a source of ignition; or
4. that is adjacent to a Class I, Zone 0 location from which ignitable concentrations of vapors could be communicated, unless communication is prevented by adequate positive pressure ventilation from a source of clean air and effective safeguards against ventilation failure are provided.

Zone 2

A Class I, Zone 2 location is a location

1. in which ignitable concentrations of flammable gases or vapors are not likely to occur in normal operation and, if they do occur, will exist only for a short period; or

2. in which volatile flammable liquids, flammable gases, or flammable vapors are handled, processed, or used but in which the liquids, gases, or vapors normally are confined within closed containers or closed systems from which they can escape only as a result of accidental rupture or breakdown of the containers or system, or as a result of the abnormal operation of the equipment with which the liquids or gases are handled, processed, or used; or
3. in which ignitable concentrations of flammable gases or vapors normally are prevented by positive mechanical ventilation but which may become hazardous as a result of failure or abnormal operation of the ventilating equipment; or
4. that is adjacent to a Class I, Zone 1 location from which ignitable concentrations of flammable gases or vapors could be communicated, unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air and effective safeguards against ventilation failure are provided.

Class II

A Class II location is defined in NEC 500 as an area where combustible dust presents a fire or explosion hazard. Class II locations are divided into two divisions based on the normal presence or absence of dust.

Division 1

A Class II, Division 1 location is one

1. in which combustible dust is in the air under normal operating conditions in quantities sufficient to produce explosive or ignitable mixtures;
2. where mechanical failure or abnormal operation of machinery or equipment might cause such explosive or ignitable mixtures to be produced and might also provide a source of ignition through simultaneous failure of electrical equipment, operation of protective devices, or other causes; or
3. in which combustible dusts of an electrically conductive nature may be present in hazardous quantities.

Division 2

A Class II, Division 2 location is one where

1. combustible dust is not normally in the air in quantities sufficient to produce explosive or ignitable mixtures;
2. dust accumulations are normally insufficient to interfere with the normal operation of electrical equipment or other apparatus, but where combustible dust may be suspended in the air as a result of infrequent malfunctioning of handling or processing equipment; and
3. combustible dust accumulations on, in, or in the vicinity of the electrical equipment may be sufficient to interfere with the safe dissipation of heat from electrical equipment or may be ignitable by abnormal operation or failure of electrical equipment.

e. Describe and explain PPE.

The following is taken from 29 CFR 1910.137 & 268.

Personal protective equipment is functionally derived from the hazards and risks that have been previously identified and analyzed for the particular work. PPE comprises clothing, tools, equipment, etc., necessary to work safely.

Qualified employees shall be trained and competent in the use of special precautionary techniques, PPE, insulating and shielding materials, and insulated tools for working on or near exposed energized parts of electric equipment. Employers shall ensure that an employee in charge conducts a job briefing with the employees involved before they start each job. The briefing shall cover at least the following subjects: hazards associated with the job, work procedures involved, special precautions, energy source controls, and PPE requirements. Body belts, safety straps, lanyards, lifelines, and body harnesses shall be inspected before use each day to determine whether the equipment is in safe working condition. Defective equipment may not be used.

Work related to tasks such as testing, troubleshooting, voltage measuring, etc., on or near live parts, and performed by qualified persons shall be permitted to be performed without an energized electrical work permit, provided appropriate safe work practices are followed and appropriate PPE is used.

A shock hazard analysis shall determine the voltage to which personnel will be exposed, boundary requirements, and the PPE necessary in order to minimize the possibility of electrical shock to personnel.

A flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc flash. The analysis shall determine the flash protection boundary and the PPE that people within the flash protection boundary shall use.

Fall arrest equipment, work positioning equipment, or travel restricting equipment shall be used by employees working at elevated locations more than 4 feet (1.2 m) above the ground on poles, towers, or similar structures if other fall protection has not been provided. Fall protection equipment is not required to be used by a qualified employee climbing or changing location on poles, towers, or similar structures, unless conditions, such as, but not limited to, ice, high winds, the design of the structure (for example, no provision for holding on with hands), or the presence of contaminants on the structure, could cause the employee to lose his or her grip or footing. This paragraph applies to structures that support overhead electric power generation, transmission, and distribution lines and equipment. It does not apply to portions of buildings, such as loading docks, to electric equipment, such as transformers and capacitors, nor to aerial lifts. Requirements for fall protection associated with walking and working surfaces are contained in subpart D of 29 CFR 1910; requirements for fall protection associated with aerial lifts are contained in 29 CFR 1910.67. Employees undergoing training are not considered qualified employees for the purposes of this provision. Unqualified employees (including trainees) are required to use fall protection any time they are more than 4 feet (1.2 m) above the ground.

The following requirements apply to personal fall arrest systems:

- When stopping or arresting a fall, personal fall arrest systems shall limit the maximum arresting force on an employee to 900 pounds (4 kilonewtons [kN]) if used with a body belt.
- When stopping or arresting a fall, personal fall arrest systems shall limit the maximum arresting force on an employee to 1,800 pounds (8 kN) if used with a body harness.
- Personal fall arrest systems shall be rigged such that an employee can neither free fall more than 6 feet (1.8 m) nor contact any lower level.
- If vertical lifelines or droplines are used, not more than one employee may be attached to any one lifeline.
- Snaphooks may not be connected to loops made in webbing-type lanyards.
- Snaphooks may not be connected to each other.

Additional information regarding PPE can be reviewed in NFPA 70E, Article 130.

f. Identify and discuss elements of an electrical safety program, such as the two-man rule, stored energy, and component labeling.

Two-Man Rule

The following is taken from 29 CFR 1910.269.

At least two employees shall be present while the following types of work are being performed:

- Installation, removal, or repair of lines that are energized at more than 600 volts
- Installation, removal, or repair of de-energized lines if an employee is exposed to contact with other parts energized at more than 600 volts
- Installation, removal, or repair of equipment such as transformers, capacitors, and regulators if an employee is exposed to contact with parts energized at more than 600 volts
- Work involving the use of mechanical equipment, other than insulated aerial lifts, near parts energized at more than 600 volts
- Other work that exposes an employee to electrical hazards greater than or equal to those posed by operations that are specifically listed in 29 CFR 1910.269, paragraphs (l)(1)(i)(A) through (l)(1)(i)(D)

However, this rule does not apply to the following operations:

- Routine switching of circuits, if the employer can demonstrate that conditions at the site allow this work to be performed safely
- Work performed with live-line tools if the employee is positioned so that he or she is neither within reach of nor otherwise exposed to contact with energized parts
- Emergency repairs to the extent necessary to safeguard the general public

Stored Energy

The following is taken from DOE-HDBK-1092-2004.

The employer shall establish a program consisting of energy control procedures, employee training, and periodic inspections to ensure that, before any employee performs any servicing or maintenance on a machine or equipment where the unexpected energizing, start-up, or release of stored energy could occur and cause injury, the machine or equipment is isolated from the energy source and rendered inoperative.

If there is a possibility of re-accumulation of stored energy to a hazardous level, verification of isolation shall be continued until the servicing or maintenance is completed or until the possibility of such accumulation no longer exists.

Procedures shall be used during shift or personnel changes to ensure the continuity of LOTO protection, including provision for the orderly transfer of LOTO device protection between off-going and on-coming employees, to minimize their exposure to hazards from the unexpected energizing or start-up of the machine or equipment or from the release of stored energy.

A direct ground shall be applied to the exposed terminals when the stored energy drops to a level at which it is safe to do so.

Where required, install grounding equipment/conductor device on the phase conductors or circuit parts, to eliminate induced voltage or stored energy, before touching them. Where it has been determined that contact with other exposed energized conductors or circuit parts is possible, apply ground connecting devices rated for the available fault duty. In regard to identifying elements of control, the procedure shall include requirements for releasing stored electric or mechanical energy that might endanger personnel. All capacitors shall be discharged, and high-capacitance elements shall also be short-circuited and grounded before the associated equipment is touched or worked on. Springs shall be released or physical restraint shall be applied when necessary to immobilize mechanical equipment and pneumatic and hydraulic pressure reservoirs. Other sources of stored energy shall be blocked or otherwise relieved.

Sources of stored energy, such as capacitors or springs, shall be relieved of their energy, and a mechanism shall be engaged to prevent the re-accumulation of energy. The employees shall be notified that a LOTO system is going to be implemented and the reason therefore. The qualified employee implementing the LOTO shall know the disconnecting means location for all sources of electrical energy and the location of all sources of stored energy.

Component Labeling

The following is taken from DOE-HDBK-1092-2004.

Labeled or listed equipment shall be installed and used in accordance with any instructions included in the listing or labeling. Labeling is a key feature for determining suitability of identified equipment.

Labeled equipment is equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the AHJ and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Listed equipment is equipment, materials, or services included in a list published by an organization that is acceptable to the AHJ and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that the equipment, material, or service either meets appropriate designated standards or has been tested and found suitable for a specified purpose. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. Use of the system employed by the listing organization allows the AHJ to identify a listed product.

Warning labels or signs that read "DANGER — HIGH VOLTAGE — KEEP OUT" shall be attached to the equipment and shall be plainly visible where persons might come in contact with energized parts when doors are open or closed or when panels are removed from compartments containing over 150 volts AC or DC.

The AHJ may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

V. ELECTRICAL DESIGN & INSTALLATION (SAFETY AND SYSTEMS)

This section is optional and should be used by the program and/or field offices to assist them with specific technical qualifications for that office.

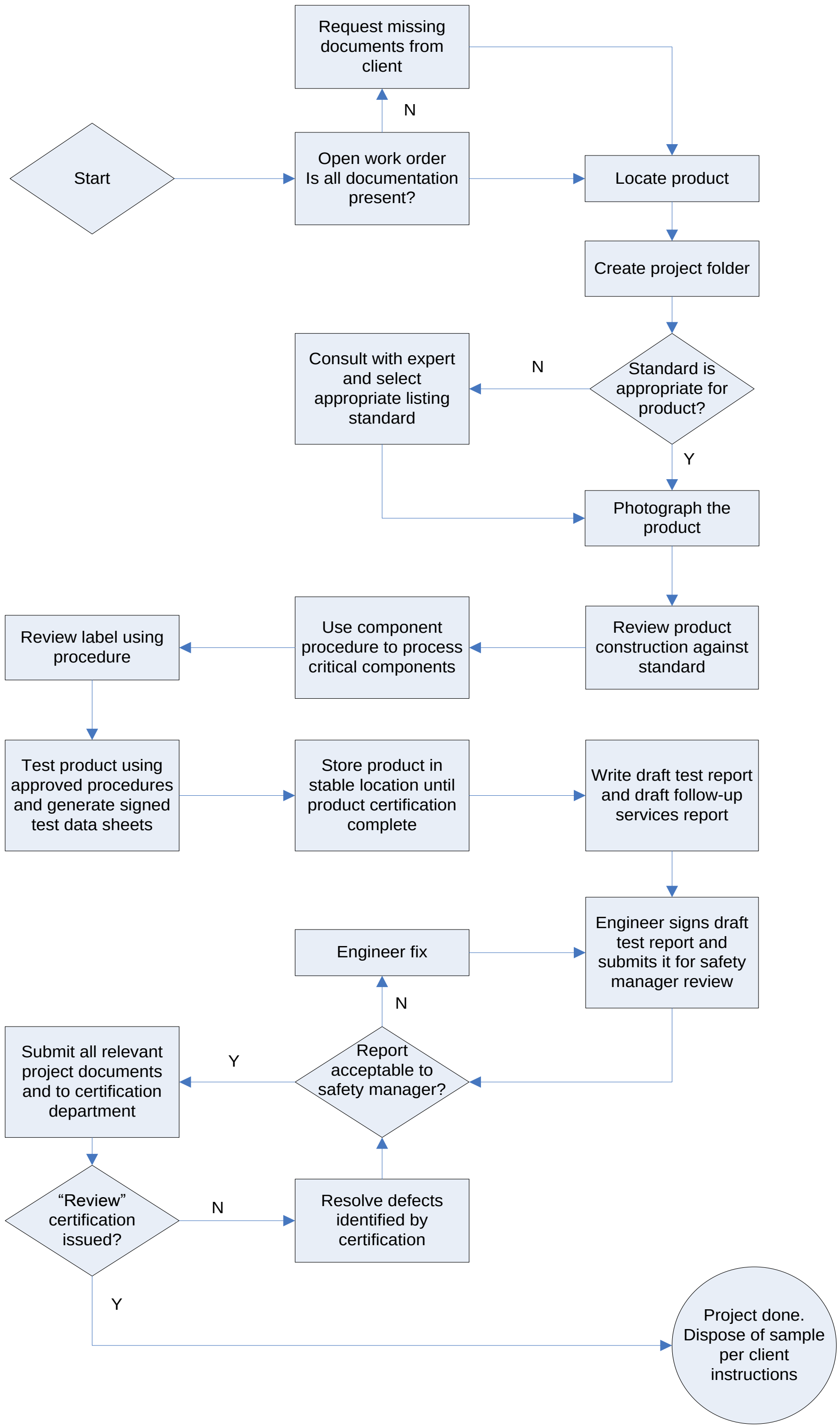
30. Electrical personnel shall demonstrate a working level knowledge of the current National Electrical Code and the requirements for wiring design and protection (NFPA 70 and NFPA 70E, Chapter 4).

[Note: The 2004 version of NFPA 70E has been superseded by the 2009 revision and is archived but still available. Because the 2009 revision was drastically reduced in scope it is not used as a reference in this guide.]

a. Describe and explain the use of listed and labeled Nationally Recognized Test Laboratory (NRTL) electrical equipment.

The following is taken from Curtis, Jon. *Conformity*, "Electrical Product Safety for Retailers".

There are 18 organizations running electrical product safety certification schemes (illustrated in figure 44) in the United States and 9 in Canada. Commonly referred to as NRTLs, these organizations find that approximately 20 percent of designs submitted for initial testing have deviations that need to be corrected for compliance with accepted safety standards prior to certification of the designs. Not all of these defects would have gone on to become recalls or to harm users, but simple math indicates that the NRTLs help contain significant risk.



Source: Curtis, Jon. *Conformity*, "Electrical Product Safety for Retailers"

Figure 44. The NRTL listing/certification process

Underwriters Laboratories is the largest, most recognized, North American provider of services, but over the last decade several other NRTLs with global laboratory networks have developed significant market share and are widely accepted by major retailers. Many of these alternative NRTLs are attractive for their turnaround and pricing policies. Most retailers now offer their vendors a choice of any of the globally distributed NRTL providers in order to reduce supply chain expenses and delays through the application of competitive market forces.

The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. Use of the system employed by the listing organization allows the AHJ to identify a listed product.

b. Describe and explain branch circuit identification.

The following is taken from NFPA 70B.

Where more than one nominal voltage system exists in a building, each ungrounded conductor of a multiwire branch circuit, where accessible, shall be identified by phase and system. The means of identification shall be permitted to be by separate color coding, marking tape, tagging, or other approved means and shall be permanently posted at each branch circuit panelboard.

Where the premise's wiring system has branch circuits supplied from more than one nominal voltage system, each ungrounded conductor of a branch circuit shall be identified by phase or line and system at all termination, connection, and splice points. The means of identification shall be permitted to be by separate color coding, marking tape, tagging, or other approved means. The method utilized for conductors originating within each branch-circuit panelboard or similar branch-circuit distribution equipment shall be documented in a manner that is readily available or shall be permanently posted at each branch-circuit panelboard or similar branch-circuit distribution equipment.

c. Describe and explain GFCI protection for personnel.

A GFCI is a device intended for the protection of personnel that functions to de-energize a circuit or portion thereof within an established period of time when a current to ground exceeds the values established for a Class A device.

GFCI protection is prescribed variously based on the specific location and/or facility at hand. Detailed descriptions are listed in NFPA 70E, Article 430, and in most location descriptions discussed in NFPA 70, beginning in Article 525.

d. Describe and explain outside circuits and conductors for 600 volt (or less) systems.

Article 225 of NFPA 70 covers requirements for outside branch circuits and feeders run on or between buildings, structures, or poles on the premises; and electrical equipment and wiring for the supply of utilization equipment that is located on or attached to the outside of buildings, structures, or poles.

Where within 3.0 m (10 ft) of any building or structure other than supporting poles or towers, open individual (aerial) overhead conductors shall be insulated or covered. Conductors in cables or raceways, except Type MI cable, shall be of the rubber-covered type or thermoplastic type and, in wet locations, shall comply with NFPA 70, Article 310.8. Conductors for festoon lighting shall be of the rubber-covered or thermoplastic type.

e. Describe and explain overcurrent protection for 600 volt (or less) and greater-than 600 volt circuits.

Parts I through VII of NFPA 70, Article 240 provide the general requirements for overcurrent protection and overcurrent protective devices not more than 600 volts, nominal. Part VIII covers overcurrent protection for those portions of supervised industrial installations operating at voltages of not more than 600 volts, nominal. Part IX covers overcurrent protection over 600 volts, nominal.

Overcurrent protection for conductors and equipment is provided to open the circuit if the current reaches a value that will cause an excessive or dangerous temperature in conductors or conductor insulation.

See also Article 110.9 for requirements on interrupting ratings and Article 110.10 for requirements for protection against fault currents.

f. Describe and explain grounding and bonding requirements as noted in NFPA 70E, Article 410.10.

NFPA 70E, Article 410.10 paragraphs (A) through (G) cover grounding requirements for systems, circuits, and equipment. These requirements include the following topics:

- Grounding path
- General bonding
- Systems that supply premises wiring to be grounded
- Grounding connections
- Enclosure, raceway, and service cable grounding
- Equipment considered effectively grounded
- Grounding of systems and circuits of 1 kV and over (high voltage)

31. Electrical personnel shall demonstrate a familiarity level knowledge of the requirements for the installation of lightning protection systems (NFPA 780; UL 96, Lightning Protection Components; and UL 96A, Installation Requirements for Lightning Protection Systems).

a. Describe and explain the principles of lightning.

The following is taken from NFPA 780. Additional detail is available in that document.

> The fundamental principle in the protection of life and property against lightning is to provide a means by which a lightning discharge can enter or

leave the earth without resulting damage or loss. A low-impedance path which the discharge current will follow in preference to all alternative high-impedance paths offered by building materials such as wood, brick, tile, stone, or concrete should be offered. When lightning follows the higher impedance paths, damage can be caused by the heat and mechanical forces generated during the passage of the discharge.

b. Describe and explain how lightning protection systems work and their associated requirements.

The following is taken from DOE-HDBK-1092-2004.

An LPS operates to dissipate the energy from a lightning strike through a strike termination device. Lightning-protection systems should be visually inspected every 7 months and a report on their conditions filed at least annually. Any evidence of corrosion, broken wires or connections, or any other problem that negates the system's usefulness shall be noted and the problem repaired.

Lightning protection systems should be tested electrically every 14 months to ensure testing during all seasons, or immediately following any repair or modification. The testing shall be conducted only with instruments designed specifically for earth-ground system testing. The instruments shall be able to measure 10 ohms ±10% for ground resistance testing and 1 ohm ±10% for bonding testing. Electrical resistance readings shall be recorded.

Inspection records shall contain the most recent electrical test report and any subsequent visual inspection reports for each building with a LPS.

32. Electrical personnel shall demonstrate a working level knowledge of electrical diagrams, such as one-line diagrams, schematics, construction drawings, as-built drawings, and wiring diagrams.

Elements 'a' through 'e' are performance-based KSAs. The Qualifying Official will evaluate their completion.

a. Using a schematic, identify an electrical component by its symbology.

b. Using a logic diagram for a control circuit, identify and describe the effects of an action taken.

c. Using a one-line diagram, identify power sources and loads.

d. Using a one-line diagram or schematic diagram, analyze the effects of a component failure in a system.

e. Using a construction drawing, identify the emergency power supplies.

f. Discuss the origin and purpose of "as-built" drawings.

The following is taken from U.S. Army Corps of Engineers, Huntsville Engineering and Support Center (CEHNC) 1180-3-1, Chapter 10, *As-built Drawing.*

"As-built" drawings are drawings that depict the actual conditions of a completed construction, providing a record of each project feature. These working as-built drawings will typically be red-lined markups of two sets of the construction plans: one for use by the contractor and one for use by the Government. The working as-built drawings must be reviewed at least monthly by the Resident Engineer in conjunction with the approval of progress payments. The contract requires the Systems Contractor to prepare, maintain and deliver to the Government a set of redlined, record drawings, which show the actual as-built conditions of the construction phases. After Government review and approval, these marked-up drawings will be sent to the contractor who will produce three copies of a final set of as-built drawings. One set for the Corps of Engineers, one for the User or Owner, and one for the Systems Contractor who must also keep a permanent set of as built drawings.

The as-built drawing procedure has three steps:

- All changes, no matter how minor, as well as all clarifications are entered into a change database and recorded by the Systems Contractor on two sets of redlined or record drawings. Changes and clarifications refer to shop drawings, field electrical controller products, change orders, modifications, and RFIs which have been reviewed and approved by the Government.
- Redlined drawings must be transferred to the Architect-Engineer for CM verification, baseline comparison, entry into the computer-aided design and drafting system, and creation of a reproducible set of drawings labeled As-Built Drawings.
- When as-built drawings are completed and approved by the Government, the entire set is then sent to the Systems Contractor to use during the systemization and operations phases of the contract. Office of Safety and Compliance policy and procedures establish storage, updating, and maintaining of as-builts in the data control center during these phases.

33. Electrical personnel shall demonstrate a familiarity level knowledge of the configuration management process as applied to electrical documentation (e.g., documenting, controlling, revising, and issuance of electrical drawings) and drawings that are updated and issued "as built" (DOE-STD-1073-2003, Configuration Management Program and DOE O 414.1C, Quality Assurance).

a. Discuss the change control process described in DOE-STD-1073-2003.

The information for KSAs 'a' and 'b' is taken from DOE-STD-1073-2003.

Contractors must establish and use a formal change control process as part of the CM process. The objective of change control is to maintain consistency among design requirements, the physical configuration, and the related facility documentation, even as changes are made. The change control process is used to ensure changes are properly reviewed and coordinated across the various organizations and personnel responsible for activities and programs at the nuclear facility.

Through the change control process, contractors must ensure that

- changes are identified and assessed through the change control process,
- changes receive appropriate technical and management review to evaluate the consequences of the change,
- changes are approved or disapproved,
- waivers and deviations are properly evaluated and approved or denied and the technical basis for the approval or the denial is documented,
- approved changes are adequately and fully implemented or the effects of the partial implementation are evaluated and accepted,
- implemented changes are properly assessed to ensure the results of the changes agree with the expectations, and
- documents are revised consistent with the changes and the revised documents are provided to the users.

b. Describe the purpose and objectives of the operational configuration management program, and explain how it relates to electrical systems.

Configuration management is a disciplined process that involves both management and technical direction to establish and document the design requirements and the physical configuration of a nuclear facility and to ensure that they remain consistent with each other and the documentation.

The size, complexity, and missions of DOE nuclear facilities vary widely and CM processes may need to be structured to individual facilities, activities, and operations. It would generally be inappropriate to apply the same CM standards to widely different activities, for example, a reactor facility and a small, simple laboratory. The detailed examples and methodologies in DOE-STD-1073-2003 are provided to aid those developing their CM processes; however, they are provided for guidance only and may not be appropriate for application to all DOE nuclear activities. The individuals defining the CM process for a particular nuclear activity will need to apply judgment to determine whether the examples and the methods presented in DOE-STD-1073-2003 are appropriate for the activity.

Nevertheless, the basic objectives and general principles of CM are the same for all activities. The objectives of CM are to

- establish consistency among design requirements, physical configuration, and documentation (including analysis, drawings, and procedures) for the activity, and
- maintain this consistency throughout the life of the facility or activity, particularly as changes are being made.

Performance data tools, drawings, technical discipline reviews, and detailed project design are all considerations that apply to CM of electrical systems.

The following are examples of critical characteristics for electrical components:

- Component number
- Drawing number (e.g., schematic, one-line diagram, etc.)
- Manufacturer
- Model number
- Serial number

- Component type
- Power (watts)
- Voltage (e.g., 125 DC, 4 kV AC, etc.)
- Amperage
- Contact rating
- Other (e.g., environmental qualification, fuse type, location, etc.)

c. Discuss the following elements of the configuration management program as they relate to electrical systems:

- **Design requirements**
- **Document control**
- **Change control**
- **Assessments**
- **Design reconstitution adjunct**
- **Material condition and aging adjunct**

The information for Design requirements, Document control, Change control and Assessments is taken from DOE-STD-1073-2003. The information for Design reconstitution adjunct and Material condition and aging adjunct is taken from DOE-STD-1073-1993 (archived).

Design Requirements

Design requirements are those engineering requirements reflected in design output documents (such as drawings and specifications) that define the functions, capabilities, capacities, physical sizes and dimensions, limits and setpoints, etc. specified by design engineering for an SSC. The design requirements provide the results of the design process.

A CM program's elements encompass the following functions: establishing and maintaining the facility design requirements, establishing system and process boundaries, assigning SSC grades based on the associated design requirements, identifying the specific list of SSCs for inclusion in the CM program, and establishing and maintaining the design basis for the design requirements.

The objective of the design requirements element is to establish and maintain the design requirements and the associated design basis. The design requirements should be formally established, documented, and maintained. For each SSC, the design requirements should be categorized into the types established by the equipment scope criteria. A technical management review should be performed to determine the adequacy of the design requirements. If the design requirements are not fully documented, not accurate, or not complete, the design requirements should be reconstituted to the extent identified by the design reconstitution (DR) adjunct program. The design requirements should be incorporated into an equipment database that correlates each SSC with the SSC grade, the design requirements, the technical topics involved, and the associated documentation. The design requirements for new facilities and modifications to existing facilities should be established, categorized, and documented as they are developed, in a form amenable to review and addition to the equipment database.

The boundaries for each system and process should be established in such a manner as to contain the components necessary to satisfy the design requirements for that system or process. Each SSC should be assigned a grade based on the most important type of design requirements applicable to it. The SSC grade should be used as the basis for the degree of control on all activities associated with the SSC. On the basis of the equipment scope criteria and the assignment of SSC grades, the specific SSCs included in the CM program should be identified. The basis for design requirements should be formally established, correlated with the design requirements, documented, and maintained.

A technical management review should be performed to determine the adequacy of the design basis. If the design basis is not fully documented, not accurate, or not complete, it should be reconstituted to the extent identified by the DR adjunct program. The design basis for new or modified design requirements should be established and documented as these requirements are developed.

With the exception of components whose design requirements have been established and found to be adequate and outside the equipment scope criteria, all components within a CM system should be included in the CM program, even those without a safety, environmental, or mission function. Once the design requirements are fully established and adequate, the CM equipment scope criteria may be used to consider component exclusions. However, the inclusion of components other than safety, environment, and mission components is generally advisable for CM systems to enhance overall configuration control.

Document Control

The objective of the document control element is to identify and maintain documents within the CM program consistent with the physical configuration and design requirements. The types of documents that need to be included in the CM program should be determined, and document owners should be established for each of these document types. The document owners should be responsible for the technical content of assigned documents. Within each document type, the specific documents to be included in CM document control should be identified for each SSC. The document owners should establish priorities for document revision and retrieval.

Originals or master copies of documents within the CM program should be stored and protected. Retention times should be established to meet the needs of the document owners and users and the minimums specified by DOE O 243.1, *Records Management Program.* Only the currently-approved revisions of documents within the CM program should be used. Revisions to documents within the CM program to incorporate pending changes should be completed in a timely manner. The number of unincorporated document changes allowed to accumulate before revisions are implemented should be determined according to the priority of the document, the complexity of the changes and the overlap of the changes. For each document within the CM program, the following information should be readily available: revision level, current status, document owner, information regarding pending changes, and other data necessary for control and tracking, such as storage location and outstanding document change notices.

Documents should be retrieved in a timely manner upon request. Maximum retrieval times for each document should be established, and they should be based on the priorities established by the document owners. Documents should be identifiable from a document database, which should be able to identify documents within the CM program related to particular SSCs, types of SSCs, technical topics, and other information to support identification, such as SSC vendors. When a copy of a document within the CM program is issued, pending changes and associated information should be identified.

Early in CM program development, a determination should be made as to which documents will be included. The steps necessary to accomplish this are as follows:

- Identify document types used at the facility.
- Determine which document types should be in the CM program.
- Determine which specific documents should be in the CM program.

First, a complete survey of document types in use should be conducted with support of the various organizations at the facility. Each organization should identify the document types it prepares and the important document types it uses. Document types identified during the initial assessments should also be addressed.

After document types are identified, a document owner should be assigned to each document type. The natural document owner is the person or organization responsible for developing and revising the technical content of documents within the assigned document type. The owners should review the document types for which they are responsible to identify those important for supporting the CM program objective and criteria. They should then perform an importance evaluation in light of their experience with, and knowledge of, the document types. Document scope criteria may vary according to the importance of the SSCs involved. These criteria should be defined to include only those document types that support the design or operation of facility SSCs included in the CM program. Document types that reflect the facility's design requirements and those that are necessary for day-to-day operation should receive the highest priority for inclusion in the CM program.

Finally, the document owners, with the assistance of those persons responsible for the document retrieval function, should identify the individual documents within each document type and determine which of these documents should be included in the CM program.

Change Control

The objective of the change control element is to maintain consistency among the design requirements, the physical configuration, and the facility documentation as changes are made. All mechanisms that can lead to temporary or permanent changes in the design requirements, facility configuration, or facility documentation within the CM program should be identified. Such mechanisms might include hardware modifications not controlled as projects, hardware modifications controlled as projects, maintenance changes, operational changes, procurement changes, document changes, and computer software changes. Change mechanisms should be evaluated to determine which are adequate as is, and which need to be improved, consolidated, or terminated.

The resulting change mechanisms should be integrated with the CM program. Within approved CM change mechanisms, each proposed change, including temporary changes and partially implemented changes, should be described sufficiently to support technical reviews, management reviews, and approvals.

Each specific proposed change should be reviewed to determine if it is within the bounds of the design requirements. Changes to the design requirements should be evaluated and approved by the design authority prior to implementation. The technical reviews should evaluate safety, environmental, and mission impacts; determine appropriate post-implementation acceptance criteria; and identify the affected SSCs and facility documentation.

Before implementation, management should review proposed changes (including those that do not involve a change to design requirements) to verify that the technical reviews have been performed adequately, that the change package is complete and ready for implementation, and that any external approvals necessary prior to implementation have been obtained. On the basis of these reviews, management should take approval action.

Each change should be implemented in accordance with its approved change package. The change process should include mechanisms for field change requests, and technical reviews and approvals of field changes should be commensurate with those of the original change package. The change process should generate accurate as-built information. After the physical implementation of changes, post-modification testing should be conducted.

Each change should be documented and that documentation should include a description of the change, as well as an account of the technical reviews, management approvals, as-built information, and post-modification test results. Documents that are included in the CM program and are affected by a change, either directly or indirectly, should be revised.

Specific changes should be identified only within established change processes. The need for a potential change may be identified by anyone within the facility and should be documented by the requester to support the processing of the change request. As defined by the CM program criteria, each proposed change should be described adequately to support technical and management reviews prior to approval. Change initiation should include the name of the requester, a description of the proposed change, the affected SSCs and the associated SSC grade, the reason for the change, alternative solutions, the due date, and constraints. It should also include any other information needed for review, tracking, approval, and further processing.

Effective change control involves formal, multi-disciplined, technical reviews for each change. Some of these are necessary to maintain configuration and others are defined as good management practices. The technical reviews defined by the CM program criteria to maintain configuration can be grouped into these areas: design envelope review; identification of affected hardware and documents; identification of post-implementation acceptance criteria; and, safety, environment, and mission reviews.

As defined by the CM program criteria, management should review the proposed change to verify that the technical reviews have been performed adequately, the change package is complete and ready for implementation, any necessary external approvals have been obtained, and that the change is authorized for implementation.

Assessments

The objective of the assessments element is to help define facility CM needs and to measure how effective the CM program is in establishing and maintaining the program's basic relationships. CM assessments are conducted in an initial phase, in a post-implementation phase, and throughout the life of the facility.

The adequacy of CM programs and procedures should be assessed using vertical and horizontal slice assessments.

Initial Assessments

During the planning for the CM program, initial assessments should be conducted to determine the strengths and weaknesses of existing programs and procedures with regard to determining where upgrade actions and resource investments are necessary. Two vertical slice assessments relevant to the facility should be conducted. One of these should be on a safety system related to the principal facility hazard, either nuclear or non-nuclear. Two horizontal slice assessments relevant to the facility should also be performed. One of these should be on change control and the other on a technical topical area, such as seismic qualification or fire protection.

Post-implementation Assessments

After the CM program upgrades are implemented, a horizontal slice assessment should be performed for each CM program element to determine if that element addresses identified weaknesses and is effective in accomplishing the CM functions.

For each system design information summary (DIS) developed by the DR adjunct program, a field validation should be performed to ensure that the design requirements are accurately reflected in the physical configuration and the associated facility documentation. After the material condition and aging (MCA) adjunct program is developed, a technical quality review should be performed of its assumptions, methods, and products.

After the CM program and its adjunct programs have been implemented, a combination of vertical and horizontal slice assessments should be performed periodically to measure the overall CM program effectiveness and to determine if CM controls are adequate and appropriate. The results of these assessments should establish the basis for revisions to the CM program plan, either increasing or decreasing controls.

Physical configuration assessments, or walkdowns, should be performed for representative sample SSCs to determine the degree of agreement between the physical configuration and the configuration depicted in the facility documentation. Physical walkdowns should be included as part of the programmatic assessments conducted during the initial assessments, post-implementation assessments, and periodic effectiveness assessments. If substantive discrepancies (either in number or type) are discovered, appropriate immediate corrective actions should be developed to establish agreement between the physical configuration and the documentation. The corrective actions should include additional walkdowns to characterize the problem and to determine the extent of the problem. They should also include technical evaluations to determine whether the physical configuration or the documentation should be changed.

Structures, systems, and components within the CM program should be tested periodically to determine if they are still capable of meeting their design requirements. This monitoring should also address surveillance actions, periodic in-service inspections and tests, and other monitoring of SSCs to ensure safe and reliable operation of the facility. Monitoring should also include measurements and trending of data related to the actual aging degradation of equipment, to the extent identified by the MCA adjunct program and approved by the design authority.

An SSC within the CM program should be tested after modification (and before being turned over for service) to determine if it is capable of meeting its design requirements (i.e., the post-implementation acceptance criteria). If a changed SSC fails to meet its post-implementation acceptance criteria, turnover for operation should be postponed until either a technical review has been completed and any follow-up actions are completed or the SSC is returned to its original condition and tested satisfactorily.

The assessments element may be considered fully developed on completion of the following:

- Initial CM programmatic and physical configuration assessments
- Detailed action plans and procedures for conducting post-implementation assessments
- Ongoing assessment programs established by procedure and effectively implemented

Senior management should retain overall responsibility for management assessments (i.e., all initial and post-implementation assessments and the periodic program effectiveness assessments). Direct participation of senior management during these assessments is essential. This process should also involve other levels of management, as appropriate. Management assessment results should be documented. Senior management should take prompt action and document decisions in response to recommendations resulting from the management assessment process. Follow-up should include an evaluation of the effectiveness of management’s actions.

Design Reconstitution Adjunct

If the design requirements are not fully documented, not accurate, or not complete, the design requirements should be reconstituted to the extent identified by the DR adjunct program.

The objective of the DR adjunct program is to establish, organize, and document design information (i.e., both design requirements and design basis), where existing design information is not adequate. A program plan, an action plan, and implementing procedures should be developed for the DR adjunct program. The DR program plan should be based on the initial assessments and the graded approach. The DR adjunct program should be implemented in stages to provide a timely initial set of design information and more information as it becomes available. It should include prioritization of the development and issuance of DISs. Design information summaries for systems or technical topics necessary to support the facility accident analysis and TSRs should receive the highest priority.

The identification and retrieval of design information should be accomplished in stages, with emphasis on the most important and most accessible information first. The objective and scope of source documents to be reviewed should be defined for each document identification and retrieval stage. The recommended stages are the formal review, the smart search, and the comprehensive search. The formal review should address those on-hand documents, such as the facility safety analysis and TSRs, that contain summary-type design information; the smart search should identify and retrieve those types of documents that can be identified as most likely to contain design requirements; and the comprehensive search should identify and retrieve any remaining documents that might contain design information, including DOE correspondence and vendor correspondence.

Technical review and identification of design information from each source document should include both design requirements and design basis information. Extracted design information should be identified as to the applicable facility SSC, type of SSC, technical topic area, and whether it is a design requirement or design basis. The technical review and identification of design information from each source document should be complete, such that the document does not have to be reconsidered during subsequent searches and reviews.

Extracted design information should be verified by a second party to ensure that the design information was extracted completely and accurately from the source documents. Extracted design information should be technically validated to ensure that it is reasonable, that it is applicable to the current facility mission and configuration, and that the analytical methods and technical assumptions used in the design process are valid and appropriate. Design basis information should be correlated with the design requirements. Extracted design information should also be evaluated to identify any missing design requirements or design basis information. Design information summaries should be field validated to ensure that design requirements are properly reflected in the physical configuration and in the associated facility documentation.

Validated situations involving the following should be documented as open items: apparent contradictions in the information from different source documents; concerns; unanswered technical questions; and cases of missing, undocumented, or inaccurate information. The open items should be dispositioned by a formal resolution process and should be tracked to completion and closeout, including documentation of their resolution. SS open items (i.e., discrepancies) should be promptly addressed by existing programs for determining operability and reportability and resolved by those programs.

Missing design information should be evaluated to determine which part needs to be regenerated. Missing design information that is critical, including that necessary to support the facility accident analysis and TSRs, should be regenerated in order of priority.

Extracted design requirements should be entered into the CM equipment database promptly after verification and technical validation. Design information summaries should include a system description (including systems interface information), system operability requirements, system-level design requirements, component-level design requirements, the design basis, and related design topical information. They also should identify design requirements by type; attributes of the design that were not mandatory for the designer should be distinguished from other types of design requirements. The authorization basis should be clearly distinguished from other aspects of the design basis. The DISs should be written for easy use by individuals at all levels of experience. A DIS should be initially issued when the design requirements are complete and technically validated, including the regeneration of missing critical design requirements. This initial version should also contain available technically validated design basis information and should identify open items to be resolved. The DIS should be revised and reissued when the design basis has been reconstituted (including regeneration of missing critical design basis) and the field validation has been completed.

Material Condition and Aging Adjunct

The objective of the MCA adjunct program is to prevent the failure of facility life-limiting components from aging degradation and the associated impact on facility operations. Aging degradation can so impair the performance capability of equipment that it no longer meets its design requirements, and this can compromise the CM program basic relationships.

A program plan, an action plan, and implementing procedures should be developed for the MCA adjunct program. The program plan should be based on the initial assessments and the graded approach.

Components in the facility, including passive components (e.g., structures), should be screened to identify those that are potentially life limiting for the facility. The remaining lifetime for each potentially life-limiting component should be evaluated. Major aging degradation mechanisms that could affect potentially life-limiting components should be identified. The present material condition of each such component should be determined.

The remaining lifetime of each potentially life-limiting component, with no life extension techniques applied, should be estimated using engineering judgment. The facility remaining lifetime is the shortest estimated remaining lifetime for a potentially life-limiting component.

If DOE has not specified a facility desired lifetime, the contractor should request that it do so. If not specified, the desired lifetime should be taken to be the same as the remaining lifetime without the application of life extension techniques. As appropriate, the feasibility of continued operations and the feasibility of extended operations should be assessed. Objects of such an assessment would include the following: management alternatives for continued operation or extended operations of the facility; the estimated costs for each alterative as a function of time; and recommendations regarding facility continued operations and extended operations.

Detailed component screening, aging degradation evaluations, more rigorous determinations of facility remaining lifetime, the feasibility of continued operations, and the feasibility of extended operations should be performed. The physical characteristics related to aging degradation of specific life-limiting components should be determined, and measurements that could be made to determine the material condition of life-limiting components should be defined. Baseline measurements should be performed to establish the material condition of facility life-limiting components. The results of these measurements should be included in the aging degradation evaluations.

Aging degradation measurements and associated frequencies should be provided to the design authority as proposed new design requirements. Detailed aging degradation evaluations should also be provided to the design authority as the design basis for the new design requirements. The results of the periodic aging degradation measurements should be trended and extrapolated to update the remaining lifetime determinations after each set of measurements. As needed, life extension techniques for life-limiting components should be developed and implemented.

d. Discuss the purpose, concepts, and general process for applying the graded approach to operational configuration management.

- **Using the guidance in DOE-STD-1073-2003, discuss the system engineer concept as it applies to oversight of safety systems. Specifically address the areas of configuration management, assessment of system status and performance, and technical support for operation and maintenance activities, or for Documented Safety Analysis (DSA) reviews.**
- **Using DOE O 414.1C, discuss how the pedigree of electrical equipment should be maintained when supporting a nuclear related activity, and/or performing a safety function.**

DOE-STD-1073-2003, Configuration Management Program

One of the challenges of change control is to be cognizant of many ongoing changes—from proposal, through development, to implementation—and to understand the integrated effect of the various changes. The system engineering concept has been used in the commercial nuclear industry to provide a technical focal point for each system. The system engineer develops resident technical expertise and facility knowledge, centralizes resolution of SSC performance problems for more timely and effective response, and interfaces between the facility operations and maintenance organizations and the design engineering organization. The systems engineering concept benefits CM as well as many other facility activities including facility status and troubleshooting, operations support, coordination of testing and other system-related activities, and communication among departments.

For the purpose of change control, it is recommended that DOE contractors, in a manner similar to the commercial industry, institute the systems engineering concept. The duties, responsibilities, and interfaces of each system engineer need to be clearly defined, documented, and communicated to and understood by supporting facility organizations. System engineer responsibilities should include the following major items:

- Monitoring and tracking the status of the system, especially during changes (e.g., physical changes in progress and temporary physical changes)
- Conducting and/or observing equipment performance monitoring, evaluating the results of performance monitoring and surveillance, trending important data, and initiating corrective actions
- Reviewing and approving post-modification, post-maintenance, surveillance, and special test procedures and test results
- Providing assistance to operations and maintenance, as needed

- Identifying any situation where the design engineering organization should be consulted for advice or services

To implement systems engineering, selected facility engineers would be assigned the responsibility of important systems. These individuals should have an engineering degree or a strong technical background combined with a knowledge of the assigned system and how it relates to overall facility operation. An understanding of the policies, procedures, and organizational interfaces is also important. The number of systems assigned to each engineer should be limited (e.g., two to five) based on system complexity, the experience of the individual, and time considerations.

DOE O 414.1C, Quality Assurance

DOE O 414.1C, Criterion 5, states that work performed must be consistent with technical standards, administrative controls, and hazard controls adopted to meet regulatory or contract requirements using approved instructions, procedures, etc. Items must be identified and controlled to ensure proper use. Items must be maintained to prevent damage, loss, or deterioration. And finally, equipment used for process monitoring or data collection must be calibrated and maintained as well.

34. Electrical personnel shall demonstrate a familiarity level knowledge with battery installations, maintenance, testing, and replacement as described in NFPA 70E, Chapter 3; IEEE Std-450; IEEE C2 - NESC; manufacturers' recommendations; etc.

[Note: The 2004 version of NFPA 70E has been superseded by the 2009 revision and is archived but still available. Because the 2009 revision was drastically reduced in scope it is not used as a reference in this guide.]

Unless otherwise noted, all of the information for this competency statement is taken from NFPA 70E, Chapter 3.

a. Describe and explain connections and capacities.

Connections

Batteries usually consist of a number of identical cells connected in series. The voltage of a series connection of cells is the voltage of a single cell multiplied by the number of cells. If cells of sufficiently large capacity are available, then two or more series-connected strings of equal numbers of cells could be connected in parallel to achieve the desired rated capacity. The rated capacity of such a battery is the sum of the capacities of a group of cells comprising a single cell from each of the parallel branches. Cells of unequal capacity should not be connected in series. Parallel connections of batteries should be limited to four strings. Parallel connections of batteries are not recommended for constant current-charging applications. Cells connected in series have high voltages that could produce a shock hazard.

Manufacturers can usually provide suitable racks for batteries that provide protection and easy maintenance. It is important to have properly sized racks that space cells to minimize overheating and corrosion problems, allow easy maintenance, and still utilize available space in an optimum manner. Connections between cells should minimize strain on battery posts.

Capacities

Battery capacity is the quantity of electricity (electric charge), usually expressed in ampere-hour, that a fully charged battery can deliver under specified conditions. Additionally, it is the manufacturer's statement of the number of ampere-hours or watt-hours that can be delivered by a fully charged battery at a specific discharge rate and electrolyte temperature, to a given end-of-discharge voltage.

The requirements of NFPA 70E, Article 320, apply to the safety requirements related to installations of batteries and battery rooms with a stored capacity exceeding 1 kilowatt-hour or a floating voltage that exceeds 115 volts but does not exceed 650 volts.

If information regarding the short-circuit protection of a battery is not available from the manufacturer, the prospective fault level at the battery terminals shall be considered to be twenty times the nominal battery capacity at the 3-hour rate.

When the battery capacity exceeds 100 ampere-hours or where the nominal battery voltage is in excess of 50 volts, suitable warning notices indicating the battery voltage and the prospective short-circuit current of the installation shall be displayed.

A dry cell battery shall be considered an inherently limited Class 2 power source, provided the voltage is 30 volts or less and the capacity is equal to or less than that available from series connected no. 6 carbon-zinc cells.

b. Describe and explain DC systems grounding and ground-fault detection.

One of the following four types of available DC grounding systems, Type 1 through Type 4, shall be used. Stationary battery systems should not be grounded.

- Type 1: The ungrounded DC system in which neither pole of the battery is connected to ground. Work on such a system should be carried out with the battery isolated from the battery charger. If an intentional ground is placed at one end of the battery, an increased shock hazard would exist between the opposite end of the battery and ground. Also, if another ground develops within the system (e.g., dirt and acid touching the battery rack), it creates a short-circuit that could cause a fire. An ungrounded DC system should be equipped with an alarm to indicate the presence of a ground fault.
- Type 2: The solidly grounded DC system where either the positive or negative pole of the battery is connected directly to ground.
- Type 3: The resistance grounded DC system, where the battery is connected to ground through a resistance. The resistance is used to permit operation of a current relay, which in turn initiates an alarm.
- Type 4: A tapped solid ground, either at the center point or at another point to suit the load system.

c. Describe and explain DC circuit protection and alarms.

The information on DC Circuit Protection is taken from IEEE Std 446-1995. The information on Alarms is taken from NFPA 70E.

DC Circuit Protection

The battery manufacturer shall be consulted regarding the sizing of the battery short-circuit protection. If information regarding the short-circuit protection of a battery is not available from the manufacturer, the prospective fault level at the battery terminals shall be considered to be twenty times the nominal battery capacity at the 3-hour rate.

Circuit protection shall not be required for control and instrumentation that are totally within the cell line working zone.

Various types of circuit protection are satisfactory for ground-fault protection. Some commonly used types are circuit breakers with series trips, circuit-interrupting equipment tripped by ground-fault current-sensing devices, and, to a lesser extent, fuses. Selection and application of circuit-protective equipment requires a detailed analysis of each system and circuit to be protected, including the system and equipment grounding arrangements.

Alarms

Alarms shall be provided for early warning of the following abnormal conditions of battery operation:

- For vented batteries:
  - Over-voltage
  - Under-voltage
  - Over-current
  - Ground-fault

- For valve-regulated lead-acid (VRLA) batteries, the abnormal conditions listed above for vented batteries, plus over-temperature as measured at the pilot cell
- The alarm system shall provide an audible alarm and visual indication at the battery location, and where applicable, at a remote manned control point

35. Electrical personnel shall demonstrate a familiarity level knowledge of ventilation and battery room requirements as cited in 29 CFR 1910; 29 CFR 1926; NFPA 70E, Chapter 3; IEEE Std-450; IEEE C2 – NESC; etc.

[Note: The 2004 version of NFPA 70E has been superseded by the 2009 revision and is archived but still available. Because the 2009 revision was drastically reduced in scope it is not used as a reference in this guide.]

Unless otherwise noted, all of the information for this competency statement is taken from NFPA 70E, Chapter 3.

a. Describe and explain DC systems grounding and ground-fault detection.

See KSA 34b for discussion of grounding and ground-fault detection.

b. Describe and explain ventilation requirements for different battery types.

Ventilation systems, forced or natural, shall be maintained to prevent the buildup of explosive mixtures. This maintenance shall include a functional test of any associated detection and alarm systems.

Vented-Type Batteries

Batteries shall be located in rooms or enclosures with outside vents or in well-ventilated rooms, so arranged to prevent the escape of fumes, gases, or electrolyte spray into other areas. Ventilation shall be provided so as to prevent liberated hydrogen gas from exceeding 1 percent concentration. Room ventilation shall be adequate to assure that pockets of trapped hydrogen gas do not occur, particularly at the ceiling, to prevent the accumulation of an explosive mixture. Exhaust air shall not pass over electrical equipment unless the equipment is listed for the use. Inlets shall be no higher than the tops of the battery cells and outlets at the highest level in the room. Where mechanical ventilation is installed, the following shall be required:

- Airflow sensors shall be installed to initiate an alarm if the ventilation fan becomes inoperative.
- Control equipment for the exhaust fan shall be located more than 1,800 mm (6 ft) from the battery and a minimum of 100 mm (4 in.) below the lowest point of the highest ventilation opening.
- Where mechanical ventilation is used in a dedicated battery room, all exhaust air shall be discharged outside the building.
- Fans used to remove air from a battery room shall not be located in the duct unless the fan is listed for the use.

VRLA-Type Batteries

Ventilation shall be provided so as to prevent liberated hydrogen gas from exceeding a 1 percent concentration. Room ventilation shall be adequate to ensure that pockets of trapped hydrogen gas do not occur, particularly at the ceiling, to prevent the accumulation of an explosive mixture. Exhaust air shall not pass over electrical equipment unless the equipment is listed for the use. Inlets shall be no higher than the tops of the battery cells and outlets at the highest level in the room. Where mechanical ventilation is installed, the following shall be required:

- Airflow sensors shall be installed to initiate an alarm if the ventilation fan becomes inoperative.
- Control equipment for the exhaust fan shall be located more than 1,800 mm (6 ft) from the battery and a minimum of 100 mm (4 in.) below the lowest point of the highest ventilation opening.
- Where mechanical ventilation is used in a dedicated battery room, all exhaust air shall be discharged outside the building.
- Fans used to remove air from a battery room shall not be located in the duct unless the fan is listed for the use.

Ventilation shall be provided to maintain design temperature to prevent thermal runaway that can cause cell meltdown leading to a fire or explosion.

Sealed Gelled Electrolyte-Type Batteries

Ventilation shall be provided to maintain design temperature to prevent thermal runaway that can cause cell meltdown leading to a fire or explosion. Where mechanical ventilation is installed, airflow sensors shall be installed to initiate an alarm if the ventilation fan becomes inoperative.

c. Describe and explain battery room restrictions, barriers, illumination, and enclosure requirements.

A battery room is a room specifically intended for the installation of batteries that have no other protective enclosure.

Batteries shall be installed in one of the following:

- Dedicated battery rooms
- An area accessible only to authorized personnel
- An enclosure with lockable doors or a suitable housing that shall be lockable and provide protection against electrical contact and damage to the battery

Battery room lighting shall be installed to provide a minimum level of illumination of 30 lux (30 ft-candles). Emergency illumination shall be provided for safe egress from the battery room. Lighting fixtures shall not be installed directly over cells or exposed live parts.

The battery room shall be accessible only to authorized personnel and shall be locked when unoccupied. The battery room and enclosure doors shall open outward. The doors shall be equipped with quick-release, quick-opening hardware. The battery room shall be located so that access to the batteries is unobstructed. Direct-current switching equipment, rotating machinery other than exhaust fans, and other equipment not directly part of the battery and charging facilities shall be external to the battery room. Alternatively, DC switching equipment shall be separated from the battery by a partition of a height no less than 2 m (6 ft 6 in.) and of sufficient length to prevent accidental contact with live surfaces. Foreign piping shall not pass through the battery room. Passageways shall be of sufficient width to allow the replacement of all battery room equipment. Emergency exits shall be provided as required. Access and entrance to working space about the battery shall be provided as required by NFPA 70E, Article 400.15.

d. Describe and explain battery protection requirements.

Batteries of the unsealed type shall be located in enclosures with outside vents or in well-ventilated rooms and shall be arranged so as to prevent the escape of fumes, gases, or electrolyte spray into other areas. Ventilation shall be provided to ensure diffusion of the gases from the battery and to prevent the accumulation of an explosive mixture. Racks and trays shall be substantial and shall be treated to make them resistant to the electrolyte. Floors shall be of acid-resistant construction unless protected from acid accumulations. Face shields, aprons, and rubber gloves shall be provided for workers handling acids or batteries. Facilities for quick drenching of the eyes and body shall be provided within 25 feet (7.62 m) of battery-handling areas. Facilities shall be provided for flushing and neutralizing spilled electrolyte and for fire protection.

VI. ELECTRICAL VITAL SAFETY SYSTEMS (VSS)*

This section is optional and should be used by the program and/or field offices to assist them with specific technical qualifications for that office.

*** This section also applies to safety significant, SC, and defense-in-depth structures, systems, and components.**

36. <u>Mandatory Performance Activity</u>: Electrical personnel shall demonstrate a familiarity level of knowledge of 10 CFR 830, Nuclear Safety Management, and DOE O 414.1C as related to electrical safety programs, processes, and systems, to include:

- **Knowledge of site VSS interfaces for electrical, software, and instrument and control systems (complete competency 38);**
- **The basic purpose of the Unreviewed Safety Question (USQ) process;**
- **General purpose and constitution of the DSA;**
- **Purpose and content of Technical Safety Requirements (TSR) documentation.**
- **Review and evaluate a USQ determination, including walking down the proposed change/potential inadequacy with the cognizant contractor electrical VSS system engineer or DOE Facility Representative (FR).**
- **Review and evaluate an authorization agreement, and then discuss TSRs (and/or other controls) with the cognizant contractor electrical VSS system engineer.**
- **Review and evaluate a Safety Evaluation Report (SER) and discuss with the cognizant contractor electrical VSS system engineer.**
- **Walkdown a facility with Safety System Oversight (SSO) person, safety analyst, or cognizant contractor electrical VSS engineer and identify the safety controls contained in a TSR.**
- **Complete a review of a hazard analysis or accident analysis, including walking down the scope of work area or accident scenario with the cognizant contractor electrical VSS system engineer or DOE FR.**

a. Discuss the reasons for performing a USQ determination.

The information for KSAs ‘a’ through ‘e’ is taken from 10 CFR 830.

The USQ process is the mechanism for keeping a safety basis current by reviewing potential USQs, reporting USQs to DOE, and obtaining approval from DOE prior to taking any action that involves a USQ.

Reasons for performing a USQ would be due to the following:

- Changes to a facility
- Changes to procedures
- New tests or experiments
- Discovery of an inadequate safety analysis

b. Describe the situations for which a safety evaluation is required to be performed.

DOE will prepare a SER to document the results of its review of a DSA. A DSA must contain any conditions or changes required by DOE.

A SER is the report prepared by DOE to document

- the sufficiency of the DSA for a hazard category 1, 2, or 3 DOE nuclear facility;
- the extent to which a contractor has satisfied the requirements of subpart B of 10 CFR 830; and
- the basis for approval by DOE of the safety basis for the facility, including any conditions for approval.

c. Define the conditions for a USQ.

Need for a USQ means that
- a situation exists where the probability of an occurrence or the consequences of an accident or the malfunction of equipment important to safety previously evaluated in the DSA could be increased;
- the possibility of an accident or malfunction of a different type than any evaluated previously in the DSA could be created;
- a margin of safety could be reduced; or
- the DSA may not be bounding or may be otherwise inadequate.

d. Describe the responsibilities of contractors authorized to operate defense nuclear facilities regarding the performance of safety evaluations.

The contractor responsible for a hazard category 1, 2, or 3 DOE new nuclear facility must submit for DOE approval a procedure for its USQ process on a schedule that allows DOE approval in a SER issued pursuant to section 207(d) of 10 CFR 830.

If a contractor responsible for a hazard category 1, 2, or 3 DOE nuclear facility discovers or is made aware of a potential inadequacy of the DSA, the contractor must
- take action, as appropriate, to place or maintain the facility in a safe condition until an evaluation of the safety of the situation is completed;
- notify DOE of the situation;
- perform a USQ determination and notify DOE promptly of the results; and
- submit the evaluation of the safety of the situation to DOE prior to removing any operational restrictions initiated to meet paragraph (g)(1) of 10 CFR 830.203.

e. Describe the actions to be taken by a contractor upon identifying information that indicates a potential inadequacy of a previous safety analyses or a possible reduction in the margin of safety, as defined in the TSRs.

A contractor may take emergency actions that depart from an approved TSR when no actions consistent with the TSR are immediately apparent, and when these actions are needed to protect workers, the public, or the environment from imminent and significant harm. Such actions must be approved by a certified operator for a reactor or by a person in authority as designated in the TSRs for nonreactor nuclear facilities. The contractor must report the emergency actions to DOE as soon as practicable.

A contractor for an environmental restoration activity may follow the provisions of 29 CFR 1910.120 or 1926.65 to develop the appropriate hazard controls (rather than the provisions for TSRs in paragraph (a) of 10 CFR 830), provided the activity involves either
- work not done within a permanent structure, or

- the decommissioning of a facility with only low-level, residual, fixed radioactivity.

f. Discuss the purpose of the TSRs.

The following is taken from DOE O 414.1C .

TSRs contain the limits, controls, and related actions that establish the specific parameters and requisite actions for the safe operation of a nuclear facility and include, as appropriate for the work and the hazards identified in the DSA for the facility, safety limits, operating limits, surveillance requirements, administrative and management controls, use and application provisions, and design features, as well as a bases appendix.

g. Describe the responsibilities of contractors authorized to operate defense nuclear facilities regarding the TSRs.

The information for KSAs ‘g’ through ‘n’ is taken from 10 CFR 830.

A contractor responsible for a hazard category 1, 2, or 3 DOE nuclear facility must

- develop TSRs that are derived from the DSA;
- prior to use, obtain DOE approval of TSRs and any change to TSRs;
- notify DOE of any violation of a TSR;
- operate facilities and equipment in accordance with the TSR controls and safety basis.

h. Define the following terms and discuss the purpose of each:
- **Safety limit**
- **Limiting control settings**
- **Limiting conditions for operation**
- **Surveillance requirements**

Safety Limit

Safety limits are the limits on process variables associated with those SC physical barriers, generally passive, that are necessary for the intended facility function and that are required to guard against the uncontrolled release of radioactive materials.

Limiting Control Settings

Limiting control settings are the settings on safety systems that control process variables to prevent exceeding a safety limit.

Limiting Conditions for Operation

Limiting conditions for operation are the limits that represent the lowest functional capability or performance level of safety SSCs required for safe operations.

Surveillance Requirements

Surveillance requirements are requirements relating to test, calibration, or inspection to ensure that the necessary operability and quality of safety SSCs and their support systems required for safe operations are maintained, that facility operation is within safety limits, and that limiting control settings and limiting conditions for operation are met.

i. Describe the general content of each of the following sections of the TSRs:

- **Use and Application**
- **Safety Limits**
- **Operating Limits**
- **Surveillance Requirements**
- **Administrative Controls**
- **Basis**
- **Design Features**

Use and Application

Use and application provisions are the basic instructions for applying TSRs.

Safety Limits

Safety limits are the limits on process variables associated with those SC physical barriers, generally passive, that are necessary for the intended facility function and that are required to guard against the uncontrolled release of radioactive materials.

Operating Limits

Operating limits are those limits required to ensure the safe operation of a nuclear facility, including limiting control settings and limiting conditions for operation.

Surveillance Requirements

Surveillance requirements are requirements relating to test, calibration, or inspection to ensure that the necessary operability and quality of safety SSCs and their support systems required for safe operations are maintained, that facility operation is within safety limits, and that limiting control settings and limiting conditions for operation are met.

Administrative Controls

Administrative controls are the provisions relating to organization and management, procedures, recordkeeping, assessment, and reporting necessary to ensure safe operation of a facility.

Basis

The basis of the limits and other requirements in TSRs are described in a bases appendix.

Design Features

The design features of a nuclear facility specified in the TSRs that, if altered or modified, would have a significant effect on safe operation.

j. Discuss the basic purposes and objectives of a DSA.

A DSA is a documented analysis of the extent to which a nuclear facility can be operated safely with respect to workers, the public, and the environment, including a description of the conditions, safe boundaries, and hazard controls that provide the basis for ensuring safety.

k. Describe the responsibilities of contractors authorized to operate DOE nuclear facilities regarding the development and maintenance of a DSA.

The contractor responsible for a hazard category 1, 2, or 3 DOE nuclear facility must obtain approval from DOE for the methodology used to prepare the DSA for the facility unless the contractor uses a methodology set forth in table 2 of appendix A to subpart B, 10 CFR 830 (reproduced in table 6).

Table 6. Safe harbor methodologies

The contractor responsible for * * *	May prepare its documented safety analyses by * * *
(1) A DOE reactor...	Using the method in U.S. Nuclear Regulatory Commission Regulatory Guide 1.70, Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants, or successor document.
(2) A DOE nonreactor nuclear facility…………………….	Using the method in DOE-STD- 3009, Change Notice No. 1, January 2000, Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports, July 1994, or successor document.
(3) A DOE nuclear facility with a limited operational life….	Using the method in either: (1) DOE-STD-3009-, Change Notice No. 1, January 2000, or successor document, or (2) DOE-STD-3011-94, Guidance for Preparation of DOE 5480.22 (TSR) and DOE 5480.23 (SAR) Implementation Plans, November 1994, or successor document.
(4) The deactivation or the transition surveillance and maintenance of a DOE nuclear facility.	Using the method in either: (1) DOE-STD-3009, Change Notice No. 1, January 2000, or successor document, or (2) DOE-STD-3011-94 or successor document.
(5) The decommissioning of a DOE nuclear facility…….	(1) Using the method in DOE-STD- 1120-98, Integration of Environment, Safety, and Health into Facility Disposition Activities, May 1998, or successor document; (2) Using the provisions in 29 CFR 1910.120 (or 29 CFR 1926.65 for construction activities) for developing Safety and Health Programs, Work Plans, Health and Safety Plans, and Emergency Response Plans to address public safety, as well as worker safety; and (3) Deriving hazard controls based on the Safety and Health Programs, the Work Plans, the Health and Safety Plans, and the Emergency Response Plans.
(6) A DOE environmental restoration activity that involves either work not done within a permanent structure or the decommissioning of a facility with only low-level residual fixed radioactivity.	(1) Using the method in DOE-STD-1120-98 or successor document, and (2) Using the provisions in 29 CFR 1910.120 (or 29 CFR 1926.65 for construction activities) for developing a Safety and Health Program and a site-specific Health and Safety Plan (including elements for Emergency Response Plans, conduct of operations, training and qualifications, and maintenance management).
(7) A DOE nuclear explosive facility and the nuclear explosive operations conducted therein.	Developing its documented safety analysis in two pieces: (1) A Safety Analysis Report for the nuclear facility that considers the generic nuclear explosive operations and is prepared in accordance with DOE-STD-3009, Change Notice No. 1, January 2000, or successor document, and (2) A Hazard Analysis Report for the specific nuclear explosive operations prepared in accordance with DOE-STD- 3016-99, Hazards Analysis Reports for Nuclear Explosive Operations, February 1999, or successor document.
(8) A DOE hazard category 3 nonreactor nuclear facility....	Using the methods in Chapters 2, 3, 4, and 5 of DOE-STD- 3009, Change Notice No. 1, January 2000, or successor document to address in a simplified fashion: (1) The basic description of the facility/activity and its operations, including safety structures, systems, and components; (2) A qualitative hazards analysis; and (3) The hazard controls (consisting primarily of inventory limits and safety management programs) and their bases.
(9) Transportation activities..	(1) Preparing a Safety Analysis Report for Packaging in accordance with DOE-O-460.1A, Packaging and Transportation Safety, October 2, 1996, or successor document and (2) Preparing a Transportation Safety Document in accordance with DOE-G-460.1-1, Implementation Guide for Use with DOE O 460.1A, Packaging and Transportation Safety, June 5, 1997, or successor document.
(10) Transportation and onsite transfer of nuclear	(1) Preparing a Safety Analysis Report for Packaging in accordance with DOE-

The contractor responsible for * * *	May prepare its documented safety analyses by * * *
explosives, nuclear components, Naval nuclear fuel elements, Category I and Category II special nuclear materials, special assemblies, and other materials of national security.	O-461.1, Packaging and Transportation of Materials of National Security Interest, September 29, 2000, or successor document and (2) Preparing a Transportation Safety Document in accordance with DOE-M-461.1-1, Packaging and Transfer of Materials of National Security Interest Manual, September 29, 2000, or successor document.

Source: 10 CFR 830, subpart B, appendix A

l. Define the following terms and discuss the purpose of each:

- **Safety basis**
- **Design features**
- **Safety evaluation report**

Safety Basis

Safety basis means the DSA and hazard controls that provide reasonable assurance that a DOE nuclear facility can be operated safely in a manner that adequately protects workers, the public, and the environment.

Design Features

Design features means the design features of a nuclear facility specified in the TSRs that, if altered or modified, would have a significant effect on safe operation.

Safety Evaluation Report

Safety evaluation report is the report prepared by DOE to document

- the sufficiency of the DSA for a hazard category 1, 2, or 3 DOE nuclear facility;
- the extent to which a contractor has satisfied the requirements of subpart B of 10 CFR 830; and
- the basis for approval by DOE of the safety basis for the facility, including any conditions for approval.

m. Describe the requirements for the scope and content of a DSA and discuss the general content of each of the required sections of a DSA.

The DSA for a hazard category 1, 2, or 3 DOE nuclear facility must, as appropriate for the complexities and hazards associated with the facility,

- describe the facility (including the design of safety SSCs) and the work to be performed;
- provide a systematic identification of both natural and man-made hazards associated with the facility;
- evaluate normal, abnormal, and accident conditions, including consideration of natural and man-made external events, identification of energy sources or processes that might contribute to the generation or uncontrolled release of radioactive and other hazardous materials, and consideration of the need for analysis of accidents which may be beyond the design basis of the facility;
- derive the hazard controls necessary to ensure adequate protection of workers, the public, and the environment; demonstrate the adequacy of these controls to eliminate,

limit, or mitigate identified hazards; and define the process for maintaining the hazard controls current at all times and controlling their use;

- define the characteristics of the safety management programs necessary to ensure the safe operation of the facility, including (where applicable) QA, procedures, maintenance, personnel training, conduct of operations, emergency preparedness, fire protection, waste management, and radiation protection; and
- with respect to a nonreactor nuclear facility with fissionable material in a form and amount sufficient to pose a potential for criticality, define a criticality safety program that:
  - ensures that operations with fissionable material remain sub-critical under all normal and credible abnormal conditions,
  - identifies applicable nuclear criticality safety standards, and
  - describes how the program meets applicable nuclear criticality safety standards.

n. Discuss the uses that contractor management makes of a DSA.

The results of a DSA lead to a solid safety basis, meaning that the DSA and hazard controls provide reasonable assurance that a DOE nuclear facility can be operated safely in a manner that adequately protects workers, the public, and the environment.

37. Electrical personnel shall demonstrate a familiarity level knowledge of all assigned electrical power VSS and how they are addressed during the design, construction, and operation of nuclear facilities

Elements ‘a’ and ‘b’ are performance-based KSAs. The Qualifying Official will evaluate their completion.

a. <u>Mandatory Performance Activity</u>: Walkdown electrical power VSSs with the cognizant contractor electrical VSS system engineer or DOE FR. Locate and identify major components, subsystems, and interfaces.

b. Identify all assigned electrical power VSS (site-specific), and discuss the functional classifications, safety functions, and functional requirements of these systems.

c. Discuss electrical power distribution with the regard to the following elements (IEEE Red Book; reference IEEE Std-141 or another source can be used as a guide in developing the discussion):

- **Basic design considerations and electrical distribution design**
- **Voltage considerations**
- **Surge voltage protection techniques**
- **System protective devices**
- **Power factor and its effects in electrical distribution systems**
- **Power switching, transformation, and motor-control apparatus**
- **Cable system basics**
- **Busway design**

The following is taken from IEEE Std 141-1993.

Basic Design Considerations

Safety of life and preservation of property are two of the most important factors to be considered in the design of the electric system. Codes must be followed and recommended practices or standards should be followed in the selection and application of material and equipment. Equally important is providing equipment that is properly and adequately sized and rated to handle available fault levels in the system in accordance with established fault duty calculation procedures. Adequate safety features should be incorporated into all parts of the system. Listed below are the electric system operating and design limits that should be considered in order to provide safe working conditions for personnel:

- Interrupting devices must be able to function safely and properly under the most severe duty to which they may be exposed.
- Protection must be provided against accidental contact with energized conductors, such as enclosing the conductors, installing protective barriers, or installing the conductors at sufficient height to avoid accidental contact.
- Isolating switches must not be operated while they are carrying current, unless they are designed to interrupt such current. They should be equipped with safety interlocks and warning signs if load or transformer magnetizing current-load-interrupting and fault-closing capability are not provided.
- In many instances it is desirable to isolate a power circuit breaker using disconnect switches. In such cases, the circuit breaker must be opened before the disconnect switches. Safety interlocks to ensure this sequence should be used, together with detailed and specific personnel operating instructions.
- The system should be designed so that maintenance work on circuits and equipment can be accomplished with the particular circuits and equipment de-energized and grounded. System design should provide for locking out circuits or equipment for maintenance, including grounding instructions. A written procedure should be established to provide instructions on tagging or locking out circuits during maintenance, and re-energizing after completion of the maintenance work following disconnection of the grounding equipment.
- Electric equipment rooms, especially those containing apparatus over 600 V, such as transformers, motor controls, or motors, should be equipped and located to eliminate or minimize the need for access by non-electrical maintenance or operating personnel. Conveniently located exits should be provided to allow quick exit during an emergency.
- Electric apparatus located outside special rooms should be provided with protection against mechanical damage due to equipment location, personnel access, and vehicular traffic. The area should be accessible to maintenance and operating personnel for emergency operation of protective devices.
- Equipment location should be carefully considered. A non-hazardous area should be set aside for electrical equipment, or it may be necessary to locate explosion-proof equipment in the hazardous area. The advantages and disadvantages of not only initial cost but the maintenance cost and the ability to maintain the integrity of the equipment should all be carefully considered.
- Warning signs should be installed on electric equipment accessible to unqualified personnel, on fences surrounding electric equipment, on doors giving access to electrical rooms, and on conduits or cables above 600 V in areas that include other

equipment or pipelines. An electrical single-line diagram should be installed in each electrical switching room.

- An adequate grounding system must be installed.
- Emergency lights should be provided where necessary to protect personnel against sudden lighting failure. In facilities, the Life Safety Codes requires that escape routes and exits have emergency lighting. In addition, process control locations and electric switching centers should be equipped with standby lighting.
- Operating and maintenance personnel should be provided with complete operating and maintenance instructions, including wiring diagrams, equipment ratings, and protective device settings. Spare fuses of the correct ratings should be stocked.

Electrical Distribution Design

The distribution system should include provisions for predictive and PM requirements in the initial design. Accessibility and availability for inspection and repair with safety are important considerations in selecting equipment. Space should be provided for inspection, adjustment, and repair in clean, well-lighted, and temperature-controlled areas.

Investigate the various types of plant distribution systems and select the system or systems best suited to the requirements of the plant. A variety of basic circuit arrangements is available for industrial plant power distribution. Selection of the best system or combination of systems will depend upon the needs of the manufacturing process. In general, system costs increase with system reliability if component quality is equal. Maximum reliability per unit investment can be achieved by using properly applied and well-designed components.

The first step is the analysis of the manufacturing process to determine its reliability need and potential losses and costs in the event of power interruption. Some plant processes are minimally affected by interruption. Here a simple radial system may be satisfactory. Other plant processes may sustain long-term damage or experience excessive cost by even a brief interruption; therefore, a more complex system with an alternate power source for critical loads may be justified.

Primary Distribution Systems

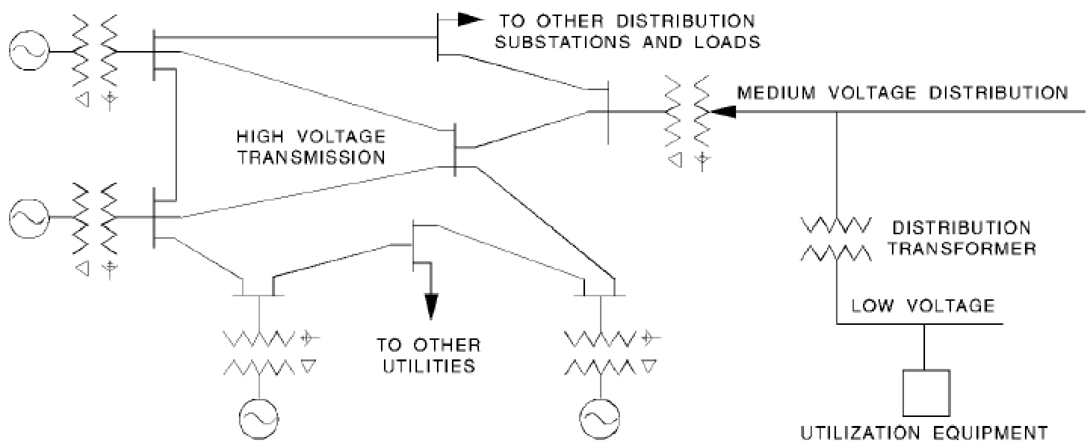
- Include primary switching, fusing, other protective devices, transformer connections, ratings, system grounding, nominal loading (kilovolt-amperes and amperes), and low-voltage protective-device arrangement for unit substation and load centers. Indicate each protective device’s continuous-current rating, symmetrical interrupting current and asymmetrical momentary or closing-and-latching current rating, manufacturer, type, and model identification. Indicate tap settings on all primary transformers.
- Indicate bus ratings in amperes.
- Identify major load centers and indicate general electrical configuration.
- Identify nominal loads in kilovolt-amperes and amperes on unit substations, transformers, and load centers.
- Identify and show all major MV loads and motors, including associated transformers and all other major, significant, and identifiable loads, such as motor loads on MCCs, large press and other motor or drive loads, dedicated lighting loads, arc furnaces, induction furnaces, special purpose loads, such as data processing and computer

applications, welding loads, powerhouse loads, including waste treatment, air compressor loads, etc.

Voltage Considerations

An understanding of system voltage nomenclature and the preferred voltage ratings of distribution apparatus and utilization equipment is essential to ensure proper voltage identification throughout a power distribution system. The dynamic characteristics of the system need to be recognized and the proper principles of voltage control applied so that satisfactory voltages will be supplied to all utilization equipment under all normal conditions of operation. Consideration should be given for transient and momentary voltage variations to ensure appropriate performance of utilization equipment.

A general understanding of the principles of power transmission and distribution in utility systems is necessary since most industrial plants obtain most of their electric power from the local electric utility. Figure 45 shows a simplified, one-line diagram of a typical utility power generation, transmission, and distribution system.



Source: IEEE Std 141-1993

Figure 45. Typical utility generation, transmission, and distribution system

Voltage Classes

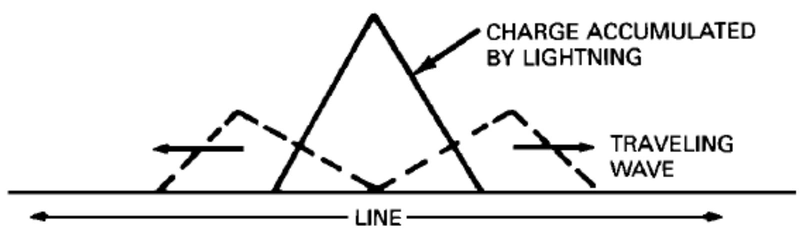
- High-voltage-class voltages are used to transmit large amounts of electric power between transmission substations. Transmission substations located adjacent to generating stations step the generator voltage up to the transmission voltage. Other transmission substations transform the high voltage down to MV for subtransmission and primary distribution. Transmission lines also interconnect transmission substations to provide alternate paths for power transmission for higher reliability.
- Medium-voltage-class voltages are used for subtransmission and primary distribution. Medium voltages often supply distribution transformers that step the MV down to low voltage to supply utilization equipment. Medium voltages may also supply distribution substations that transform the voltage from a higher to a lower voltage in the MV class. Medium voltages of 13,800 V and below are also used to supply utilization equipment such as large motors.

- Low-voltage-class voltages are used to supply utilization equipment.

Surge Voltage Protection Techniques

Transient overvoltages are due to natural and inherent characteristics of power systems. Overvoltages may be generated by lightning or by a sudden change of system conditions (such as switching operations, faults, load rejection, etc.), or both. Broadly, the overvoltage types are normally classified as lightning-generated and all others as switching-generated. The magnitude of these overvoltages can be above maximum permissible levels and therefore need to be reduced and protected against if damage to equipment and possible undesirable system performance are to be avoided.

A direct lightning stroke current surge will have the form of a steep front wave that will travel away from the stricken point in both directions along the power system conductors (figure 46). As the surge travels along the conductors, losses cause the magnitude of the voltage surge to constantly diminish. If the voltage magnitude is sufficient to produce corona, the decay of the voltage surge will be fairly rapid until below the corona starting voltage. Beyond this point the decay will be more deliberate. Properly rated surge arresters at the plant terminal of the incoming lines will generally reduce the overvoltage to a level the terminal station apparatus can withstand.



Source: IEEE Std 141-1993

Figure 46. Two traveling bodies of charge result when a quantity of charge is deposited on conducting line by lightning

In instances where the local industrial plant system is without lightning exposure, except from the exposed high-voltage lines through step-down transformers effectively protected with high-side surge arresters, lightning surges are likely to be quite moderate. Likewise, surges due to switching phenomena, although more common, are generally not as severe.

Only occasionally would line-to-ground potentials on the local system reach arrester-protective levels. The large number of radiating cable circuits with their array of connected apparatus acts to greatly curb the slope and magnitude of the voltage surge that reaches any particular item of connected apparatus. However, transformers and other equipment items connected as a single load at the end of circuits are particularly vulnerable. Experience has indicated that certain types of apparatus are susceptible to voltage surges for almost any circuit connection arrangement, and it is advisable to fully investigate the possibility of damaging voltage surges.

The occurrence of abnormal applied voltage stresses, transient, short-time, or sustained steady-state, contributes to premature insulation failure. Electrical organic insulation deterioration to the point of failure results from an aggregate accumulation of insulation damage that finally reaches the critical stage, in which a conducting path is rapidly driven through the insulation sheath and failure (short circuit) takes place. Large amounts of current may then be driven through the faulted channel, producing large amounts of heat. An excessive increase in temperature results, which rapidly expands the zone of insulation damage, and complete destruction occurs rather quickly unless the supply of electric current is interrupted. Some insulation punctures that might be discovered after special nondestructive testing of apparatus will require repair or replacement.

The optimum method of avoiding insulation failure is having balanced, or coordinated, protection. An acceptable system of insulation protection will be influenced by a number of factors. Of prime importance is a knowledge of the insulation system withstand capability and endurance qualities. These properties are indicated by insulation-type designations and specified high-potential and surge-voltage test withstand capabilities. Another facet of the problem relates to the identification of likely sources of overvoltage exposure and the character, magnitude, duration, and repetition rate that are likely to be impressed on the apparatus and circuits.

The appropriate application of surge-protective devices will lessen the magnitude and duration of surges as seen by the protected equipment, and is the most effective tool for achieving the desired insulation security. A working understanding of the behavior pattern of electric surge voltage propagation along electrical conductors is necessary to achieve the optimum solution. The problem is complicated by the fact that insulation failure results not only because of impressed overvoltages, but also because of the aggregate sum total duration of such overvoltages. No simple devices are available that can correctly integrate the cumulative effects of sequentially applied excessive overvoltage. The time factor must be estimated and then factored into the design and application of the protection system.

As stated, lightning is a major source of transient overvoltage. Some industrial operations use open-wire overhead lines that are subject to direct exposure to lightning, allowing lightning surges to be propagated into the industrial distribution system. However, many industrial complexes have cable entrances with surge-arrester protection installed at the overhead-to-underground junction. Although the surge arresters protect the cable entrance, they will not necessarily protect the substation equipment from incoming surges; additional arresters may have to be installed at the cable open-end point or last transformer.

System Protective Devices

Power system protective devices provide the intelligence and initiate the action that enables circuit switching equipment to respond to abnormal or dangerous system conditions. Normally, relays control power circuit breakers rated above 600 V and current-responsive, self-contained elements operate multiple-pole, low-voltage circuit breakers to isolate circuits experiencing overcurrents on any phase. Similarly, fuses function alone or in combination with other suitable means to properly provide isolation of faulted or overloaded circuits. In other cases, special types of relays that respond to abnormal electric system conditions may cause circuit breakers or other switching devices to disconnect defective equipment from the remainder of the system.

Power Factor and its Effects in Electrical Distribution Systems

Maintaining a high power factor in a plant can yield direct savings. Some, such as reduced power bills and release of system capacity, are quite obvious; others, such as improved voltage and decreased I^2R losses, are less obvious but nonetheless real, as are many indirect savings as a result of more efficient performance.

The cost of improving the power factor in existing plants and of maintaining proper levels as load is added depends on the power-factor value selected and the equipment chosen to supply the compensating reactive power.

Adding capacitors generally is the most economical way to improve the plant power factor, especially in existing plants. There are cases in which synchronous motors may prove most economical or beneficial.

Capacitors have several beneficial features, including relatively low cost, ease of installation, minimal maintenance requirements, very low losses, plus the fact that they are manufactured in a variety of sizes. Individual units also can be combined into suitable banks to obtain a large range of ratings. Thus, capacitors can be added in small or large units to meet existing operating requirements with additional units added only when necessary to meet increased future requirements. Caution must be exercised in applying capacitors, however, as they are sensitive to overvoltage and may severely impact systems that have nonlinear loads requiring harmonic currents and/or equipment sensitive to switching transients.

Power Switching, Transformation, and Motor-Control Apparatus

Switching apparatus can be defined as a device for opening and closing, or for changing the connections of a circuit. The general classification of switching apparatus as defined in IEEE Std 141-1993, chapter 10, includes switches, fuses, circuit breakers, and service protectors. The types of switches normally used for power circuits include the following: isolating; load interrupter; safety switches for 600 V and lower power applications, including bolted-pressure switches and high-pressure contact switches and power protectors; transfer switches for load transfer, including emergency and standby switching.

Transformers have many classifications that are useful in industry to distinguish or define certain characteristics of design and application. There are two classifications based on the rating of transformers measured in kilovolt-amperes: the distribution type covers the range of 3 to 500 kVA; the power type covers all ratings above 500 kVA.

The majority of motors utilized by industrial firms are integral HP induction motors of squirrel-cage design supplied from distribution systems of three-phase 600 V AC and below.

The choice of an integral HP controller depends on a number of factors:

- Power System. Does it use DC or AC; is it single-phase or three-phase? What is the voltage and frequency? Will the system permit large inrush currents during full-voltage starting without excessive voltage drop?

- Motor. Is the controller to be used with DC, squirrel-cage induction, wound-rotor induction, synchronous motor, or adjustable frequency drives? What is the HP? Will the motor be jogged or reversed frequently? What is the acceleration time from start to full speed? Will the motor design specify reduced current inrush?
- Load. Is the load geared, belt-driven, or direct-coupled? Loaded or unloaded start?
- Operation. Is operation to be manual or automatic?
- Protection. Are fuses or circuit protectors to be used for short-circuit protection? To size the elements of motor overload relays, the full-load current of the motor, the ambient temperature at the motor, controller, and the service factor of the motor should be known.
- Environment. Will the motor and controller be subjected to excessive vibration, dirt, dust, oil, or water? Will either be located in a hazardous or corrosive area?
- Cable Connections and Space. Will there be the required space for cable entrance, bending radius, terminations, and for reliable connections to line and load buses? Will capacitors be installed at the motor terminal box for power factor correction? Will surge-protective equipment, surge arresters, and capacitors, be installed at the motor terminal box? Will CTs for motor differential protection be installed at the motor terminal box?

Cable System Basics

The primary function of cable is to carry energy reliably between source and utilization equipment. In carrying this energy, there are heat losses generated in the cable that must be dissipated. The ability to dissipate these losses depends on how the cables are installed, and this affects their ratings.

Cables may be installed in raceway, in cable trays, underground in duct or direct buried, in cable bus, as open runs of cable, or may be messenger supported.

The selection of conductor size requires consideration of the load current to be carried and the loading cycle, emergency overloading requirements and duration, fault clearing time and interrupting capacity of the cable overcurrent protection or source capacity, voltage drop, and ambient temperatures for the particular installation conditions. Caution must be exercised when locating conductors in high ambient heat areas so that the operating temperature will not exceed that designated for the type of insulated conductor involved.

Insulations can be classified in broad categories as solid insulations, taped insulations, and special purpose insulations. Cables incorporating these insulations cover a range of maximum and normal operating temperatures and exhibit varying degrees of flexibility, fire resistance, and mechanical and environmental protection. The installation of cables requires care in order to avoid excessive pulling tensions that could stretch the conductor or insulation shield, or rupture the cable jacket when pulled around bends. The minimum bending radius of the cable or conductors should not be exceeded during pulling around bends, at splices, and particularly at terminations to avoid damage to the conductors. The engineer should also check each run to ensure that the conductor jamming ratio is correct and the maximum allowable sidewall pressure is not exceeded.

Provisions should be made for the proper terminating, splicing, and grounding of cables.

Minimum clearances must be maintained between phases and between phase and ground for the various voltage levels. The terminating compartments should be designed and constructed to prevent condensation from forming. Condensation or contamination on MV terminations could result in tracking over the terminal surface with possible flashover. Many users test cables after installation and periodically test important circuits. Test voltages are usually DC of a level recommended by the cable manufacturer for the specific cable. Usually this test level is well below the DC strength of the cable, but it is possible for accidental flashovers to weaken or rupture the cable insulation due to the higher transient overvoltages that can occur from reflections of the voltage wave.

The application and sizing of all cables rated up to 35 kV is governed by the NEC. Cable use may also be covered under state and local regulations recognized by the local electrical inspection AHJ in a particular area.

Busway Design

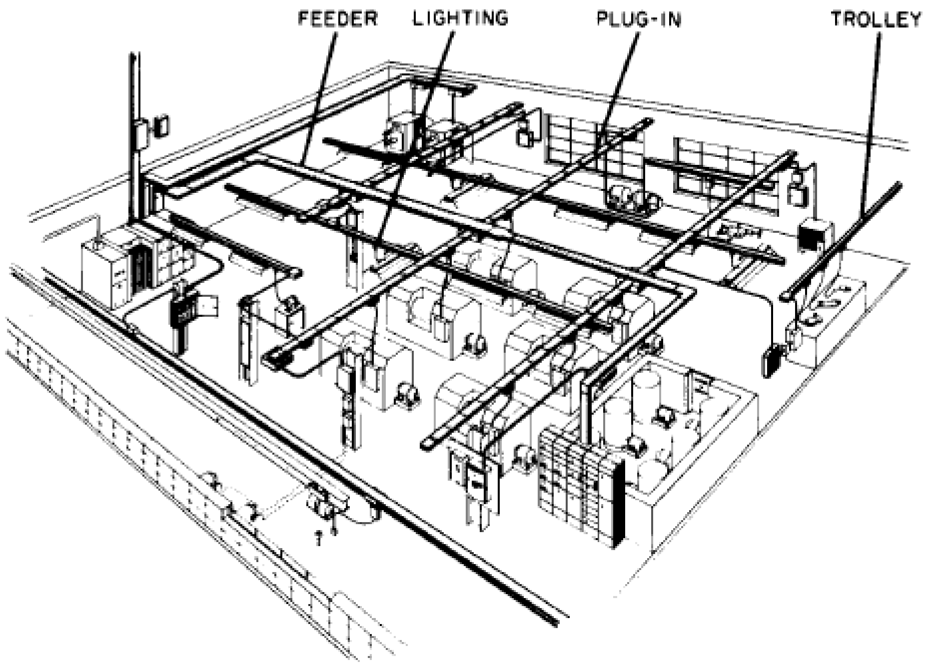
Busways are an integral part of the low-voltage distribution system for industrial plants at 600 V and below. Busways are particularly advantageous when numerous current taps are required. Plug-in devices with circuit breakers or fusible switches may be installed and wired without de-energizing the busway if so labeled by the manufacturer. Power circuits over 600 A are usually more economical and require less space with busways than with conduit and wire. Busways may be dismantled and reinstalled in whole or in part to accommodate changes in the electrical distribution system layout.

Busway conductors and current-carrying parts can be either copper or aluminum or copper alloy rated for the purpose. Compared to copper, electrical grade aluminum has lower conductivity (the minimum for aluminum is 55%; for copper, 97%) and less mechanical strength. Generally, for equal current-carrying ability, aluminum is lighter weight and less costly. To prevent oxides or insulating film on the surfaces, all contact locations on current-carrying parts are plated with tin or silver (the exception being copper conductors in lighting busways and trolley busways). Power and distribution busways use Belleville springs (concave washers) and bolting practices at the joints to maintain mechanical integrity.

Busway is usually manufactured in 10 ft sections. Since the busway must conform to the building structure, all possible combinations of elbows, tees, and crosses are available. Feed and tap fittings to other electric equipment, such as switchboards, transformers, motor-control centers, etc., are available. Plugs for plug-in busway use fusible switches and/or molded-case circuit breakers to protect the feeder or branch circuit. Neutral conductors may be supplied, if required.

Four types of busways are available, complete with fittings and accessories, providing a unified and continuous system of enclosed conductors (figure 47):

1. Feeder busway for low-impedance and minimum voltage drop for distribution of power as needed
2. Plug-in busway for easy connection or rearrangement of loads
3. Lighting busway to provide electric power and mechanical support for lighting or small loads
4. Trolley busway for mobile power tapoffs to electric hoists, cranes, portable tools, etc.



Source: IEEE Std 141-1993

Figure 47. Versatility of busways, showing use of feeders, plug-in, lighting, and trolley lights

d. Discuss protection and coordination with regard to the following elements (IEEE Buff Book; reference IEEE Std-242 or another source can be used as a guide in developing the discussion):

- **Fault calculations**
- **Short-circuit current calculations for single and three-phase circuits**
- **Instrument transformer basics**
- **Protective relay selection and application**
- **Fuse selection and application**
- **Low-voltage circuit breaker fundamentals (IEEE Blue Book; reference IEEE Std-1015)**
- **Ground-fault protection fundamentals**
- **Conductor, motor, transformer, generator, and bus and switchgear protection**
- **Maintenance, testing, and calibration of electrical systems**

All of the following is taken from IEEE Std-242, except for Low-voltage circuit breaker fundamentals, which is taken from IEEE Std-1015.

Fault Calculations

The process of calculating protective device fault levels requires a series of steps. Today, most analysts choose to perform these calculations using computers, and the procedure outlined in the bulleted list below assumes that computers are used. However, the basic principles apply to manual calculations, although the analyst in that instance should be more careful to decide up front precisely what information is needed in order to minimize the amount of tedious work to be done.

- State the problem to be solved. The nature of the problem determines the type of calculation to be done and, in turn, dictates what specific data are required. In the present context, the calculation is of fault currents for protective devices. However, unlike fault calculations for breaker applications, protective device calculations generally are not done for every bus.
- Collect data. This step entails understanding the interconnection of the various components that make up the system, as well as collecting data on each of the components. A one-line diagram is usually an essential tool in correlating system data, and some analysts choose to use the one-line diagram as the principal tool for recording all the data.
- Put aside information that does not apply to the immediate problem. Generally, power factor capacitors, surge arresters, and surge capacitors do not contribute to the distribution of fault current as recognized by protection engineers, so these components may be ignored. More generally, however, some information may affect the magnitude of protective device currents, but not necessarily the currents of interest in the immediate problem; and in the interest of saving time, ignoring these data may be possible. A good example of this type of data is zero-sequence data. Delta-connected transformers establish boundaries for zero-sequence calculations, and, if the problem statement calls for ground-fault data in only one area of the system, entanglement with zero- sequence data in other areas may be avoided.
- Decide on a common base for the per-unit calculations.
- Convert component impedances to per-unit values on the appropriate base quantities. These per-unit values should be arranged in the fashion required by the computer software. For a manual calculation, they should be recorded on a one-line diagram. Computer software usually accepts nominal nameplate parameters and performs this tedious and exacting task.
- Perform the network reduction calculations necessary to arrive at driving-point positive- and zero-sequence impedance values at each point of interest defined by the original statement of the problem. Using these driving-point impedances, the sequence impedance network interconnections should be set up to calculate per-unit magnitudes of sequence currents. Finally, these per-unit values should be converted into ampere values. Again, this tedious, time-consuming calculation is most often done with the computer today.
- Set up the sequence impedance connections needed for the desired currents. Again, many computer programs can do this step automatically, but it is instructive to take raw driving-point impedances and perform this step by hand.
- Record the calculated currents. This step is often overlooked although it is extremely important.

Short-Circuit Current Calculations for Single- and Three-Phase Circuits

Short-circuit currents can create massive destruction to the power system. Short circuits typically have magnitudes many times greater than load currents. The consequences of these high-magnitude currents can be catastrophic to normal operation of the power system. First, the presence of short-circuit currents in system conductors results in additional heating, which the system is usually not designed to sustain continuously. These currents also introduce severe mechanical forces on conductors, which can break insulators, distort transformer windings, or cause other physical damage. The flow of high-magnitude short-circuit currents through system impedances may also result in abnormally low voltages, which in turn lead to otherwise healthy equipment being forced to shut down. Finally, at the point of the short circuit itself, generally the release of energy in the form of an arc, if left uncorrected, can start a fire, which may spread well beyond the point of initiation.

Of all the demands placed upon the power system protection engineer, the most analytical is to determine the magnitude of voltages and currents that the system can produce under various short-circuit conditions. Only when these quantities are understood can the application of protective devices proceed with confidence that they will perform their intended function when short circuits occur.

The most fundamental principle involved in determining the magnitude of short-circuit current is Ohm’s Law: the current that flows in a network of impedances is related to the driving voltage by the relationship

$$I = \frac{V}{Z}$$

Where:
I = short circuit current
V = voltage
Z = impedance

The general procedure for applying this principle entails the three steps involved in Thevenin’s Theorem of circuits.

- Develop a graphical representation of the system, called a one-line (or single-line) diagram, with symbolic voltage sources and circuit impedances.
- Calculate the total impedance from the source of current (i.e., the driving voltage) to the point at which a hypothetical short-circuit current is to be calculated. This value is the Thevenin equivalent impedance, sometimes called the driving point impedance.
- Knowing the open circuit pre-fault voltage, use Ohm’s Law to calculate the short circuit current magnitude.

Of course, the actual application of these basic principles is more involved, and the remainder of IEEE Std-242, chapter 2.6 is devoted to a treatment of the specific details of short-circuit current calculations.

Instrument Transformer Basics

A CT transforms line current into values suitable for standard protective relays and isolates the relays from line voltages. A CT has two windings, designated as primary and secondary, which are insulated from each other. The various types of primary windings are covered in IEEE Std 242-2001, section 3.2.1. The secondary is wound on an iron core. The primary winding is connected in series with the circuit carrying the line current to be measured; and the secondary winding is connected to protective devices, instruments, meters, or control devices. The secondary winding supplies a current in direct proportion and at a fixed relationship to the primary current.

The four common types of CTs are as follows:

- A wound CT has a primary winding consisting of one or more turns mechanically encircling the core or cores. The primary and secondary windings are insulated from each other and from the core(s) and are assembled as an integral structure (figure 48).

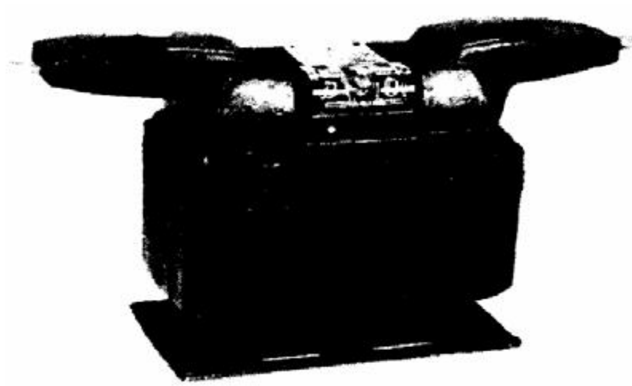


Figure 48. Wound CT

- A bar CT has a fixed, insulated, straight conductor in the form of a bar, rod, or tube that is a single primary turn passing through the magnetic circuit and is assembled to the secondary, core and winding (figure 49).

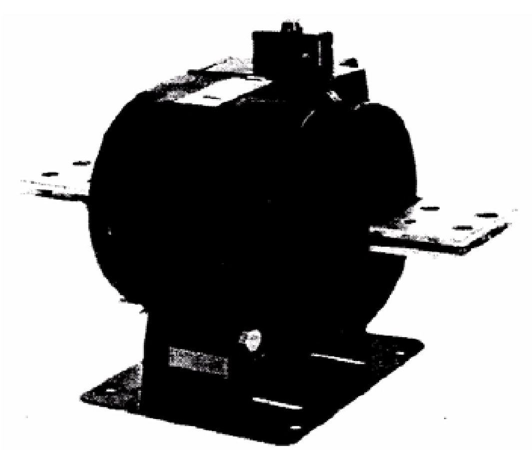


Figure 49. Bar CT

- A window CT has a secondary winding insulated from and permanently assembled on the core, but has no primary winding as an integral part of the structure. Primary insulation is provided in the window through which one or more turns of the line conductor can be passed to provide the primary winding (figure 50).

Source: Figures 48–50, IEEE Std 242-2001

Figure 50. Window CT

- A bushing CT has an annular core and a secondary winding insulated from, and permanently assembled on the core, but has no primary winding or insulation for a primary winding. This type of CT is used with a fully insulated conductor as the primary winding and used typically in equipment where the primary conductor is a component part of other apparatus, for example, on bushings of a transformer or circuit breaker.

  The secondary windings of bushing CTs are usually fully distributed around the core. Typically they are multiratio with each winding tap also being fully distributed.

Protective Relay Selection and Application

Power systems should be designed so that protective relays operate to sense and isolate faults quickly to limit the extent and duration of service interruptions. Protective relays are important in industrial power systems because they can prevent large losses of production due to unnecessary equipment outages or unnecessary equipment damage occurring as a result of a fault or overload. Other considerations are safety, property losses, and replacements.

Protective relays have been called the watchdogs, or silent sentinels, of a power system. Protective relays are classified by the variable they monitor or by the function they perform. For instance, an overcurrent relay senses current and operates when the current exceeds a predetermined value. Another example is a thermal overload relay that senses the temperature of a system component, either directly or indirectly (as a function of current), or both, and operates when the temperature is above a rated value.

The application of relays is often called an art rather than a science because judgment is involved in making selections. The selection of protective relays requires compromises between conflicting objectives, while maintaining the capability of operating properly for several system operating conditions. These compromises include providing

- maximum protection
- minimum equipment cost
- reliable protection
- high-speed operation
- simple designs
- high sensitivity to faults
- insensitivity to normal load currents
- selectivity in isolating a minimum portion of the system

Planning for the protection system should be considered in the power system design stage to ensure that a good system can be implemented. The cost of applying protective relays should be balanced against the potential costs of not providing protection.

Fuse Selection and Application

Fuse selection, application, and classification are dealt with in detail in IEEE Std 242-2001, chapters 5 and 6. A general overview is presented here.

A low-voltage fuse is a device that protects a circuit by opening its current-responsive element when an overcurrent passes through it. A fuse, as defined in the *Authoritative Dictionary of IEEE Standards*, seventh edition, is an overcurrent protective device with a circuit-opening fusible part that is heated and severed by the passage of the overcurrent through it. Note: A fuse comprises all the parts that form a unit capable of performing the prescribed functions. It may or may not be the complete device necessary to connect it into an electric circuit.

A fuse has the following functional characteristics:

- It combines both the sensing and interrupting elements in one self-contained device.
- It is direct acting in that it responds to a combination of magnitude and duration of circuit current flowing through it.
- It normally does not include any provision for manually making and breaking the connection to an energized circuit, but requires separate devices (e.g., a disconnect switch) to perform this function.
- It is a single-phase device. Only the fuse in the phase or phases subjected to overcurrent responds to de-energize the affected phase or phases of the circuit or equipment that is faulty.
- After having interrupted an overcurrent, it is renewed by the replacement of its current-responsive element before restoration of service.

ANSI standards and IEEE standards define high-voltage fuses as fuses rated above 1,000 V. High-voltage fuses are available in voltages through 169 kV maximum rating. ANSI C84.1-2006, *American National Standard for Electric Power Systems and Equipment—Voltage Ratings (60 Hertz)*, defines MV systems as having a nominal voltage greater than 1,000 V and less than 100,000 V. High-voltage systems are defined as having a nominal voltage equal to or greater than 100,000 V and equal to or less than 230,000 V. High-voltage fuses are, therefore, used on both medium- and high-voltage systems up to their maximum voltage ratings.

Low-Voltage Circuit Breaker Fundamentals (IEEE Blue Book; reference IEEE Std-1015)

A selectively coordinated power system has protective devices that isolate the smallest portion of the system when interrupting a short circuit or overload and thus limit damage to components. This is accomplished with low-voltage circuit breakers by the selection of appropriate operating ratings, trip characteristics, and trip settings so that only the closest circuit breaker on the source side of an overcurrent condition clears the abnormality.

The low-voltage circuit breaker has a protective element that operates in response to the magnitude and duration of current passing through it. It is direct acting in that the current through it provides energy to release the opening mechanism. The characteristic time-current curve has a band of operating area. The upper limit of the band represents the maximum total clearing time for the circuit breaker. The lower limit of the band shows the maximum resettable delay, i.e., the maximum time that a given amount of through current (e.g., a fault or overload) may persist and then subside without tripping the circuit breaker. Bands indicating the pickup current (vertical asymptote) of the characteristic show the tolerance of the pickup point. Currents less than the long-time pickup band can be sustained without tripping the circuit breaker. Currents at or above the upper limit of the band will result in tripping of the circuit breaker.

The low-voltage power circuit breaker (LVPCB) may be found in two general varieties: those with electromechanical trip devices, and those with electronic trip devices. Each has some combination of long-time delay, short-time delay, instantaneous, and ground-fault trip elements. IEEE C37.17-1997, *American National Standard for Trip Devices for AC and General Purpose DC Low Voltage Power Circuit Breakers*, defines those characteristics and their limits. Dual trip devices have long-time and instantaneous elements. Selective trip devices have long-time and short-time elements. Triple selective devices have long-time, short-time, and instantaneous elements.

Electromechanical trip devices use a magnetic circuit directly applied to the circuit-breaker current-carrying conductor. A variety of springs, dashpots, and escapements provide the time-current characteristic (figure 51). The time delay band is relatively broad due to the tolerance of the mechanical devices, temperature, wear, age, etc. Sensitive ground-fault protection must be provided by external sensing and remote tripping devices. Those remote devices must trip the LVPCB by a shunt trip.

Electronic trip devices have become the industry standard. Sensors detect the current and provide tripping energy. The time-current characteristic is electronically developed and is more accurate with narrower tolerances than for the electromechanical device (figure 52). The long-time element provides overload protection and the short-time and instantaneous elements provide fault protection.

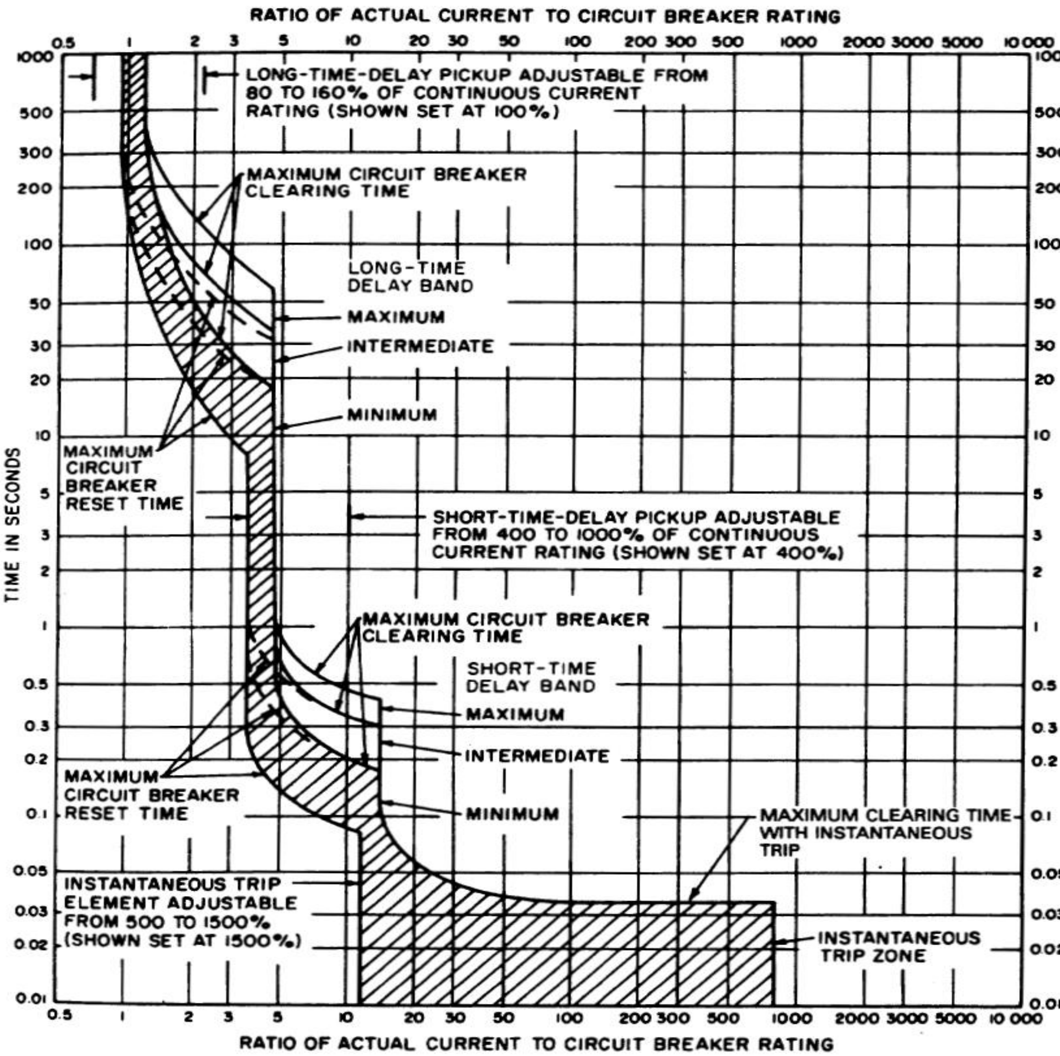
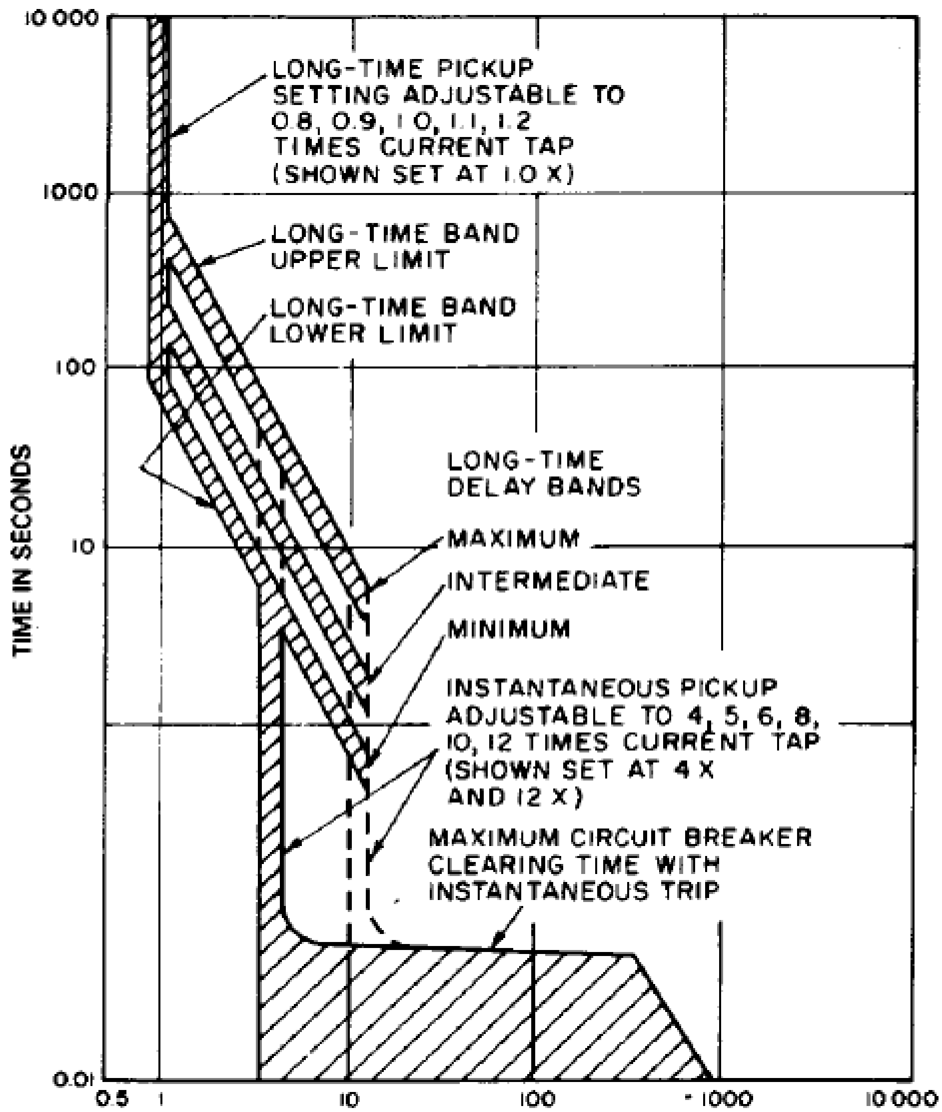


Figure 51. Typical time-current plot for electromechanical trip devices



Source: Figures 51 and 52, IEEE Std 1015-1997

Figure 52. Typical time-current plot for electronic trip devices

Ground-Fault Protection Fundamentals

Distribution circuits that are solidly grounded or grounded through low impedance require fast clearing of ground faults. This need for speed is especially true in low-voltage grounded wye circuits that are connected to busways or long runs of metallic conduit. The problem involves sensitivity in detecting low ground-fault currents as well as coordination between main and feeder circuit protective devices.

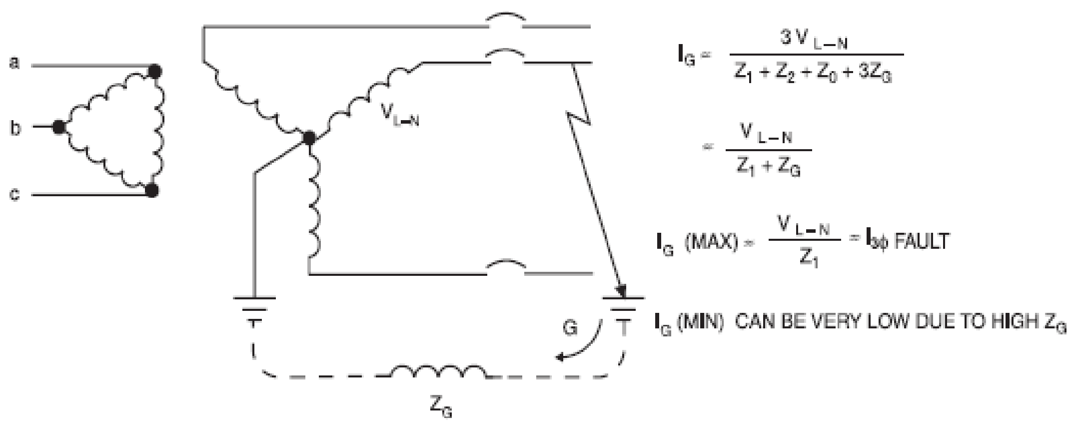
Most industrial and commercial power systems are supplied from electric utility systems that are solidly grounded (figure 53). If the user must immediately convert to lower voltage, the power transformers typically have a delta-connected primary and a wye-connected secondary that can again be connected solidly to ground. This configuration results in a system that can be conveniently protected against over-voltages and ground faults. The system has flexibility because the neutral can be carried with the phase conductors, and this feature permits connecting loads from phase to phase and from phase to neutral.

Systems Above 600 V

Ground relaying of MV and high-voltage systems that are solidly grounded has been successfully accomplished for many years using residually connected ground relays or zero-sequence sensing. The circuit breakers normally have CTs to provide the signal for the phase-overcurrent relays, and the ground-overcurrent relay is connected in the wye point (i.e., residual) to provide increased sensitivity for ground faults. Ground-fault magnitudes usually are comparable to phase-fault magnitudes and are, therefore, easily detected by relays or fuses unless they occur in equipment windings near the neutral point.

Systems 600 V and Below

All 208 V systems are solidly grounded so that loads can be connected from line to neutral to provide 120 V service. Similarly, all 480 V systems that are to serve 277 V lighting should also be solidly grounded. As a result of this requirement, 480 V systems in most commercial buildings and many industrial plants are solidly grounded. Even where 277 V lighting is not used, 480 V systems in many industrial plants are solidly grounded to limit overvoltages and to facilitate clearing ground faults.



Source: IEEE Std 242-2001

Figure 53. Direct or solid grounding (uses ground relays to trip)

Conductor Protection

The proper selection and rating or derating of power cables is as much a part of cable protection as the application of the short-circuit and overcurrent protection devices. The whole scheme of protection is based on a cable rating that is matched to the environment and operating conditions. Methods of assigning these ratings are discussed in chapter 9 of IEEE 242-2001.

Motor Protection

Many factors should be considered in choosing motor protection: motor importance, motor rating (from one to several thousand HP), thermal limit of rotor or stator, environment, power system source and its neutral grounding method, type of motor controller, etc. Protection for each specific motor installation should meet the requirements of the application. Power quality of the plant distribution system should be given appropriate attention, especially with regard to voltage sags and surges, harmonics, service interruptions, and operation of distribution line re-closers.

Transformer Protection

Transformer failure may result in loss of service. However, prompt fault clearing, in addition to minimizing the damage and cost of repairs, usually minimizes system disturbance, the magnitude of the service outage, and the duration of the outage. Prompt fault clearing usually prevents catastrophic damage. Proper protection is, therefore, important for transformers of all sizes, even though they are among the simplest and most reliable components in the plant's electrical system.

Generator Protection

Generator protection requires the consideration of many abnormal conditions that are not present with other system elements. The following abnormal conditions may occur with generators:

- Overheating
  - Stator (due to overload or loss of cooling)
  - Rotor (due to overexcitation, loss of cooling)
- Winding faults
  - Stator (phase and ground faults)
  - Rotor (ground faults and shorted turns)
- Overspeed and underspeed
- Overvoltage
- Loss of excitation
- Motoring
- Unbalanced current operation
- Out of step
- Subsynchronous oscillations
- Inadvertent energization
- Nonsynchronized connection

Where the equipment is unattended, it should be provided with automatic stator and rotor protection against all harmful conditions. In installations where an attendant is present, use of alarms on some abnormal conditions may be preferable to removing the generator from service. Generator protective schemes vary depending on the objectives to be achieved.

Bus and Switchgear Protection

The substation bus and switchgear are the parts of the power system used to direct the flow of power to various feeders and to isolate apparatus and circuits from the power system. These parts include the bus bars, circuit breakers, fuses, disconnection devices, CTs, voltage transformers, and the structure on or in which they are mounted. The term *bus* refers to the bus within an assembly of equipment (e.g., MV, metal-enclosed switchgear, MV control, low-voltage switchgear, power switchboards, panelboards, MCCs, bus duct).

Maintenance, Testing, and Calibration of Electrical Systems

Chapter 16 of IEEE 242-2001 sets out recommendations and procedures for the maintenance of electrical switchgear having rated voltages not greater than 34.5 kV. At voltages above this level, the design of equipment, system operations, and consequently maintenance requirements and practices may differ significantly. However, the principles formulated in this recommended practice, especially the principles regarding the safety of personnel, are for the most part applicable at the higher voltages.

e. Discuss electrical system grounding with regard to the following elements (IEEE Green Book; reference IEEE Std-142 or another source can be used as a guide in developing the discussion):

- **Electrical system grounding fundamentals**
- **Electrical equipment grounding fundamentals**
- **Static and lightning grounding fundamentals**

The following is taken from IEEE Std 142-1991.

Grounding of an electrical system is a decision that must be faced sometime by most engineers charged with planning or modifying electrical distribution. Grounding in some form is generally recommended, although there are certain exceptions. Several methods and criteria exist for system grounding; each has its own purpose. It is the intention of this section to assist the engineer in making decisions on the subject by presenting basic reasons for grounding or not grounding and by reviewing general practices and methods of system grounding.

The practices set forth in IEEE Std 142-1991, chapter 1, are primarily applicable to industrial power systems that distribute and utilize power at medium or low voltage, usually within a smaller geographical area than is covered by a utility. Where distances or power levels may dictate circuitry and equipment similar to a utility, consideration of utility practices is warranted. However, restrictions of the NEC, particular needs of service, and the experience and training of the workforce should also be considered.

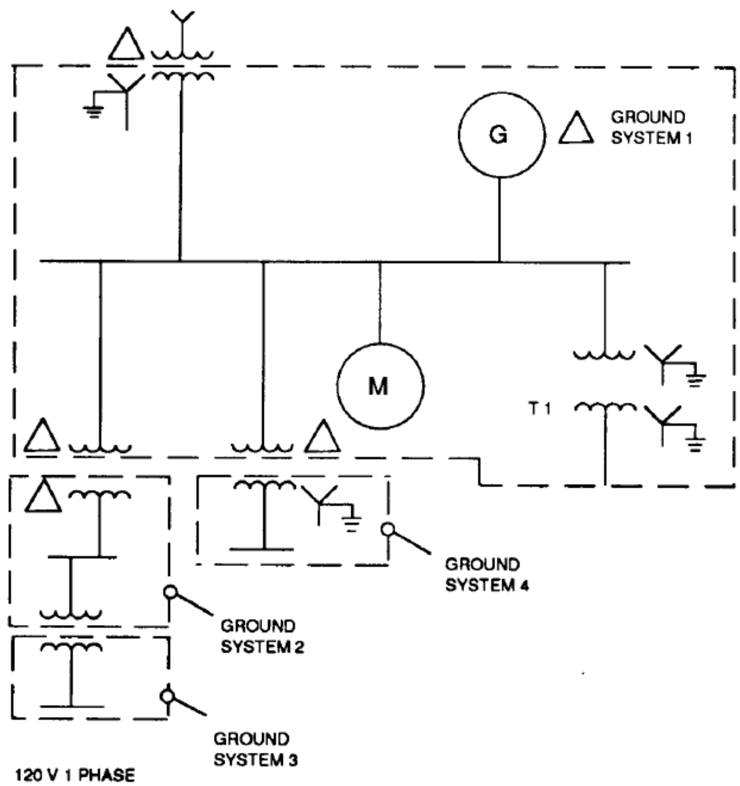
Where an industrial power system includes power-generating equipment, the reasons for grounding these components may be the same as those for grounding similar components of public utility systems. The methods of grounding would generally be similar under like conditions of service. However, in the industrial setting, conditions of service may be altered by

- location within the power system
- individual generator characteristics
- manufacturing process requirements

All of these may affect grounding decisions.

The NEC, sponsored by the NFPA, contains regulations pertaining to system and equipment grounding applicable to industrial, commercial, and special occupancy facilities. These rules are considered minimum requirements for the protection of life and property and should be carefully reviewed during the course of system design.

System grounding, or the intentional connection of a phase or neutral conductor to earth, is for the purpose of controlling the voltage to earth, or ground, within predictable limits. It also provides for a flow of current that will allow detection of an unwanted connection between system conductors and ground and which may instigate operation of automatic devices to remove the source of voltage from conductors with such undesired connections to ground. The NEC prescribes certain system grounding connections that must be made to be in compliance with the code. The control of voltage to ground limits the voltage stress on the insulation of conductors so that insulation performance can be more readily predicted. The control of voltage also allows reduction of shock hazard to persons who might come in contact with live conductors. An example of a grounding system is shown in figure 54.



Source: IEEE Std 142-1991

Figure 54. Grounding systems

Electrical Equipment Grounding Fundamentals

As found in chapter 2 of IEEE 142-1991, the term “equipment grounding” refers to the interconnection and grounding of the nonelectrical metallic elements of a system. Examples of components of the equipment-grounding system are metallic conduit, motor frames, equipment enclosures, and a grounding conductor. Note that a grounding conductor is a part of the equipment grounding system, as distinguished from a grounded conductor, which is a part of the power distribution system.

The basic objectives of an equipment-grounding system are the following:

- To reduce electric shock hazard to personnel
- To provide adequate current carrying capability, both in magnitude and duration, to accept the ground-fault current permitted by the overcurrent protection system without creating a fire or explosive hazard to building or contents
- To provide a low impedance return path for ground-fault current necessary for the timely operation of the overcurrent protection system

Effective equipment grounding practices can minimize personal injuries. A breakdown of insulation can cause accidental contact between an energized electrical conductor and the metal frame that encloses it. Such contact tends to energize the frame to the voltage level of the conductor. Avoiding shock-hazard voltage requires nullifying this tendency. The equipment-grounding system should do this by forming a low impedance path to ground.

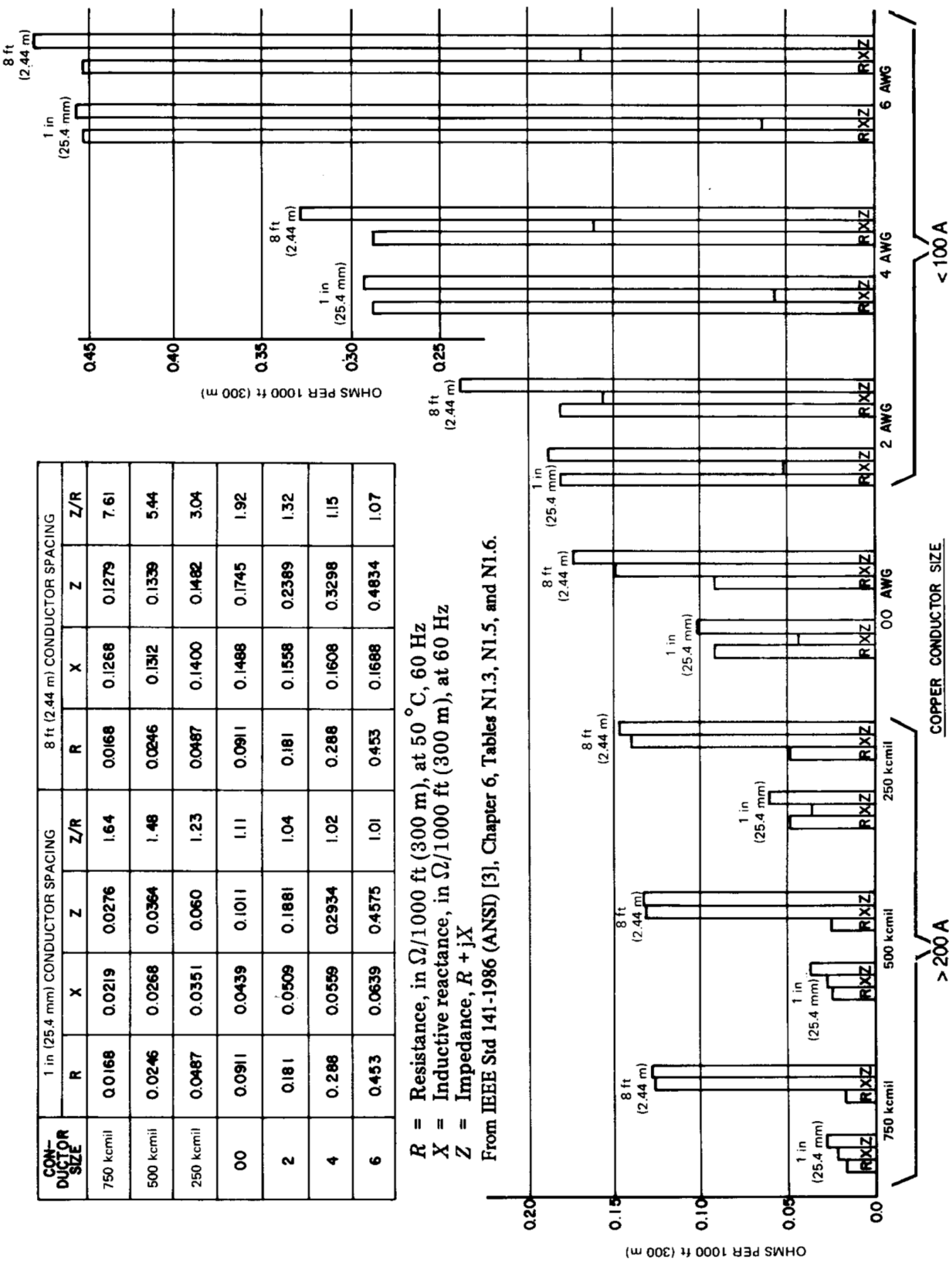
The impedance of the grounding conductor must be low enough to accept the available line-to-ground-fault current without creating a hazardous impedance voltage drop. The available ground-fault current of the supply system will have a direct bearing on the equipment-grounding conductor requirements.

The grounding conductor must also function to conduct the available ground-fault current (magnitude and duration) without excessive temperature rise or arcing. The use of a large cross-section grounding conductor is not enough. All parts of the fault circuit, including the terminations and other parts, must be capable of carrying the fault current without distress. The installation must also provide a lower impedance fault return path than other possible parallel paths that may have inadequate current-carrying capacity. Summaries of large-loss fires indicate that approximately one out of four fires in manufacturing establishments originate in electrical systems. These reports undoubtedly place some unjustified blame on electrical systems. Effective design, installation, and maintenance of equipment-grounding systems are vital elements in reducing these fire hazards.

Joints and connectors are critical components of the fault return path. Good workmanship is essential to a safe system and must be demanded. Supervision of installation, inspection, and proper maintenance should assure that the grounding system is not compromised. One of the more critical connections is the locknut connection between metallic raceway or cable and the sheet metal enclosure. Particular assurance that this connection be made and maintained clean and tight is imperative. A grounding bushing, as required by NFPA 70 for services and systems of over 250 V to ground, with its terminal bonded to an adequate terminal within the enclosure, is recommended for all applications.

The equipment-ground system is an essential part of the overcurrent protection system. The overcurrent protection system requires a low-impedance ground return path to operate promptly and properly. The earth ground system is rarely of low enough impedance and is not intended to provide an adequate return path. The impedance of the grounding conductor must be low enough that sufficient ground-fault current will flow to operate the overcurrent protective device and clear the fault rapidly. In AC applications, it is the total impedance (R + jX) that controls the current division among paralleled paths. In 60 Hz circuits rated 40 A or less, the circuit reactance (jX) is an insignificant part of the circuit impedance. Because reactance increases significantly with conductor separation, reactance is the predominant element of impedance for open wire and tray systems for circuits rated above 200 A. For cable systems or conductors in conduit with close proximity, reactance is a significant component of impedance for circuits rated over 200 A. The reactance of an AC circuit is determined mainly by the spacing between outgoing and return conductors and is only slightly affected by conductor size (figure 55). The circuit resistance is directly affected by conductor size. This means that the ratio of X/R and the relative effect of reactance on circuit impedance increases as the conductor size increases.

Note: Increased separation spacing between grounding and phase conductors increases not only the reactance X_g of the grounding conductor but also the zero-sequence reactance X_o of the phase conductors. In 60 Hz AC circuits rated above 40 A, it becomes mandatory that the installed grounding conductor be physically placed to present a much lower reactance than other less capable parallel paths.



CONDUCTOR SIZE	1 in (25.4 mm) CONDUCTOR SPACING				8 ft (2.44 m) CONDUCTOR SPACING			
	R	X	Z	Z/R	R	X	Z	Z/R
750 kcmil	0.0168	0.0219	0.0276	1.64	0.0168	0.1268	0.1279	7.61
500 kcmil	0.0246	0.0268	0.0364	1.48	0.0246	0.1312	0.1339	5.44
250 kcmil	0.0487	0.0351	0.060	1.23	0.0487	0.1400	0.1482	3.04
00	0.0911	0.0439	0.1011	1.11	0.0911	0.1488	0.1745	1.92
2	0.181	0.0509	0.1881	1.04	0.181	0.1558	0.2389	1.32
4	0.288	0.0559	0.2934	1.02	0.288	0.1608	0.3298	1.15
6	0.453	0.0639	0.4575	1.01	0.453	0.1688	0.4834	1.07

R = Resistance, in Ω/1000 ft (300 m), at 50 °C, 60 Hz
X = Inductive reactance, in Ω/1000 ft (300 m), at 60 Hz
Z = Impedance, $R + jX$

From IEEE Std 141-1986 (ANSI) [3], Chapter 6, Tables N1.3, N1.5, and N1.6.

Source: IEEE Std 142-1991

Figure 55. Variation of R and X with conductor size and spacing

Static and Lightning Grounding Fundamentals

Chapter 3 of IEEE Std 142-1991 covers static electricity, its generation, proven methods of safeguarding from the hazards of this phenomenon by grounding and other methods, and lightning-protection grounding. The discussion below provides a general overview of these concepts.

The accumulation of static electricity on equipment, on materials being handled or processed, and on operating personnel introduces a potentially serious hazard in any occupancy where flammable or explosive liquids, gases, dusts, or fibers are present. The discharge of an accumulation of static electricity from an object to ground or to another charged object of different voltage can be the cause of a fire or an explosion if it takes place in the presence of readily flammable materials or combustible vapor and air mixtures. Such fires and explosions have caused injury to personnel and loss of life, as well as millions of dollars of loss in property damage and business interruption.

Protection of human life is the first objective in attempting to control static charges. Besides the danger to lives from explosions or fires that may result from a static spark, there is also the danger that a person, becoming startled when suddenly subjected to a static shock, may fall or accidentally come into contact with some moving equipment.

The second aim in eliminating or mitigating static electricity is to prevent losses in the following categories:

- Capital investment in buildings and equipment due to fires or explosions
- Operating costs for storing flammable materials
- Overhead and loss of production due to fires or explosions
- Capital investment in sensitive electronic equipment due to excessive or rapidly changing voltage
- Loss of electronically stored data due to voltage transients

If losses such as those listed can be avoided by proper static control, the expenditure required to secure this protection is good insurance.

Many static problems can be solved by bonding the various parts of the equipment and grounding the entire system. Bonding (connecting the two objects together) minimizes voltage differences between conductive objects, thus preventing sparking between two bodies, as shown in figures 56 and 57. Grounding minimizes voltage differences between objects and the ground, as shown in figure 58. Bonding and grounding should be done by bare or insulated wire, no. 6 or no. 4 AWG (for mechanical strength), though the current is on the order of microamperes. Any ground adequate for power circuits or lightning protection is adequate for protection from static electricity. Even a ground resistance of 1 MW is adequate for static grounding. Where grounding or bonding wires are exposed to damage, they should be run in rigid metal conduit or pipe. Equipment or tanks inherently bonded or grounded by their contacts with ground do not need special means of bonding. For moving objects, a grounding brush or wipe of carbon, brass, or spring bronze may be used, as shown in figure 59.

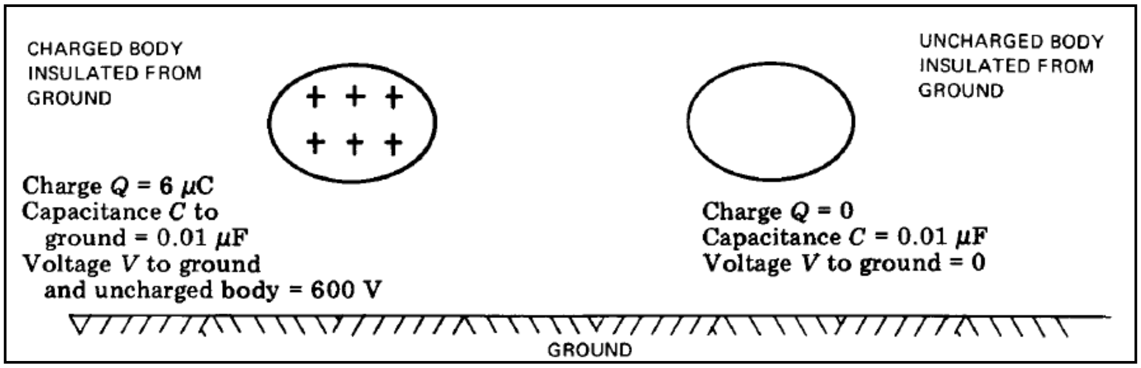


Figure 56. Charged and uncharged bodies insulated from ground

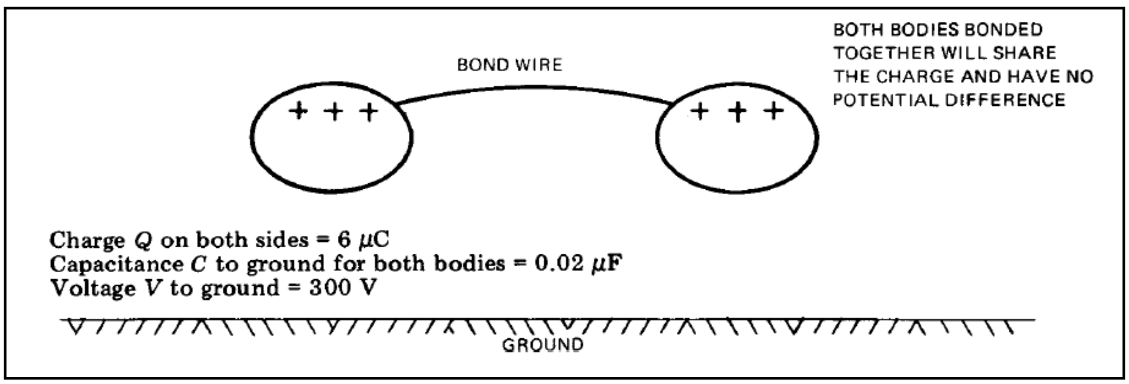


Figure 57. Both insulated bodies share the same charge

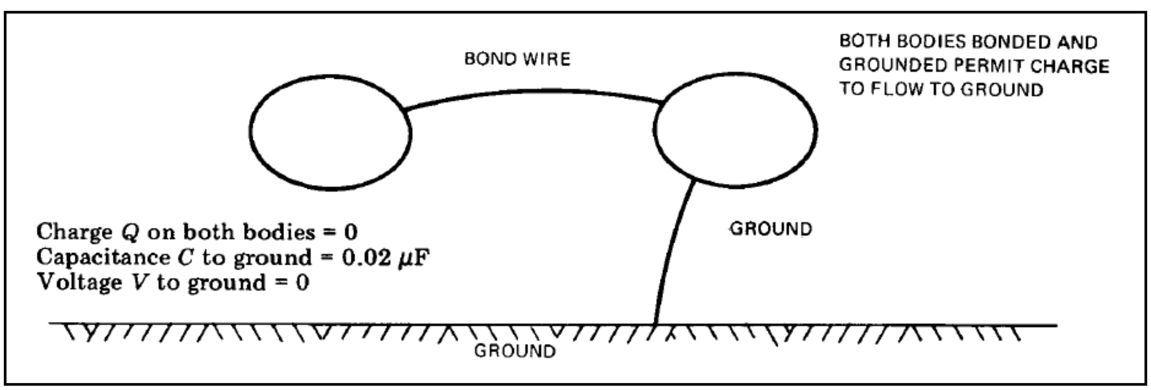
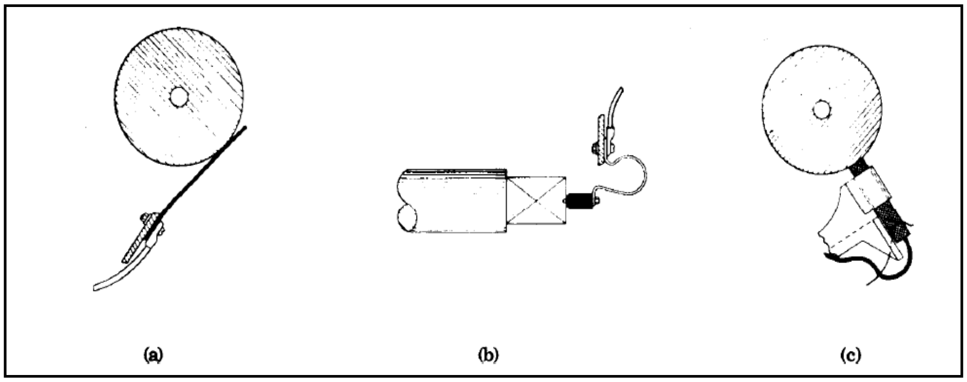


Figure 58. Both bodies are grounded and have no charge



Source: Figures 56–59, IEEE Std 142-1991

Figure 59. Methods of ground metal rollers or shafting: (a) spring bronze brush, (b) brass or carbon brush, (c) carbon brush and holder

Lightning-protection grounding is essential for the protection of buildings, transmission lines, and electrical equipment from lightning discharges and surges.

f. Discuss emergency and standby power with regard to the following elements (IEEE Orange Book; reference IEEE Std-446 or another source can be used as a guide in developing the discussion):

- **Emergency and standby power guidelines**
- **Generator and electric utility system fundamentals (IEEE Brown Book; reference IEEE Std-399)**
- **Stored energy system fundamentals**
- **Protection device fundamentals**

The following is taken from IEEE Std-446-1995.

Emergency and Standby Power Guidelines

While all who use electric power desire perfect frequency, voltage stability, and reliability at all times, this cannot be realized in practice because of the many causes of power supply disturbances that are beyond the control of the utility. For example, power failures can be caused by automobiles hitting poles; animals climbing across insulators; lightning striking overhead lines; and high winds blowing tree branches and other debris into lines.

The lightning, wind, and rain produced by thunderstorms and tornadoes can also cause power interruptions and transients. Figures 60 and 61 are useful in determining the probability of such power failures (from thunderstorms and from tornadoes, respectively) depending upon the user’s geographic location. More widely located storms, such as hurricanes, snowstorms, ice storms, and floods, also take their toll on power supply systems.

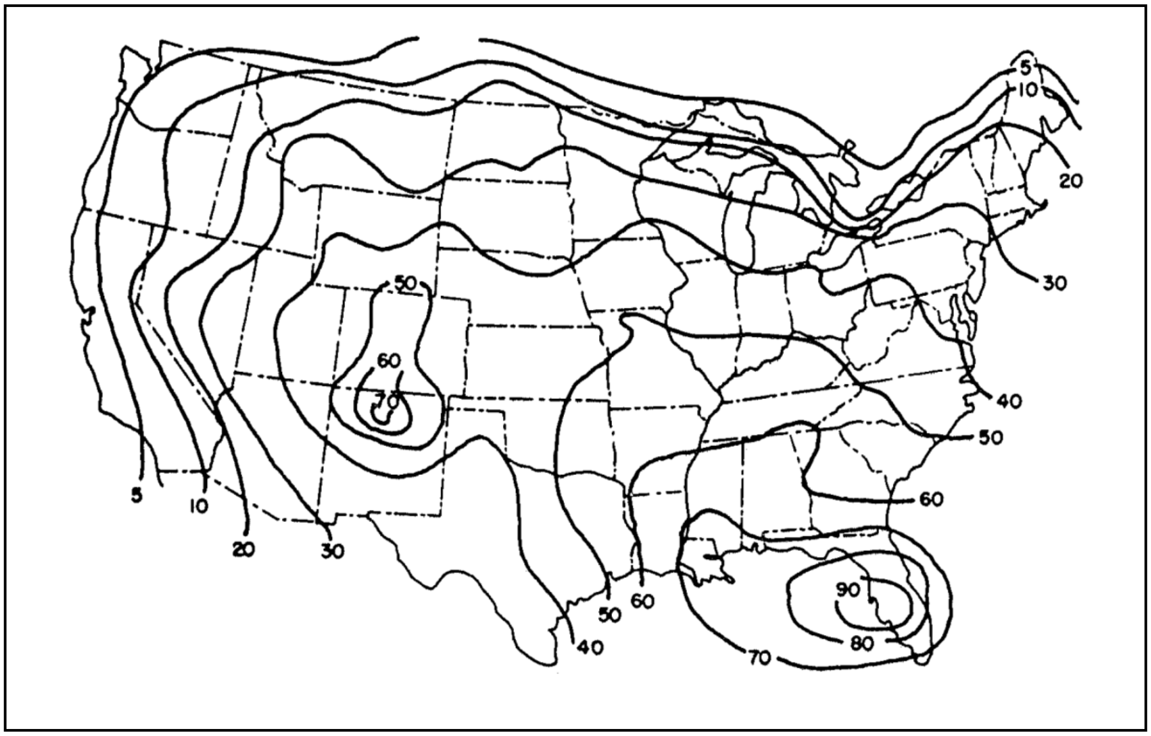
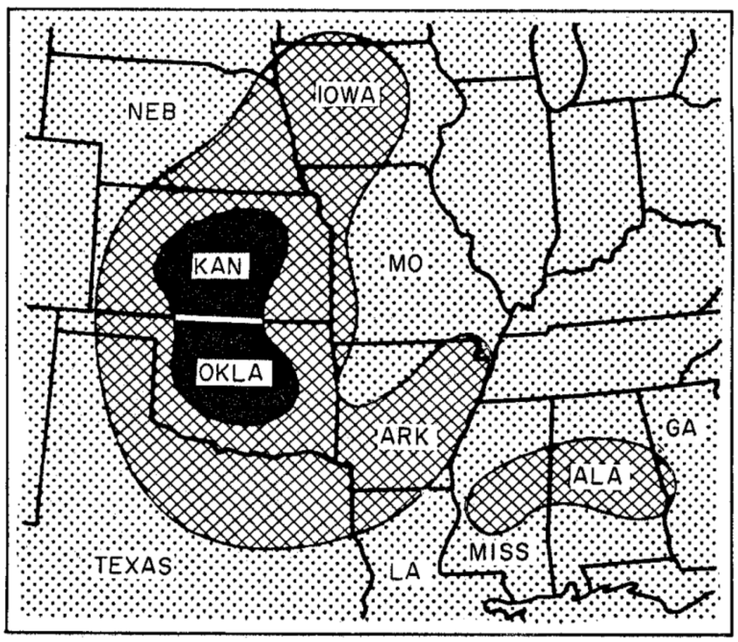


Figure 60. Average number of thunderstorm days per year



Source: Figures 60 and 61, IEEE Std 446-1995

Figure 61. Approximate density of tornadoes— cross-hatched areas: 100 to 200 in 40 years; black area: over 200 in 40 years

Tools for Determination of Power Failures

Although there is less chance for a power interruption caused by severe weather or other natural phenomena occurring on an underground system, and although an underground system has fewer dips, the duration of any interruption that occurs may be much longer because of the greater length of time required to discover the source of the cable failure and to make repairs.

Even the operation of protective devices can cause power supply disturbances. As an example, overcurrent and short-circuit protective devices require excessive current to operate and are accompanied by a voltage dip on any line supplying the excessive current until the device opens to clear the fault. Devices opening to clear a lightning flashover with subsequent reclosing cause a momentary interruption.

Since utility companies have little practical control over disturbances on their systems, they are unwilling to accept responsibility for them or to make power quality or continuity guarantees. The following disclaimer is taken from a typical utility sales contract:

> The power delivered hereunder shall be three-phase AC at a frequency of approximately 60 Hz and at a nominal voltage of 208/120 V wye. Except for temporary periods of abnormal operating conditions, variations from normal voltage shall not exceed 5% up or down. The utility will use reasonable diligence to provide a regular and uninterrupted supply of power, but in case such supply should be interrupted for any cause, the utility shall not be liable for damages resulting therefrom.

In several instances, utility companies have recognized the limitations of their power quality and have offered auxiliary equipment with special purchase agreements to satisfy the needs of those who use sensitive utilization equipment.

Utility companies are by no means the only source of power system disturbances. Disturbances and outages also occur in the plant system through the loss of power due to short circuits in wiring and failures of local generation including emergency and standby equipment.

Noise is generated in otherwise acceptable electric power by motors, welders, switches, semiconductor-controlled rectifier gating, dielectric heating, arcing short circuits, and myriad other sources.

Ordinary power meters and instrumentation cannot be used to measure power transients or disturbances. Recording devices with extremely fast response must be used to detect, measure, and record disturbance magnitudes and durations. Most disturbances will not only vary within a given 24-hour period, but depending on the geographical area, could be subject to seasonal variations.

Any meaningful data with regard to power quality, or lack of it, will become obvious only after conducting a thorough and detailed measurement recording and analysis program. Such a program would include the monitoring of an incoming power line over a representative period of time. Since much of the instrumentation is costly (typically, $3,000–$16,000) in relation to its limited duration usage, rental arrangements are often a popular choice. Without a good power disturbance monitor to measure and record disturbances continuously, there is a tendency to make judgments regarding disturbances in the power source in terms of their effects upon various electrical loads. When the lights go out and the electrical equipment all stops working, this is usually a fairly reliable indication of a power interruption. However, if the lights merely flicker or the electronic equipment malfunctions, it is difficult to judge whether or not there has been a severe change in voltage for a very short time or a very small voltage change for a much longer time. One cannot determine, without a disturbance monitor, whether or not the disturbance was unusually severe or the electronic equipment was unusually susceptible to the disturbance. Without the necessary features in a disturbance monitor, one cannot tell if the source of the disturbance was external to the load equipment or was the load equipment itself.

The following list describes methods that can be used to reduce to acceptable limits, or even eliminate, the effects of power supply disturbances:

- Modification of the design of utilization equipment so as to be impervious to power disturbances and discontinuities
- Modification of the prime power distribution system to be compatible with utilization equipment
- Modification of both equipment and systems to meet a criterion that is realistic for both
- Interposing a continuous electric supply system between the prime source and the utilization equipment; this will function as a buffer to external sources of transients, but depending on the design, could increase the magnitude of load-induced disturbances

Generator and Electric Utility System Fundamentals (IEEE Brown Book; reference IEEE Std 399)

When an equipment problem is experienced, due to failure of the electric power supply, the options are to (1) tolerate the problem and do nothing, (2) modify the equipment or system to perform satisfactorily during a power failure, or (3) alter or supplement the power supply to prevent potential occurrences of failure. In many cases, the best decision is to modify the equipment or system.

If the electric power user's study has shown that the most beneficial approach is to alter or supplement the power supply source, another study should be undertaken to determine the proper systems, configuration, and hardware that will meet the determined power requirements for the lowest cost.

Combinations of systems and hardware have been proven reliable in preventing the following types of electric power failure:

- Long-time interruption (hours)
- Medium-time interruption (minutes)
- Short-time interruption (seconds)
- Over- or under-voltage
- Over- or under-frequency

Emergency power systems are of the following two basic types:

- An electric power source separate from the prime source of power, operating in parallel, that maintains power to the critical loads should the prime source fail
- An available reliable power source to which critical loads are rapidly switched automatically when the prime source of power fails

Standby power systems are made up of the following main components:

- An alternative reliable source of electric energy separate from the prime power source, starting and regulating control if onsite standby generation is selected as the source
- Controls that transfer loads from the prime or emergency power source to the standby source

For reasons of economy, it would be prudent to establish specific needs for emergency and standby power before specifying and purchasing equipment, since equipment costs are proportional to the following requirements and specifications:

- Longer equipment life
- Increased capacity
- Closer frequency regulation
- Closer voltage regulation
- Freedom from voltage or frequency transients
- Increased availability
- Increased reliability
- Increased temporary overload capability
- Quiet operation
- Safety from fuel hazards
- Pollution-free operation
- Freedom from harmonics
- Close voltage and frequency regulation with wider-range rapid load changes

The following 2 paragraphs are taken from IEEE Std-399.

IEEE Std 399-1997 notes that the need for DC power system analysis of emergency standby power supplies has steadily increased in data processing facilities, long-distance telephone companies, and generating stations during the past several years.

DC emergency power is used for circuit breaker control, protective relaying, inverters, instrumentation, emergency lighting, communications, annunciators, fault recorders, and auxiliary motors. The introduction of computer techniques to DC power systems analysis has allowed a more rapid and rigorous analysis of these systems compared to earlier manual techniques.

Stored Energy System Fundamentals

Energy usable for electrical power generation may be stored in many ways. For example, liquid and gaseous fuels are a form of energy stored for use in engines and turbines to turn generators.

Chapter 4 of IEEE Std 446-1995 examines the two most prevalent stored energy systems: battery systems and mechanical stored energy systems. Battery systems store energy in electrochemical cells that convert chemical energy into electrical energy (figure 62). These cells are of the rechargeable storage type, designed for standby application. They are also known as *stationary cells*. The name "stationary" is derived from the fact that these cells are designed for service in a permanent location. A battery is made up of two or more cells connected together electrically, in series, parallel, or a combination of both, to obtain the desired battery voltage and capacity (in ampere-hours or watt-hours) required for the application. This energy may be used directly to power DC equipment or may be converted to useful AC power by one of two means, either by a DC motor used to drive an AC generator or by a static DC-AC converter (e.g., a static inverter).

Mechanical systems store energy in the form of kinetic energy in a rotating mass. This energy is converted to useful power by using the kinetic energy to turn an AC generator.

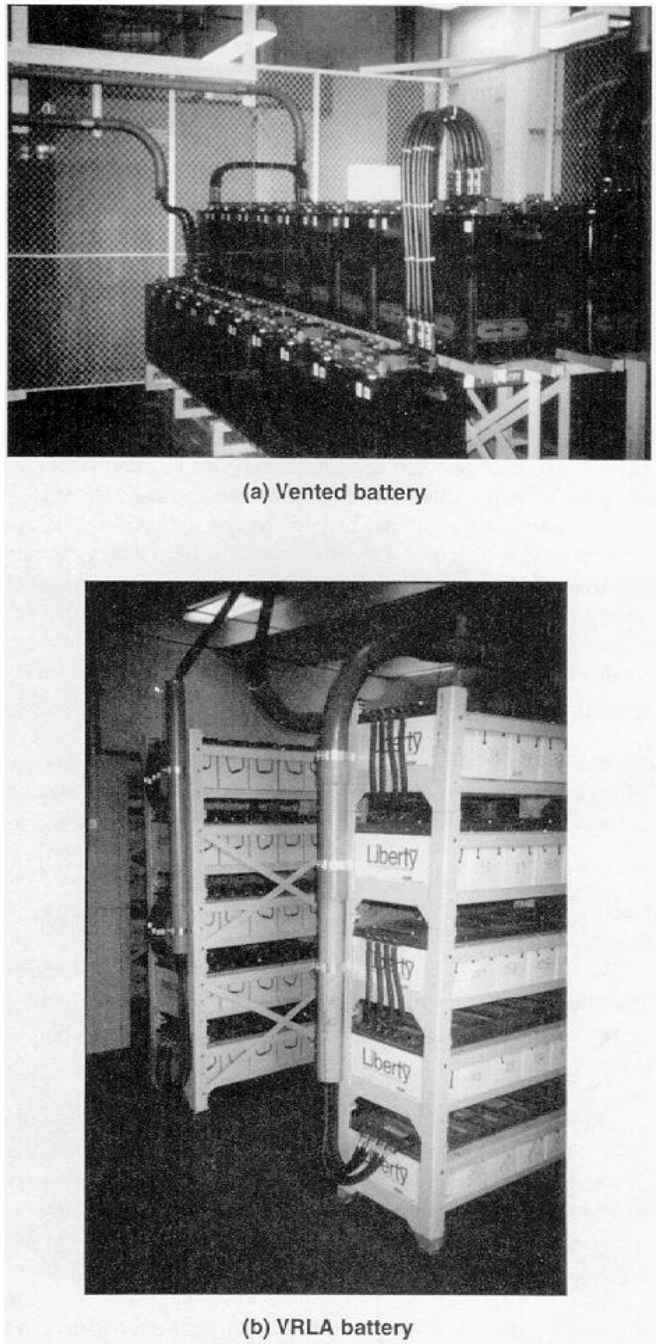
Chapter 4 also discusses methods by which motor generator sets and static inverters have been configured into power conditioning systems and UPS systems. Each system is designed to meet one or more of the following goals:

- To filter, regulate, and condition power for sensitive computers and other electronic equipment
- To isolate the load from the power source
- To permit orderly, controlled shutdown of equipment in the event of a power failure
- To bridge the interval from the occurrence of a power failure until an emergency standby generator can start and assume the load
- To provide continuous power uninterrupted by power failures

Note that power conditioning and isolation are important benefits of energy storage systems. In fact, more UPS systems are installed for power conditioning purposes than for backup power purposes since many power-related problems do not require the battery to come on-line.

So, in selecting a system, careful attention should be paid to the quality of output power in terms of harmonic distortion, stability, overload capacity, overload protection, and reliability.

The primary difference in the two energy storage systems is that a battery can be selected to provide minutes or hours of backup time, while the mechanical stored energy system has a practical time limit of less than 10 seconds. Batteries used with UPS systems are most often sized to provide 15 minutes of backup, during which time an emergency generator can be brought on-line if the normal power has not been restored.



(a) Vented battery

(b) VRLA battery

Source: IEEE Std 446-1995

Figure 62. Stationary battery installation

Protection Device Fundamentals

This section discusses recommended practices and guidelines for protection of emergency and standby power systems. Even though standard practice for protection of equipment should always be given full consideration when applying the equipment in emergency and standby use, reliability often warrants special consideration when a power supply for critical loads is designed. Although compliance with all national, state, and local codes and standards applicable to protection of the components that make up the emergency or standby power system is necessary, it may be desirable to exceed these codes and standards in the design process.

Individual components that make up the most common emergency and standby power systems, with emphasis on maintaining the required integrity and reliability of the system are to be protected. Proper application and maintenance of systems should be considered an important aspect of protection.

Of the many areas of concern for protection of components that make up an emergency or standby power system, one needing special consideration is that of magnitude and duration of short-circuit current available from the emergency or standby power source. Fault conditions obviously have a direct effect on the availability of the power supply to serve its intended purpose.

Studies should be made to determine available short-circuit current throughout the system supplied by an emergency or standby power supply, especially at switching and current-interrupting devices.

When the performance of an emergency or standby generator under fault conditions is evaluated, a critical concern is whether sufficient fault current is available for sufficient duration to selectively trip overcurrent devices in a properly coordinated system. In most cases, emergency or standby power sources do not produce as much fault current as the normal source. When both sources are designed to supply a distribution system, through automatic or manual switching devices, the magnitude of the fault current available from the normal supply usually determines the required interrupting or withstand rating of the system components. Careful planning is necessary to design a system that assures optimum selectivity and coordination with both power sources. An emergency or standby generator's available short-circuit current should be compared to the ratings of system overcurrent devices to determine how this coordination is to be achieved. Normally the emergency or standby power source should be connected into the power system so as to be physically and electrically as close to the loads as practical. This will minimize the number and size of distribution system circuit breakers involved and the number of coordination levels required.

Selective coordination of overcurrent devices is the process of applying these devices so that one will operate before another under given levels of fault currents, thereby allowing effective isolation of the faulted circuit from unfaulted circuits. For a detailed analysis of the principles of selective coordination, see IEEE Std 242-1986.

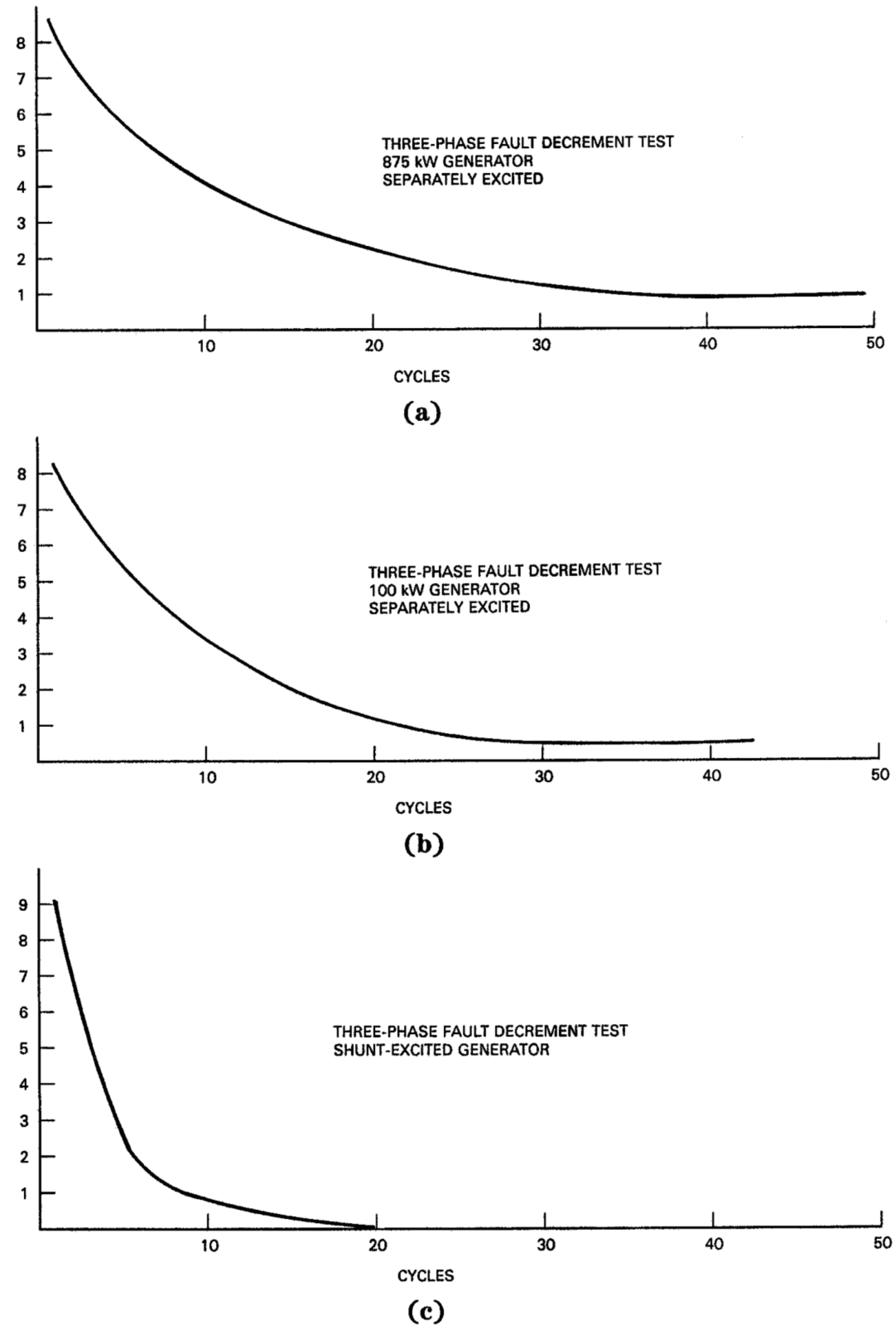
Evaluating the available fault current from an emergency or standby generator includes determining the magnitude of the fault current and how long the fault current will exist and how it may change. Test information on generator short-circuit characteristics may be necessary from the manufacturer. One should not assume that the speed of the generator will remain unchanged for a fault fed only by the generator; the effects of frequency changes and prime mover load should also be accounted for. The coordination of the mechanical and electrical stored energy in a generator set and the type of excitation system will determine how long the engine and generator will sustain fault current and how rapidly this fault current will decay. In some cases, the initial power to a fault is higher (sometimes several times higher) than the prime mover power rating. The result can be a rapid reduction in speed. This overloading of the prime mover is more likely in small generator set applications than in larger power systems since the X/R ratios of both the generator windings and distribution circuits in small systems are lower.

An excitation system usually will not respond fast enough to significantly affect the first one or two cycles of fault current, so at this point the type of excitation system does not matter. If the fault is not cleared in the first 2–4 cycles, a serious concern is whether or not the generator set can recover, after the fault is finally cleared, to maintain acceptable service to unfaulted branch circuits. For systems where the fault current decays rapidly to levels below instantaneous and delayed overcurrent trip settings, tripping will only be possible in the first few cycles. This diminishes the ability to selectively trip the overcurrent devices, leaving only the instantaneous settings to work with.

Figure 63 illustrates the rate of decay of three-phase fault current from tests on three typical generators; the first two are separately excited (with fixed excitation) and tested at no load.

The curves are approximations of actual test results. In figure 63a, about 40 cycles elapse before the fault current decays to the full-load rating of the generator. In figure 63b, the fault current decayed to the full-load rating in about 25 cycles. The quicker decline of fault current from the smaller generator is a common occurrence.

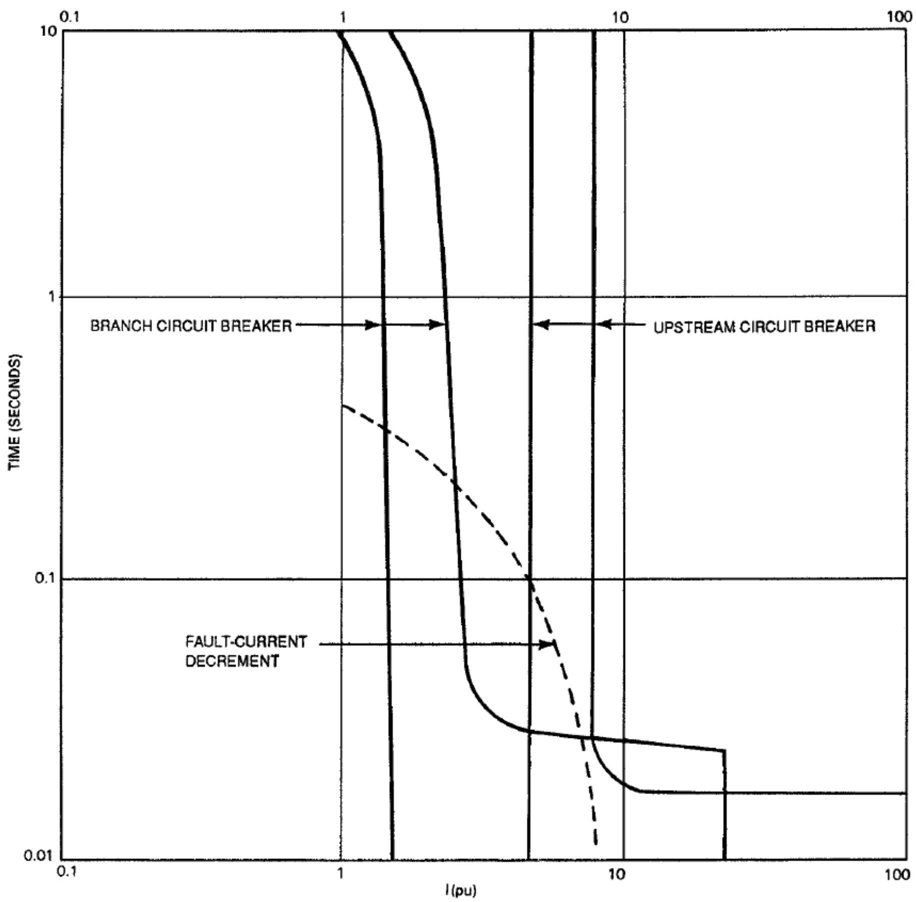
The current (I) shown is in per unit (pu) based on generator full-load current rating. Figure 63c illustrates an approximation of short-circuit current of a shunt-excited generator without short-circuit sustaining capability. In this case, the current has decayed to full-load rating in 10 cycles and to nearly zero in 20 cycles.



Source: IEEE 446-1995

Figure 63. Three-phase decrement curves for engine generators

When two circuit breakers equipped with instantaneous trips are applied in series, even though the upstream breaker is substantially larger, selective instantaneous tripping is not assured on faults below the downstream breaker unless the momentary fault current is less than the minimum instantaneous trip level of the larger upstream breaker. This concept is illustrated in figure 64. The figure shows a case where the fault current, taken from figure 63b, is above the maximum instantaneous pickup current of the larger breaker. This may unlatch and trip this larger breaker, so that both breakers trip and power is lost to unfaulted branch circuits. The decay of the current during the unlatching time of the breaker, which may be less than .01 s, is insignificant compared to the pickup tolerance of the trip unit or the variation in the asymmetrical component of the current. Once the breaker is unlatched, it is committed to trip.

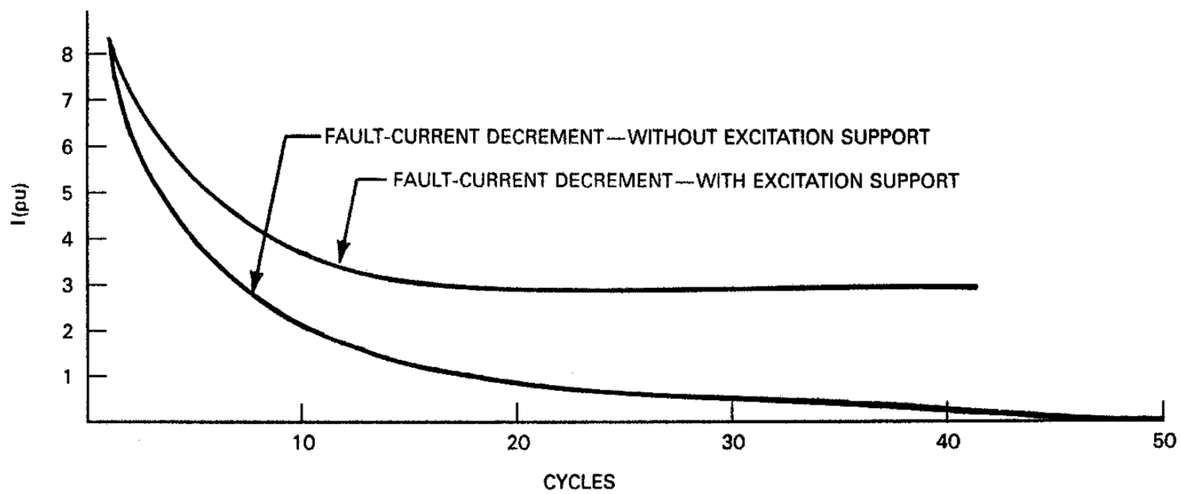


Source: IEEE 446-1995

Figure 64. Three-phase short-circuit current versus molded-case circuit breakers in series

For the cases illustrated in figure 63, only three-phase fault conditions are shown. In actual practice, unbalanced faults are much more common, especially line-to-ground in grounded systems. For this reason, evaluating only three-phase fault conditions in the application of an engine-generator is insufficient. Shunt exciter systems may derive their power from line-to-line, line-to-neutral, or from all three phases. Depending on the particular design, it is possible that faults occurring line-to-line or line-to-neutral may not decay to a self-protecting level as shown in figure 63. The degree to which this can be a problem should be determined on a case-by-case basis. It is possible for a generator and excitation system to be designed to assure collapse of the generator terminal voltage and fault current on any kind of fault at the generator terminals.

Generator and excitation systems are also available to assure a predicted level of fault current. A user should specify the type of system that best fits the needs. Figure 65 is an approximation of an actual test on a turbine-driven generator with and without excitation support under three-phase fault conditions. The curves show how little influence the excitation system has in the first few cycles, but the sustained fault current is substantially different from that without excitation support.



Source: IEEE Std 446-1995

Figure 65. Three-phase decrements for 900 kW turbine generator

This type of fault-sustaining support will produce even higher than 3 pu fault current for line-to-line and line-to-ground faults. These values are typically 5 pu and 8 pu, respectively.

38. Electrical personnel shall demonstrate a familiarity level knowledge of the possible functional interfaces/relationships between all electrical VSS and instrument and control safety software, analysis safety software, and design safety software.

Elements ‘a’, ‘b’ and ‘f ’ are performance-based KSAs. The Qualifying Official will evaluate their completion.

a. **<u>Mandatory Performance Activity</u>: With the assistance of the cognizant software quality assurance (SQA) subject matter expert, identify how functional requirements and applicability of safety analysis and design computer codes are defined, documented, and controlled relative to modeling and data assumptions, design constraints, sizing and timing conditions, and input/output parameters as described in DOE O 414.1C, Quality Assurance, and DOE G 414.1-4, Safety Software Guide for Use with 10 CFR 830, Subpart A, Quality Assurance Requirements, and DOE O 414.1C, Quality Assurance.**

b. **Review a development project for safety analysis or design software. Explain how the problem being addressed by the software was translated into functional requirements, how the requirements were established and controlled, and how the code was reconciled with the original problem.**

c. **Identify how system level requirements are established and then assigned to hardware, software, and human components of a digital instrumentation and control system.**

The information for KSAs ‘c’, ‘d’ and ‘e’ is taken from DOE G 414.1-4.

The Department has recognized the need to establish rigorous and effective requirements for the application of QA programs to safety software. In evaluating DNFSB recommendation 2002-1 and through assessing the current state of safety software, the Department concluded that an integrated and effective SQA infrastructure must be in place throughout the Department’s nuclear facilities.

System-level issues impacting safety software are the availability of trained and knowledgeable personnel to develop, maintain, and use the software; human factor issues such as understandability of the displays or ambient lighting conditions; and potential EMI/RFI, which should be analyzed. Fault tolerance and common cause failure issues, performance requirements, and proper identification and analysis of functional requirements that have safety, security or integrity implications need to be propagated to the safety software.

Safety system requirements provide the foundation for the requirements to be implemented in the software. These system requirements should be translated into requirements specific for the software. The identified software requirements may be documented in system-level requirements documents, software requirements specifications, procurement contracts, and/or acquired software agreements. These requirements should identify functional; performance; security, including user access control; interface and safety requirements; and installation considerations and design constraints, where appropriate. The requirements should be complete, correct, consistent, clear, verifiable, and feasible.

SQA cannot address the risks created by the failure of other system components (hardware, data, human process, power system failures) but can address the software “reaction” to effects caused by these types of failures. SQA should not be isolated from system-level QA and other system-level activities. In many instances, hardware fail-safe methods are implemented to mitigate risk of safety software failure. Additionally other interfaces such as hardware and human interfaces with safety software should implement QA activities.

Safety systems requirements impact instrumentation and control system software, including embedded microprocessors, distributed control systems, supervisory control and data acquisition systems, programmable logic controllers, and other related software.

A broader, more general description of system-level requirements is available in DOE O 414.1C.

d. Identify the typical requirements that define functional interfaces between safety software components and the system-level design, as described in DOE O 414.1C, Quality Assurance, and DOE G 414.1-4, Safety Software Guide for Use with 10 CFR 830, Subpart A, Quality Assurance Requirements, and DOE O 414.1C, Quality Assurance.

During design and implementation the software is developed, documented, reviewed, and controlled. The software design elements should identify the operating system, function, interfaces, performance requirements, installation considerations, design inputs, and design constraints. The software design should be complete and sufficient to meet the software requirements. The design activities and documentation should be adequate to fully describe how the software will fully interface with other system components and how the software will function internally. Data structure requirements and layouts may be necessary to fully understand the internal operations of the software.

Custom developed software will require more formality in the documentation and review of the design than configurable or utility calculations. Simple process flows, relationships between data elements, interfaces with external components, and basic database table structures may be all that are needed for configurable or utility calculations, whereas for custom-developed software, complete functional and logical designs of the software components, the input and output data, and pseudo code may be required to fully understand the safety software design. The software design description may be combined with the documentation of the software requirements or software source code.

During implementation, static analysis, clean room inspections, and reviews are common techniques to ensure the implementation remains consistent with the design and does not add complexity or functions that could decrease the safe operation of the software. Many tools exist to evaluate the complexity and other attributes of the source code design structure. Walkthroughs and more formal inspections, such as Fagan inspections, can be used to identify defects in source code, as well as design descriptions and other software development process outputs.

For software design and implementation work activity for Levels A, B, and C custom developed software applications, the design, including interfaces and data structures, should be completely documented; reviews of the design and code should be performed. Additionally, formal developer testing that includes functional, structural, timing, stress, security, and human-factors testing should be planned, performed, and the results documented. It is recommended that the complexity of the custom developed safety software be evaluated and analysis performed to reduce the complexity of the source code modules.

Configurable and utility calculation for Levels A, B, and C software applications may be graded for this work activity. This grading should include fully performing the design work activities as with custom developed software. However, less formal design and code reviews, such as simple desk checks by another individual other than the developer, may be performed. Developer testing that includes safety functions, security, and performance testing should be performed and documented. This work activity does not apply to acquired or commercial design and analysis safety software types since the design and implementation activities associated with commercial design and analysis software are performed by the service supplier. DOE controls the SQA activities of that software through procurement agreements and specifications.

The design of the software is critical to ensuring safe operation of the system. The software design should consider principles of simplicity, decoupling, and isolation to eliminate hazards. Complexity of the software design, including the logic and number of data inputs, has proven to increase the defect density in software components. The safety features should be separate from non-safety modules, minimizing the impact of failure of one module on another. The interfaces between the modules need to be defined and tested thoroughly.

e. Identify the specific records that must be maintained and the requirements for maintaining these records to document the development of safety system software.

The following documents and records must be maintained: Software Project Management Plan and/or Software Quality Assurance Plan ; Software Safety Plan, Software Configuration Management Plan or related documents; contractual documents or other software procurement and use agreement documentation; Software Requirements Specifications or related document; Software Design Description; Model description; Programmers Reference Model or other related documents; Software Safety Analysis documentation; Verification and Validation Report; Test Case Description, Outcome Report and other testing documents; Software Error Notification and Corrective Action Report; User Instructions or User Manuals; Training Packages and User Qualification.

These documents and records should be evaluated for adequacy and to determine whether they are appropriate and are being used to verify that software requirements and performance criteria described in the software requirements documentation are satisfied.

f. Review a development project for safety system software. Explain how the functional interfaces between components and the system level design were established and controlled.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

39. Mandatory Performance Activity: Electrical personnel shall demonstrate the ability to perform a quarterly walkthrough, bi-annual status walkthrough, or an assessment and generate a report identifying observations and/or findings.

Elements ‘a’ through ‘c’ are performance-based KSAs. The Qualifying Official will evaluate their completion.

a. **Describe and explain the communications that need to be made to the contractor staff with regard to establishing a point of contact, schedule, assistance (if any), etc.**

b. **For each report finding (if any), cite the appropriate requirement(s), describe the "as found" condition, and explain how it is not in compliance with the cited requirement(s).**

c. **For each report observation (if any), describe the "as found" condition and explain why it may be an issue.**

40. During a walkthrough of assigned electrical VSS, electrical personnel shall demonstrate a familiarity level knowledge of functional classifications for safety systems and the design expectations associated with all assigned electrical systems that carry these functional classifications, as described in DOE O 420.1B, Facility Safety, and its associated guide DOE G 420.1-1.

a. **Mandatory Performance Activity: During the mentioned walkthrough electrical personnel shall: identify all equipment that performs a SC, safety significant, and/or defense in depth safety function; explain the related purpose, scope, and application of DOE O 420.1B; describe key terms, essential elements, design expectations, critical decisions, and personnel responsibilities/authorities.**

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

b. **Discuss the project management terminology for which definitions are provided in DOE O 420.1B*.**

> *** Project management terms and their definitions are not provided in DOE O 420.1B. DOE O 413.3, *Program and Project Management for the Acquisition of Capital Assets,* attachment 3 includes definitions for project-management-related terms.**

c. **Discuss in detail the roles played by various management levels within the Department as they relate to the project management system.**

The following is taken from DOE O 413.3A.

Three themes regarding roles and responsibilities necessary to achieve defined project objectives include:

- strengthening line management accountability for successful project management results;
- defining the roles, responsibilities, authority, and accountability of the Federal project management team relative to the contractor project management team; and
- developing effective integrated project teams to assist the Federal project director in planning, programming, budgeting, and successfully acquiring capital assets.

Line managers are responsible for successfully developing, executing, and managing projects within the approved performance baseline. Delegation of authority from one line manager to a lower-level line manager must be documented and consistent with DOE delegation authorities and the qualifications of the lower-level line manager. Although the authority and responsibility for decision-making may be delegated to a lower-level manager, the senior manager remains accountable for the decisions made by subordinate managers.

Key roles and responsibilities of line managers are described in the following sections:

Heads of Field Organizations

- Direct initial project planning and execution roles for projects assigned by the acquisition executive.
- Initiate definition of mission need based on input from sites, laboratories, and program offices.
- Establish the integrated project team.
- Oversee development of project definition, technical scope, and budget to support mission need.
- Initiate development of the acquisition strategy before CD-1 (during the period preceding designation of the Federal project director).
- Perform functions as acquisition executive when so delegated.
- Develop project performance measures, and monitor and evaluate project performance throughout the project's life cycle.
- Allocate resources throughout the program.
- Oversee the project line-management organization and ensure the line project teams have the necessary experience, expertise, and training in design engineering, safety and security analysis, construction, and testing.
- Serve as the Federal project director until the Federal project director is appointed.
- Ensure that safety is fully integrated into design and construction for high-risk, high-hazard, and hazard category 1, 2, and 3 nuclear facilities.

Acquisition Executives

The following roles and responsibilities are for illustrative purposes, and each designated Acquisition Executive is guided by the specific limits of his/her delegated authority:

- Approve critical decisions (CDs) (CD-0 cannot be delegated below the Program Secretarial Officer level).
- Appoint and chair acquisition advisory boards to provide advice and recommendations on key project decisions.
- Approve the appointment of the Federal project director.
- Designate the design authority at CD-1.
- Monitor the effectiveness of Federal project directors and their support staff.
- Approve project changes in compliance with change control levels identified in Project Execution Plans.
- Conduct monthly and quarterly project performance reviews.
- Ensure that safety is fully integrated into design and construction for high-risk, high-hazard, and hazard category 1, 2, and 3 nuclear facilities.

Federal Project Director

Successful performance of DOE projects depends on professional and effective project management by the Federal project director. The Federal project director is responsible and accountable to the acquisition executive/Program Secretarial Officer or delegated authority, as appropriate, for executing the project.

The Federal project director's assigned project must meet cost, schedule, and performance targets unless circumstances beyond the control of the project director result in cost overruns and/or delays. Federal project directors must demonstrate initiative in incorporating and managing an appropriate level of risk to ensure best value for the government. In cases where significant cost overruns and/or delays occur, the Federal project director alerts senior management in a timely manner and takes appropriate steps to mitigate these cost overruns or delays.

Roles and responsibilities of the Federal project director's team must be clearly defined relative to the contractor management team. Further guidance is provided in DOE M 413.3-1.

- Attains and maintains certification in concert with the requirements outlined in DOE O 361.1A before they are delegated authority to serve as a Federal project director.
- Plans, implements, and completes a project using a systems engineering approach.
- Initiates development and implementation of key project documentation (e.g., project execution plan).
- Defines project cost, schedule, performance, and scope baselines.
- Is responsible for design, construction, environmental, safety, security, health, and quality efforts performed comply with the contract, public law, regulations, and Executive Orders.
- Is responsible for timely, reliable, and accurate integration of contractor performance data into the project's scheduling, accounting, and performance measurement systems.
- Evaluates and verifies reported progress; makes projections of progress and identifies trends.
- Serves as the single point of contact between Federal and contractor staff for all matters relating to a project and its performance.
- Serves as the contracting officer's representative, as determined by the contracting officer.
- Leads the integrated project team and provides broad program guidance. Delegates appropriate decision-making authority to the integrated project team members.
- Prepares and maintains the integrated project team charter and operating guidance with integrated project team support.
- Approves changes in compliance with the approved change control process documented in the project execution plan.
- Ensures that safety is fully integrated into design and construction for high-risk, high-hazard, and hazard category 1, 2, and 3 nuclear facilities.

d. Discuss the purpose of "critical decisions." Include in this discussion the responsible authorities for critical decisions.

All of the following is taken from DOE O 413.3A except for the the definition of CD immediately below, which is taken from DOE G 433.1.1.

A CD is a formal determination at a specific point in a project that allows the project to proceed. Critical decisions occur in the course of a project, for example, before conceptual design, execution, and turnover.

The five CDs are major milestones, approved by the Secretarial Acquisition Executive or acquisition executive, that establish the mission need, the recommended alternative, the acquisition strategy, the performance baseline, and other essential elements required to ensure that the project meets applicable mission, design, security, and safety requirements. Each CD marks an increase in commitment of resources by the Department and requires successful completion of the preceding phase or CD. Collectively, the CDs affirm the following:

- There is a need that cannot be met through other than material means.
- The selected alternative and approach are the optimum solution.
- Definitive scope, schedule, and cost baselines have been developed.
- The project is ready for implementation.
- The project is ready for turnover or transition to operations.

The amount of time between decisions will vary. Projects may quickly proceed through the early CDs due to a lack of complexity, the presence of constraints that reduce available alternatives, or the absence of significant technology and developmental requirements. In these cases, more than one CD may be approved simultaneously. Conversely, there may be a need to split a CD.

The following paragraphs delineate the criteria, processes, and authorities for each of the five CDs.

CD-0, Approve Mission Need

The initiation phase begins with the identification of a mission-related need. A program identifies a credible performance gap between its current capabilities and capacities and those required to achieve the goals articulated in its strategic plan and/or in the DOE target enterprise architecture for information technology capital asset projects. A mission need statement is the translation of this gap into functional requirements that cannot be met through other than material means. It should describe the general parameters of the project, how it fits within the mission of the program, and why it is critical to the overall accomplishment of the Department's mission, including the benefits to be realized. The mission need is independent of a particular solution, and should not be defined by equipment, facility, technological solution, or physical end-item. This approach allows the program the flexibility to explore a variety of solutions and not limit potential solutions. Approval of CD-0 formally establishes a project and begins the process of conceptual planning and design used to develop alternative concepts and functional requirements. Additionally, CD-0 approval allows the program to request project engineering and design funds for use in preliminary design, final design, and baseline development.

CD-1, Approve Alternative Selection and Cost Range

CD-1 approval marks the completion of the project definition phase, during which time the conceptual design is developed. This is an iterative process to define, analyze, and refine project concepts and alternatives. This process uses a systems methodology that integrates requirement analysis, risk identification and analysis, acquisition strategies, and concept exploration to evolve a cost-effective, preferred solution to meet a mission need. Approval of CD-1 provides the authorization to begin the project execution phase and allows project engineering and design funds to be used. For design-build projects, project engineering and design funds may be used to develop a statement of work/request for proposal. Additionally, long-lead procurements may be approved during this phase provided National Environmental Policy Act documentation is prepared, where applicable.

CD-2, Approve Performance Baseline

Completion of preliminary design is the first major milestone in the project execution phase. Preliminary design is complete when it provides sufficient information for development of the performance baseline in support of CD-2. The performance baseline is developed based on a mature design, a well-defined and documented scope, a resource-loaded detailed schedule, a definitive cost estimate, and defined key performance parameters. Approval of CD-2 authorizes submission of a budget request for the total project cost. For projects with design periods less than 18 months, a budget request may be submitted prior to CD-2 approval as part of tailoring.

CD-3, Approve Start of Construction

With design and engineering essentially complete, a final design review performed, all environmental and safety criteria met, and all security concerns addressed, the project is ready to begin construction, implementation, procurement, or fabrication. CD-3 provides authorization to complete all procurement and construction and/or implementation activities and initiate all acceptance and turnover activities. Approval of CD-3 authorizes the project to commit all the resources necessary, within the funds provided, to execute the project.

CD-4, Approve Start of Operations or Project Completion

CD-4 marks the achievement of the completion criteria defined in the project execution plan and approval of transition to operations. This decision is predicated on the readiness to operate and/or maintain the system, facility, or capability. Transition and turnover does not necessarily terminate all project activity. Rather, it marks a point at which the operations organizations assume responsibility for operation and maintenance. All projects must have a project transition/closeout plan that clearly defines the basis for attaining initial or full operating capability or meeting performance criteria as required for project closeout, as applicable. The key attributes in turnover are the Government’s readiness to operate, the ability to assume operational responsibility, and the acceptance of the asset.

Critical Decision Approval Authority and Threshold

The Deputy Secretary serves as the Secretarial Acquisition Executive for the Department and promulgates Department-wide policy and direction. The CD authorities, thresholds, and delegations are identified in table 7.

Table 7. Critical decision authority thresholds

Critical Decision Authority	Total Project Cost Thresholds*	Life Cycle Clean-Up Project Cost Thresholds*
Secretarial Acquisition Executive	≥ $750M (or any project on an exception basis when designated by the Secretarial Acquisition Executive) **No delegation authority**	≥ $1B (or any Clean-Up Project on an exception basis when designated by the Secretarial Acquisition Executive) **Delegation authority to Program Secretarial Office on an exception basis**
Under Secretaries	≥ $100M and < $750M (or any project on an exception basis when designated by the Under Secretaries) **Delegation authority to Program Secretarial Officer for projects < $400M**	Not Applicable
Program Secretarial Officer	≥ $20M** and < $100M **Delegation authority to a Program Manager or field organization manager. CD-0 may not be delegated below the Program Secretarial Officer.**	<$1B **Delegation authority to Headquarters or field Senior Executive Service manager. CD-0 may not be delegated below the Program Secretarial Officer.**
Chief Information Officer	> $5M and < $750M Departmental Information Technology Projects **No delegation authority**	Not Applicable

* The Deputy Secretary and the Under Secretaries must be formally notified of all CD-0 and CD-4 approvals for Non-Major System Projects.

** For projects with a Total Project Cost or Environmental Management Total Project Cost less than $20M, the Program Secretarial Officer determines Acquisition Executive authority.

Source: DOE O 413.3A

e. Describe the process by which projects are designated.

The following is taken from DOE O 413.3A,

Projects are designated as either major projects or non-major projects.

> *Major System Projects*
>
> Projects with a Total Project Cost greater than or equal to $750M or Environmental Management Clean-Up Projects with an Environmental Management Total Project Cost of $1B are Major System Projects. All Major System Project Critical Decisions must be proposed by the appropriate Program Secretarial Officer and approved by the Deputy Secretary as DOE's designated Secretarial Acquisition Executive before proceeding to the next project phase or Critical Decision.
>
> *Non-Major System Projects*
>
> Projects with a Total Project Cost less than $750M or Environmental Management Clean-Up Projects with an Environmental Management Total Project Cost less than $1B are Non-Major System Projects. The designated Acquisition Executive must approve all Non-Major System Project Critical Decisions, except for CD-0, which cannot be delegated below the Program Secretarial Officer.

f. Define the term "safety-class" and discuss the implications of an electrical system carrying this functional classification.

The information for KSAs 'f' and 'g' is taken from DOE-STD-3009-94. Additional detail is available from this source and from DOE O 420.1B

Safety-class SSCs are structures, systems, or components, including portions of process systems, whose preventive and mitigative functions are necessary to limit radioactive hazardous material exposure to the public, as determined from the accident analysis.

The results of the accident analysis form the basis for determining additional safety controls imposed on the facility (e.g., SC SSCs and TSRs) as a function of the Evaluation Guideline. These specific controls are then factored into overall safety management programs that ensure the operational discipline required by the hazards identified is maintained.

SC electrical systems must be designed to preclude single point failures.

g. Define the term "safety-significant" and discuss the implications of an electrical system carrying this functional classification.

Safety-significant SSCs are structures, systems, and components that are not designated as SC SSCs but whose preventive or mitigative function is a major contributor to defense in depth and/or worker safety as determined from safety analyses.

The results of the hazard analysis must be used to identify the design basis accidents that in turn must be used to define the functional and performance requirements of the facility safety SSCs. Safety SSCs required to prevent or mitigate accidents whose consequences approach or exceed offsite evaluation guidelines must be defined as SC SSCs, while SS SSCs must be selected for worker protection and to provide defense in depth.

As a rule of thumb, SS SSC designations based on worker safety are limited to those SSCs whose failure is estimated to result in a prompt worker fatality or serious injuries (e.g., loss of eye, loss of limb) or significant radiological or chemical exposures to workers. This is neither an evaluation guideline nor a quantitative criterion. It represents a threshold of concern for which SS SSC designation may be warranted. Estimates of worker consequences for the purpose of an SS SSC designation are not intended to require detailed analytical modeling, due to the uncertainties in analyses, especially for facility workers. Considerations should be based on engineering judgment of possible effects and the potential added value of SS SSC designation. Experience has shown that SS SSCs identified through defense-in-depth considerations also provide safety for workers.

41. Electrical personnel shall demonstrate a familiarity level knowledge of electrical safety systems criteria for VSS (IEEE Stds-308-2001, 323-2003, 379-2000, 384-1992, and 603-1998; DOE O 420.1B; DOE G 420.1-1; etc.).

a. Identify and describe the following requirements for principal design criteria of electrical power systems supporting VSS (Class 1E power systems): design basis and design basis events, independence, the equipment qualification process for Class 1E power systems, single-failure criterion, requirements for connecting of non-Class 1E systems to Class 1E systems, and Class 1E protection requirements.

Design Basis

The information for design basis and design basis events (DBEs) is taken from IEEE Std 308-2001.

A specific design basis shall be provided for the Class 1E power systems of each nuclear power generating station. The design basis shall include, as a minimum, the following:

- Events requiring operation of the Class 1E power systems
- Actuation signals for operation of the Class 1E power systems
- A list of the loads connected to the Class 1E buses and standby power supplies
- The sequence for start-up and the loading profile of the Class 1E power sources
- Time, voltage, speed, and other limits applicable to the standby generators and their prime movers when subjected to the start-up sequence of events
- The malfunctions, accidents, environmental events, and operating modes that could physically damage Class 1E power systems or lead to degradation of system performance and for which provisions shall be incorporated
- The acceptable ranges for transient and steady-state conditions of both the energy supply and environment (e.g., voltage, frequency, humidity, temperature, pressure, vibration, etc.) during normal, abnormal, and accident circumstances throughout which the equipment must perform

- Minimum equipment or system performance criteria (e.g., standby power supply unit start-up time, undervoltage relay accuracy, voltage regulation limits, load limits, battery charging time, voltage, etc.)
- Conditions that should be permitted to shut down or disconnect Class 1E power sources (e.g., differential relay actuation, engine overspeed)

Design Basis Events

Design basis events established for a unit shall indicate the postulated events that might adversely affect the Class 1E power system. The severity and expected results of those events shall be defined. The required portions of the Class 1E power systems shall be capable of performing their function when subjected to the effects of any DBE.

Independence

The following is taken from IEEE Std 384-1992. It summarizes what is available from that source.

Independence of redundant equipment and circuits shall be in accordance with IEEE Std 384-1992. Physical separation and electrical isolation shall be provided to maintain the independence of Class 1E circuits and equipment so that the safety functions required during and following any DBE can be accomplished.

The physical separation of circuits and equipment shall be achieved by the use of SC structures, separation distance, or barriers or any combination thereof. Electrical isolation shall be achieved by the use of separation distance, isolation devices, shielding and wiring techniques, or combinations thereof.

Equipment and circuits requiring independence shall be determined and delineated during the plant design and shall be identified on documents and drawings in a distinctive manner.

The independence of Class 1E circuits and equipment shall not be compromised by the functional failure of auxiliary supporting features. For example, an auxiliary supporting feature (such as Class 1E switchgear room ventilation) shall be assigned to the same division as the Class 1E system it is supporting in order to prevent the loss of mechanical function in one division from causing loss of electrical function in another division.

Equipment Qualification Process for Class 1E Power Systems

The following is taken from IEEE Std 323-2003.

A type test subjects a representative sample of equipment, including interfaces, to a series of tests, simulating the effects of significant aging mechanisms during normal operation. The sample is subsequently subjected to DBE testing that simulates and thereby establishes the tested configuration for installed equipment service, including mounting, orientation, interfaces, conduit sealing, and expected environments. A successful type test demonstrates that the equipment can perform the intended safety function(s) for the required operating time before, during, and/or following the DBE, as appropriate.

The primary objective of qualification is to demonstrate with reasonable assurance that Class 1E equipment for which a qualified life or condition has been established can perform its safety function(s) without experiencing common-cause failures before, during, and after applicable DBEs. Class 1E equipment, with its interfaces, must meet or exceed the equipment specification requirements. This continued capability is ensured through a program that includes, but is not limited to, design control, QC, qualification, installation, maintenance, periodic testing, and surveillance.

For equipment located in a mild environment for meeting its functional requirements during normal environmental conditions and anticipated operational occurrences (AOOs), the requirements shall be specified in the design/purchase specifications. A qualified life is not required for equipment located in a mild environment and which has no significant aging mechanisms. When seismic testing is used to qualify equipment located in a mild environment, pre-aging prior to the seismic tests is required only where significant aging mechanisms exist. A maintenance/surveillance program based on a vendor's recommendations, which may be supplemented with operating experience, should ensure that equipment meets the specified requirements.

Degradation with time followed by exposure to environmental extremes of temperature, pressure, humidity, radiation, vibration and, if applicable, chemical spray and submergence resulting from a DBE condition can precipitate common-cause failures of Class 1E equipment. For this reason, it is necessary to establish a qualified life for equipment with significant aging mechanisms. The qualified life determination must consider degradation of equipment capability prior to and during service. Inherent in establishing a qualified life is that a qualified condition is also established. This qualified condition is the state of degradation for which successful performance during a subsequent DBE was demonstrated.

Single-Failure Criterion

The following is taken from IEEE Std 379-2000.

Class 1E power systems shall perform all safety functions required for a DBE in the presence of

- any single detectable failure within the Class 1E power systems concurrent with all identifiable but nondetectable failures
- all failures caused by the single failure
- all failures and spurious system actions that cause or are caused by the DBE requiring the safety functions

The single failure could occur prior to, or at any time during, the DBE for which the safety system is required to function. The single-failure criterion (SFC) applies to the Class 1E power systems whether control is by automatic or manual means.

A probabilistic assessment shall not be used in lieu of the single-failure analysis. However, reliability analysis, probability assessment, operating experience, engineering judgment, or a combination thereof, may be used to establish a basis for excluding a particular failure from the single-failure analysis. For further guidance in performing reliability analyses and probabilistic assessments, see IEEE Std 352-1987 and IEEE Std 577-1976.

Where reasonable indication exists that a design that meets the SFC may not satisfy all the reliability requirements specified in the design basis, a probabilistic assessment of the Class 1E power system shall be performed. The assessment shall not be limited to single failures. If the assessment shows that the design basis reliability requirements are not met, design features shall be provided or corrective modifications shall be made to ensure that the system meets the specified reliability requirements.

Requirements for Connecting of Non-Class 1E Systems to Class 1E Systems

The following is taken from IEEE Std 308-2001.

Connection of non-Class 1E circuits to Class 1E power systems is not recommended. However, if connections are made, they should be limited to loads that need connection to a reliable standby power source. If non-Class 1E circuits are supplied from Class 1E power systems, the Class 1E systems shall not be degraded below an acceptable level as specified by IEEE Std 308-2001. The non-Class 1E circuits shall meet the independence and isolation requirements as established in IEEE Std 384-1992.

Class 1E Protection Requirements

The following is taken from IEEE Std 741-1997. It is a summary of what is available from that source.

Protective devices shall be provided to limit the degradation of the Class 1E power systems below an acceptable level in accordance with IEEE Std 741-1997.

As used in IEEE Std 741-1997, protection refers to the sense, command, and execute features with their associated interconnections (see IEEE Std 603-1991) that are provided to minimize equipment damage and any interruption of electrical service resulting from mechanical or electrical failures or other unacceptable conditions.

Protection includes equipment required to support the Class 1E power system in the performance of its safety function, and components whose function is to increase the availability and reliability of the safety-related equipment. The protection shall be capable of the following:

- Preventing failures in safety systems and equipment from disabling safety functions to below an acceptable level. The protective actions of each load group shall be independent of the protective actions provided by redundant load groups (see IEEE Std 308-2001).
- Operating the required devices upon detection of unacceptable conditions to reduce the severity and extent of electrical system disturbances, equipment damage, and potential personnel and property hazards.
- Monitoring the connected preferred power supply and, where an alternate preferred power supply is provided by the design, of automatically initiating a transfer or alerting the operator to manually transfer to the preferred alternate power supply.
- Providing indication and identification of the protective operations.
- Periodic testing to verify logic schemes and protective functions.
- Being designed in such a way that the availability of protection control power is monitored.

- Periodic testing to verify setpoints. This requirement is not applicable to fuses.

b. Identify and describe the requirements for supplementary design criteria of electrical power systems supporting VSS (Class 1E power systems): Class 1E power systems, AC power systems, DC power systems; instrumentation and control power systems, and execute and sense-and-command features.

The information for KSAs 'b' and 'c' is taken from IEEE Std 308-2001.

Class 1E Power Systems, AC Power Systems, DC Power Systems

Class 1E power systems consist of an AC power system, a DC power system, and an instrument and control power system. The Class 1E power systems shall support the safety systems by providing acceptable power under the conditions stated in the design basis. The duration of the connection between the preferred power supply and the standby power supply shall be minimized (e.g., limited to the time required to perform standby power supply testing). Refer to IEEE Std 741-1997 for information on automatic bus transfers that may be included in the design of these systems.

The AC power system shall include power supplies and distribution systems arranged to provide power to the Class 1E AC loads and controls. Features such as physical separation, electrical isolation, redundancy, and qualified equipment shall be included in the design to aid in preventing a mechanism by which a single DBE could cause redundant equipment within the station's Class 1E power system to be inoperable. Design requirements shall include the following:

- The Class 1E electric loads shall be separated into two or more redundant load groups.
- The protective actions of each load group shall be independent of the protective actions provided by redundant load groups.
- Each of the redundant load groups shall have access to both a preferred and a standby power supply.
- Two or more load groups may have a common power supply if the consequences of the loss of the common power supply to the load groups under DBEs are acceptable.
- Features shall be incorporated in the design of the standby power supply so that any DBE will not cause failures in redundant power sources. In addition, the design shall minimize common-cause failures of a preferred power source and standby power source associated with a single load group.

The DC power systems include power supplies and distribution systems arranged to provide power to the Class 1E DC loads and for control and switching of the Class 1E power systems. Features such as physical separation, electrical isolation, redundancy, and qualified equipment shall be included in the design to aid in preventing a mechanism by which a single DBE can cause redundant equipment within the station's Class 1E power system to be inoperable. (For guidance, refer to IEEE Std 946-1992.)

Design requirements shall include the following:

- The Class 1E electric loads shall be separated into two or more redundant load groups.

- The protective actions of each load group shall be independent of the protective actions provided by redundant load groups.
- Each of the redundant load groups shall have access to a power supply that consists of one or more batteries and one or more battery chargers.
- Each load group shall have its own battery charger (or chargers) with no automatic interconnecting provision. Two or more chargers may have a common AC power supply if the consequences of the loss of the power supply to the load group under design basis conditions are acceptable.
- The batteries shall have features so that common-cause failures are minimized between redundant batteries. For further guidance, refer to IEEE Std 484-1996.

Instrumentation and Control Power Systems

The instrumentation and control power systems include power supplies and distribution systems arranged to provide AC and DC electric power to the Class 1E instrumentation and control loads.

These systems shall be designed to provide a highly reliable source of power to the reactor trip system, engineered safety features, auxiliary supporting features, and other auxiliary features.

Design requirements shall include the following:

- The Class 1E instrumentation and control loads shall be separated into two or more redundant load groups.
- The protective actions of each load group shall be independent of the protective actions provided by redundant load groups.
- Two or more independent DC power supplies shall be provided for instrumentation and control. Within each redundant division, the DC source may be a common battery for both Class 1E DC power and instrumentation and control loads.
- Two or more independent AC power supplies shall be provided for instrumentation and control.
- The sources and effects of harmonics shall be considered.

To meet the requirements, special power supplies may be required that are isolated from the AC and DC power supplies used for the normal instrumentation and control of the unit(s).

Execute Features

The execute features are listed in table 8. They include actuation devices, interconnecting wire and cabling, and actuated equipment that utilize electric power to provide actions when signals are received from the sense and command features. The execute features are subject to the execute features functional and design requirements in clause 7 of IEEE Std 603-1998 and the supplementary requirements in section IEEE Std 308-2001, section 5.5.2.

If manual control of any actuated equipment in the execute features is required, the features necessary to accomplish such manual control shall

- be Class 1E;
- meet the requirements of IEEE Std 308-2001, section 5.5.1;

- be shown by analysis not to defeat the requirements of 6.2 and 7.2 of IEEE Std 603-1998 concerning manual initiation.

Table 8. Items included in systems covered by scope

General Elements	Illustrative Examples
Execute features	
Actuation devices	Circuit breakers
	Controllers
	Control relays
	Control switches
	Pilot valves
Actuated equipment	Motors
	Solenoids
	Heaters
Sense and command features	
Instrumentation, controls, and electrical protection (associated with power supplies and distribution equipment)	Surveillance indicators
	Switches
	Current transformers
	Voltage transformers
	Transducers
	Protective relays
	Frequency relays
	Microprocessors

Source: IEEE Std 308-2001

Sense and Command Features

The sense and command features are subject to the sense and command features functional and design requirements in clause 6 of IEEE Std 603-1998.

Protective devices shall be provided for the actuated equipment of the execute features to limit degradation of the Class 1E actuated equipment. Sufficient indication shall be provided to identify the actuation of the protective device. Where application of the protective devices can prevent completion of a safety function, they may be omitted (or bypassed), provided such omission does not degrade the Class 1E power system below an acceptable level. In general, the safety functions of the safety system do not include the safety functions normally associated with circuit and equipment fault protection.

c. Describe the relationship between surveillance and test requirements and design of electrical systems supporting the VSS.

Operational status information shall be provided for Class 1E power systems. The extent, selection, and application of the various surveillance methods, including periodic testing, to indicate the operational status of Class 1E power systems, depend on individual plant design requirements. Illustrative surveillance methods for Class 1E equipment are outlined in table 9.

Table 9. Illustrative surveillance methods

Equipment—Class 1E	Parameter	Illustrative Surveillance Methods				
		By Continuous Monitoring				
		INST	IND LTS	ANN	COMP	By periodic tests
Diesel generator	Auxiliary systems	o	o	xo		*
	Voltage	xo			x	
	Frequency	xo			x	
	Current	xo			x	
	Power factor	xo				
	Power	xo				
	Reactive power	xo				
	Winding temperature				x	
	Field current	xo				
	Field voltages	xo				
	Ground			xo		
	Control voltage			xo		
	Starting capability					*
	Loading capability					*
	Breaker position		xo	x	x	*
	Protective relay			x		*
Switchgear bus	Voltage	xo			x	
	Incoming current	xo			x	
	Ground			x		
	Supply breaker position		xo	x	x	*
	Control voltage			x		
	Protective relay			x		*
Station battery	Current	o				
	Breaker open			x		
	Test breaker closed			x		
Battery charger	Output voltage	o		x		
	Current (output)	o				
	Direct current power failure			x		
	Alternating current power failure			x		
	Breaker open			x		

Equipment—Class 1E	Parameter	Illustrative Surveillance Methods				
		By Continuous Monitoring				
		INST	IND LTS	ANN	COMP	By periodic tests
	High direct current voltage relay (Opens main alternating current supply breaker)					
Direct current bus	Voltage	xo		x		
	Ground	o		x		
	Cross tie breaker closed			x		
Instrument and control power system	Voltage	o				
	Current	o				
	Breaker/fuse status			x		
	Power quality (e.g., Total Harmonic Distortion)					x

Key:		
	INST	Instrumentation
	IND LTS	Indicating lights
	ANN	Annunciator
	COMP	Computer
	x	Denotes methods in the main control room.
	o	Denotes methods outside the main control room.
	*	Periodic rest is supplementary or an alternative to continuous surveillance as indicated.

Source: IEEE Std 308-2001

d. Discuss the Equipment Qualification process for Class 1E power systems in support of VSS: principles of equipment qualification, qualification methods, the qualification program, and documentation requirements.

The following is taken from IEEE Std 323-2003.

The primary objective of qualification is to demonstrate with reasonable assurance that Class 1E equipment for which a qualified life or condition has been established can perform its safety function(s) without experiencing common-cause failures before, during, and after applicable DBEs. Class 1E equipment, with its interfaces, must meet or exceed the equipment specification requirements. This continued capability is ensured through a program that includes, but is not limited to, design control, QC, qualification, installation, maintenance, periodic testing, and surveillance.

For equipment located in a mild environment for meeting its functional requirements during normal environmental conditions and AOOs, the requirements shall be specified in the design/purchase specifications. A qualified life is not required for equipment located in a mild environment and which has no significant aging mechanisms. When seismic testing is used to qualify equipment located in a mild environment, pre-aging prior to the seismic tests is required only where significant aging mechanisms exist (see IEEE Std 323-2003, section 6.2.1.1). A maintenance/surveillance program based on a vendor's recommendations, which may be supplemented with operating experience, should ensure that equipment meets the specified requirements.

Degradation with time followed by exposure to environmental extremes of temperature, pressure, humidity, radiation, vibration and, if applicable, chemical spray and submergence resulting from a DBE condition can precipitate common-cause failures of Class 1E equipment. For this reason, it is necessary to establish a qualified life for equipment with significant aging mechanisms. The qualified life determination must consider degradation of equipment capability prior to and during service. Inherent in establishing a qualified life is that a qualified condition is also established. This qualified condition is the state of degradation for which successful performance during a subsequent DBE was demonstrated.

Qualification Methods

Operations Test. A type test subjects a representative sample of equipment, including interfaces, to a series of tests, simulating the effects of significant aging mechanisms during normal operation. The sample is subsequently subjected to DBE testing that simulates and thereby establishes the tested configuration for installed equipment service, including mounting, orientation, interfaces, conduit sealing, and expected environments. A successful type test demonstrates that the equipment can perform the intended safety function(s) for the required operating time before, during, and/or following the DBE, as appropriate.

Operations Experience. Performance data from equipment of similar design that has successfully operated under known service conditions may be used in qualifying other equipment to equal or less severe conditions. Applicability of this data depends on the adequacy of documentation establishing past service conditions, equipment performance, and similarity against the equipment to be qualified and upon which operating experience exists. A demonstration of required operability during applicable DBE(s) shall be included in equipment qualification programs based on operating experience, when DBE qualification is required.

Analytical Model. Qualification by analysis requires a logical assessment or a valid mathematical model of the equipment to be qualified. The bases for analysis typically include physical laws of nature, results of test data, operating experience, and condition indicators. Analysis of data and tests for material properties, equipment rating, and environmental tolerance can be used to demonstrate qualification. However, analysis alone cannot be used to demonstrate qualification.

Equipment may be qualified by combinations of type test, operating experience, and analysis. For example, where type test of a complete assembly is not possible, component testing supplemented by analysis may be used.

The Qualification Program

The essential elements of equipment qualification include the following:

- Equipment specification, including definition of the safety function(s)
- Acceptance criteria

- Description of the service conditions, including applicable DBEs and their duration
- Qualification program plan
- Implementation of the plan
- Documentation demonstrating successful qualification, including maintenance activities required to maintain qualification. The equipment user is responsible for specifying performance requirements
- Verifying that the documentation demonstrates that the requirements have been satisfied

A technical description of the equipment to be qualified, including applicable performance and qualification standards, shall be provided.

Loadings at interfaces (i.e., physical attachments, mounting, auxiliary components, connectors [electrical and mechanical] to the equipment at the equipment boundary) shall be specified. Motive power or control signal inputs and outputs, and the physical manner by which they are supplied (e.g., connectors, terminal blocks), shall be specified. Control, indicating, and other auxiliary components mounted internal or external to the equipment and required for proper operation shall be included. Material incompatibilities at interfaces shall be considered and evaluated.

Where applicable, the equipment qualified life objective of the program shall be stated.

The equipment specification shall identify the equipment's safety function(s), including the required operating times.

Note: Components not involved in the equipment's safety function(s) may be excluded from the qualification process if it can be demonstrated and documented that assumed failures, including spurious operation, have no adverse effect on any and all safety functions, have no adverse effect on the safety function of interfaced equipment, would not mislead an operator, and shall not fail in a manner as to cause the failure of other safety-related electric equipment.

The service conditions for the equipment shall be specified. These conditions shall include the nominal values and their expected durations, as well as extreme values and their expected durations. Examples include, but are not limited to, the following:

- Ambient pressure and temperature
- Relative humidity
- Radiation environment
- Seismic operating basis earthquake and non-seismic vibration
- Operating cycles
- Electrical loading and signals
- Condensation, chemical spray, and submergence
- EMI/RFI and power surges

The postulated DBE conditions, including specified high-energy line break, loss-of-coolant accident, main steam line break, and/or safe shutdown seismic events, during or after which the equipment is required to perform its safety function(s), shall be specified. Equipment shall be qualified for the duration of its operational performance requirement for each applicable DBE condition, including any required post-DBE operability period.

Documentation Requirements

Documentation shall be retained throughout the qualified life of the equipment or its installed life. The documents required to demonstrate the qualification of Class 1E equipment located in a mild environment are the design/purchase specifications, seismic test reports (if applicable), and an evaluation and/or certificate of conformance. The design/purchase specifications shall contain a description of the functional requirements for a specific environmental zone during normal environmental conditions and AOOs.

The qualification documentation shall provide evidence that the Class 1E equipment is qualified for its application, meets its specification requirements, and has its qualified life and periodic surveillance, maintenance, and/or condition monitoring interval established. Data used to demonstrate the qualification of the equipment shall be pertinent to the application and shall be organized in a readily understandable and traceable manner that permits independent auditing of the conclusions presented.

The harsh environment documentation requirements are as follows:

- Identification of the equipment being qualified, including manufacturer, model, and model family, if applicable
- Identification of the safety-related function(s)
- Identification and description of the qualification method utilized
- Identification of test sample equipment, if applicable
- Identification of normal environmental conditions, including those resulting from AOOs, as applicable, for temperature, pressure, radiation, relative humidity, EMI/RFI, power surge environment and operational cycling, and DBEs to which the equipment is qualified
- Identification of the acceptance criteria and performance results
- Identification of the test sequence, if applicable
- Identification of installation considerations and requirements for mounting, orientation, interfaces, and conduit sealing
- Identification of tested configuration (whether any connections within the test chamber are exposed to simulated accident effects)
- Justification of how test sample equipment is representative of the qualified equipment
- Evaluation of significant aging mechanisms and the method for addressing these in the qualification program
- Identification of the qualified life of the equipment and its basis
- Identification of age conditioning test results, as applicable
- Identification of the DBE test results, as applicable, including temperature versus time curve, pressure versus time curve, humidity, chemical spray, water spray, electrical loading, mechanical loading, applied voltage, applied frequency, and submergence
- Identification of radiation test results, as applicable, including radiation type, dose rate, and total dose
- Identification of seismic test results, as applicable

- Identification of margin, as applicable, for peak temperature, peak pressure, radiation, power supply voltage, operating time, and seismic level
- Identification of any scheduled surveillance, maintenance, periodic testing, or component replacement required to maintain qualification
- Evaluation of test anomalies, including effect on qualification
- Summary and conclusions, including limitations or caveats, and qualified life, and any periodic surveillance/maintenance interval determination

e. Discuss the concept of "independence"; identify some of the general criteria for attaining "independence," e.g., physical separation, electrical isolation and devices, methods of achieving independence, and associated circuits; describe the general concept of "specific separation criteria," e.g., area classification and separation distances; discuss the major requirements for circuit breakers and fuses to be considered as "isolation" devices.

The following is taken from IEEE Std 384-1992.

Physical separation shall be provided to maintain the independence of Class 1E circuits and equipment so that the safety functions required during and following any DBE can be accomplished.

Electrical Isolation and Devices

Electrical isolation of power circuits shall be achieved by Class 1E isolation devices applied to interconnections of the following kinds of circuits (figure 66):

- Non-Class 1E and Class 1E circuits
- Associated circuits and non-Class 1E circuits

A device is considered to be a power circuit isolation device if it is applied such that the maximum credible voltage or current transient applied to the non-Class 1E side of the device will not degrade below an acceptable level the operation of the circuit on the other side of that device.

Methods of Achieving Independence

The physical separation of circuits and equipment shall be achieved by the use of SC structures, separation distance, or barriers or any combination thereof. Electrical isolation shall be achieved by the use of separation distance, isolation devices, shielding and wiring techniques, or combinations thereof.

Associated Circuits

Non-Class 1E power, control, and instrumentation circuits become associated in one or more of the following ways:

- Electrical connection to a Class 1E power supply without the use of an isolation device (see figure 66)
- Electrical connection to an associated power supply without the use of an isolation device (see figure 66)
- Proximity to Class 1E circuits and equipment without the required physical separation or barriers (see figure 67)

- Proximity to associated circuits and equipment without the required physical separation or barriers (see figure 67)
- Sharing a Class 1E or associated signal source without the use of an isolation device (see figures 68 and 69)

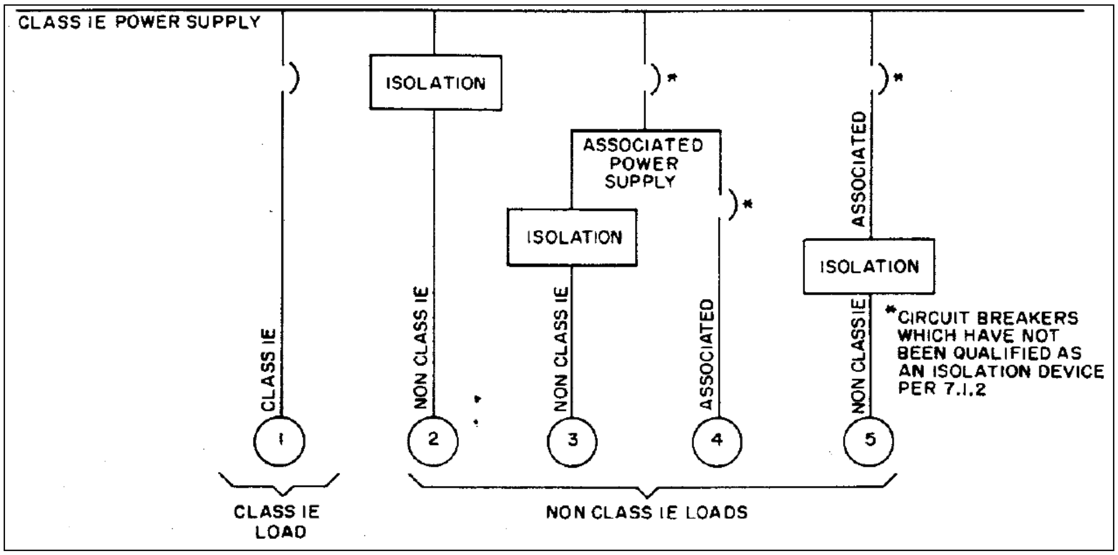


Figure 66. Association by connection and application of isolation devices

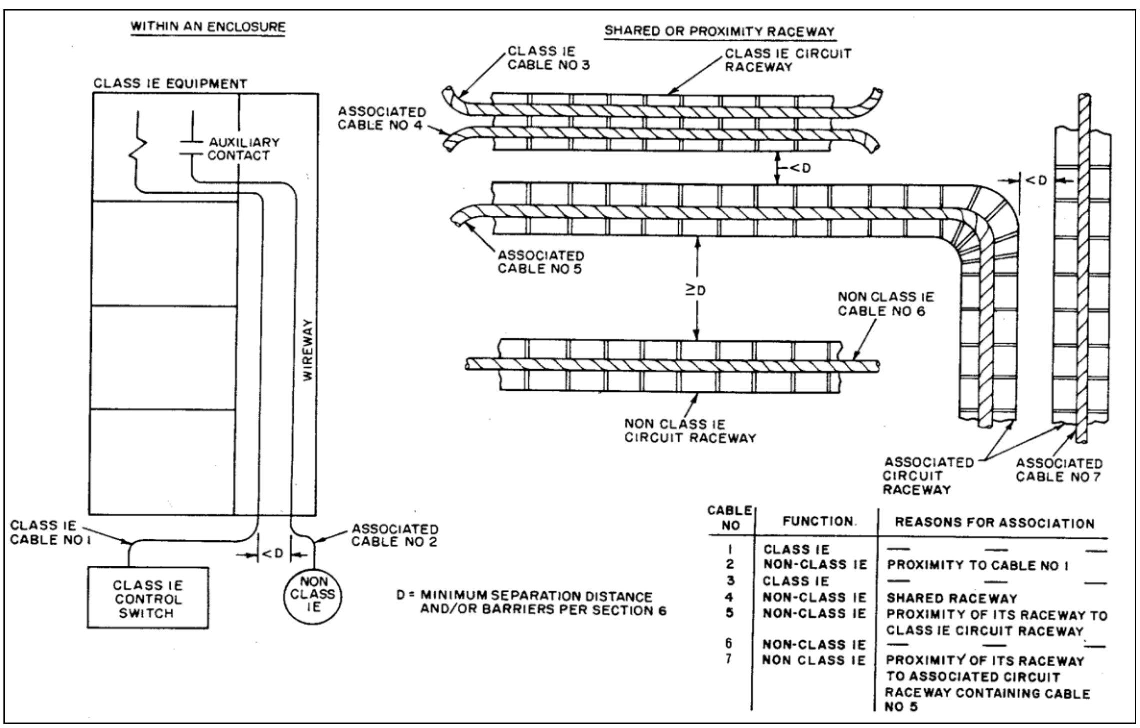


Figure 67. Association by proximity

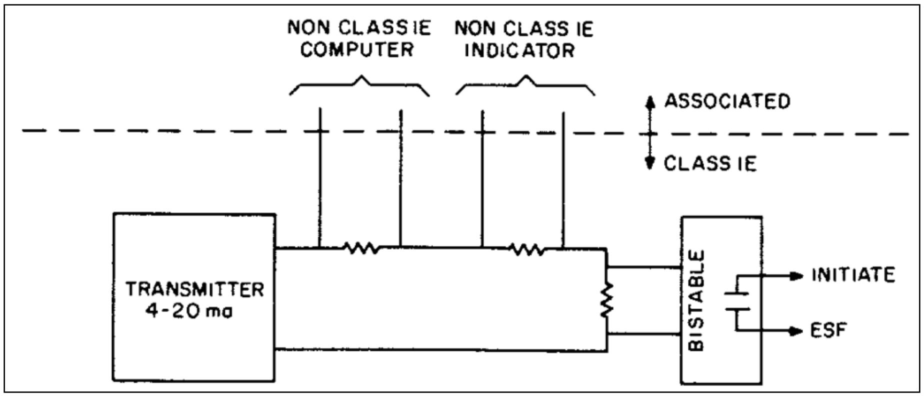
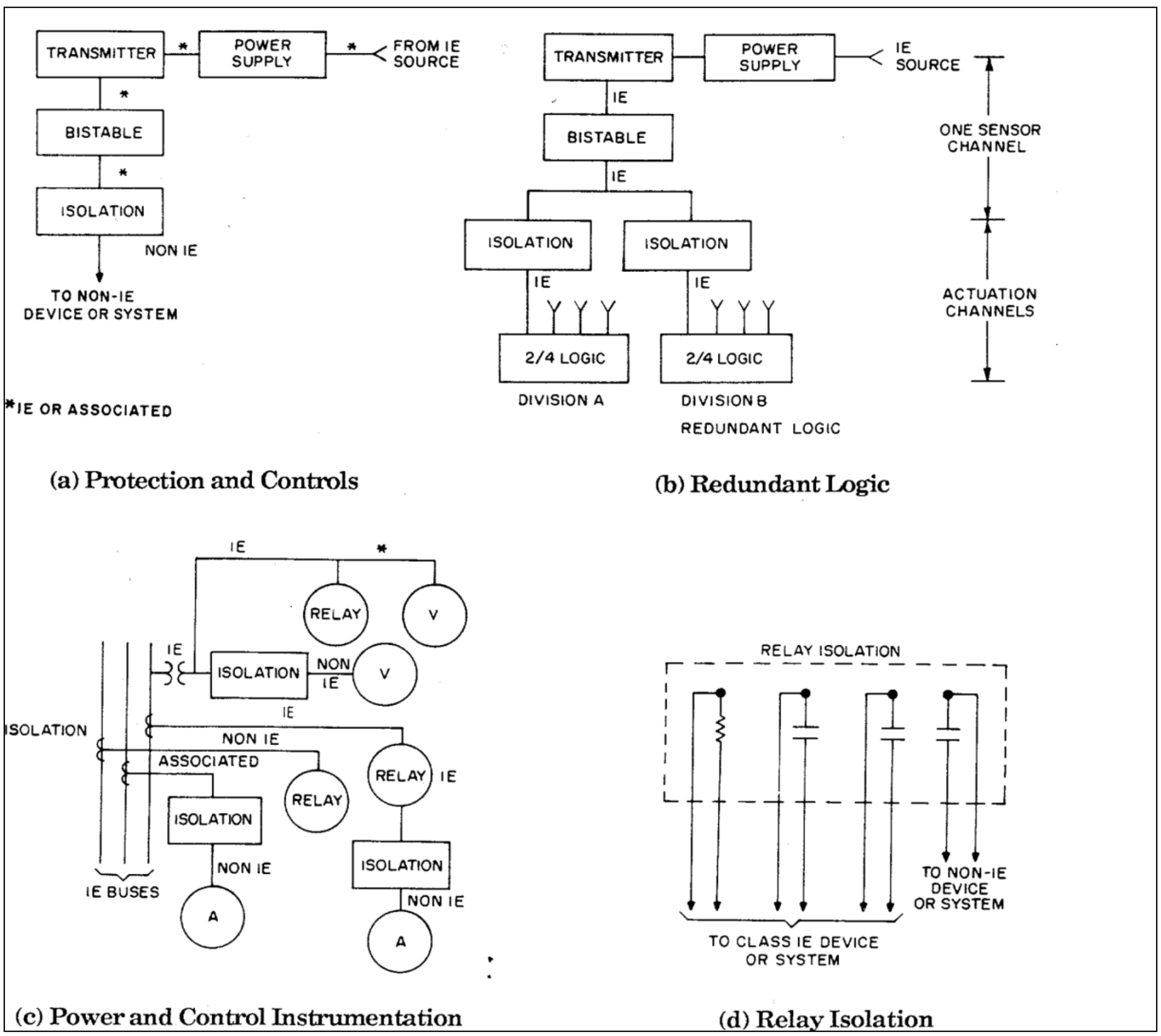


Figure 68. Association by shared signal source



Source: Figures 66–69, IEEE Std 384-1992

Figure 69. Isolation device application in control and instrumentation circuits

Associated Circuits—Independence

Associated circuits shall comply with one of the following requirements:

- They shall be uniquely identified as such or as Class 1E and shall remain with (traceable to the associated Class 1E division), or be physically separated the same as, those Class 1E circuits with which they are associated. They shall be subject to the requirements placed on Class 1E circuits, unless it can be demonstrated by analysis or testing that the absence of such requirements cannot degrade the Class 1E circuits below an acceptable level.
- They shall be in accordance with the preceding list item, from the Class 1E equipment to and including an isolation device. Beyond the isolation device, such a circuit is non-Class 1E provided that it does not again become associated with a Class 1E system.
- They shall be analyzed or tested to demonstrate that Class 1E circuits are not degraded below an acceptable level.

Associated circuits, including their isolation devices or the connected loads without the isolation devices, shall be subject to the qualification requirements placed on Class 1E circuits to ensure that the Class 1E circuits are not degraded below an acceptable level. Associated circuits need not be qualified for performance of function, since the function is non-Class 1E.

Specific Separation Criteria—Area Classification and Separation Distances

The areas through which Class 1E and associated circuit cables are routed and in which equipment is located shall be reviewed for the existence of potential hazards such as high-energy piping, missiles, combustible material, ignition sources, and flooding. These areas, explained in greater detail in IEEE Std 384-1992, shall be classified as follows:

- Non-hazard areas (see section 6.1.3)
- Limited-hazard areas (see section 6.1.4)
- Hazard areas (see section 6.1.5)

Separation commensurate with the damage potential of the hazard shall be provided for early in the design through the use of features such as separate rooms. Opposite sides of rooms or areas may be used provided there is an adequate heat removal capability.

The minimum separation distances specified in IEEE Std 384-1992, sections 6.1.3, 6.1.4, and 6.1.5, may be used to provide adequate physical separation if the following criteria are met:

- All cables involved shall meet the fire propagation requirements of IEEE Std 383-1974.
- Exposed raceways other than conduit shall be noncombustible per ASTM E136-92. Exposed conduit shall meet the requirements of metallic conduit per IEEE Std 628-1987.
- Raceway fire stops through fire barriers shall have a fire-resistance rating commensurate with the fire hazards being protected against.
- Open trays shall be as defined in NEMA VE 1-1991 for ladder or trough-type.
- Enclosed trays shall be solid-bottom-type as defined in NEMA VE 1-1991, with a solid cover or open trays with solid top and bottom covers.

These distances reflect the minimum acceptable for physical separation to maintain independence. Other considerations such as maintenance, cable pulling, and termination may require greater distances.

In IEEE Std 384-1992, sections 6.1.3, 6.1.4, and 6.1.5, separation distances are grouped into the following three categories:

- Open to open: Includes open tray to open tray, open tray to free-air cable, and free-air cable to free-air cable configurations
- Enclosed to enclosed: Includes enclosed tray to enclosed tray, enclosed tray to conduit, and conduit to conduit configurations
- Enclosed to open: Includes enclosed tray to open tray, enclosed tray to free-air cable, conduit to open tray, and conduit to free-air cable configurations

Requirements for Circuit Breakers and Fuses to Be Considered as "Isolation" Devices

When the following requirements are met, the circuit breakers may be used as acceptable isolation devices for instrumentation and control circuits:

- A device is considered an electrical isolation device for instrumentation and control circuits if it is applied so that (a) the maximum credible voltage or current transient applied to the device's non-Class 1E side will not degrade the operation of the circuit connected to the device Class 1E or associated side below an acceptable level; and (b) shorts, grounds, or open circuits occurring in the non-Class 1E side will not degrade the circuit connected to the device Class 1E or associated side below an acceptable level.
- The highest voltage to which the isolation device non-Class 1E side is exposed shall determine the minimum voltage level that the device shall withstand across the non-Class 1E side terminals, and between the non-Class 1E side terminals and ground. Transient voltages that may appear in the non-Class 1E side must also be considered.
- The separation of the wiring at the input and output terminals of the isolation device may be less than 1 in. (2.5 cm) as required in 6.6.2 of IEEE Std 384-1992, provided that it is not less than the distance between input and output terminals.
- Minimum separation requirements do not apply for wiring and components within the isolation device; however, separation shall be provided wherever practicable.
- The capability of the device to perform its isolation function shall be demonstrated by qualification test. The qualification shall consider the levels and duration of the fault current on the non-Class 1E side.

When the circuit breaker requirements listed above are met, a fuse may be used as an isolation device (except between redundant divisions) if the following additional criteria are met:

- Fuses shall provide the design overcurrent protection capability for the life of the fuse.
- The fuse time-overcurrent trip characteristic for all circuit faults shall cause the fuse to open prior to the initiation of an opening of any upstream interrupting device.
- The power source shall supply the necessary fault current to ensure the proper coordination without loss of function of Class 1E loads.

f. State the general requirement for the single-failure criterion (SFC) and identify the major conditions used to apply the SFC to safety systems design: independence and redundancy; non-detectable, cascaded, common-cause failures; design basis events; and shared systems.

All of the information for this KSA is taken from IEEE Std 379-2000 unless specified otherwise.

General Requirement for the SFC

The following is taken from IEEE Std 603-1998.

The safety systems shall perform all safety functions required for a DBE in the presence of

- any single detectable failure within the safety systems concurrent with all identifiable but nondetectable failures
- all failures caused by the single failure
- all failures and spurious system actions that cause or are caused by the DBE requiring the safety functions

The single failure could occur prior to, or at any time during, the DBE for which the safety system is required to function. The SFC applies to the safety systems whether control is by automatic or manual means. IEEE Std 379-2000 provides guidance on the application of the SFC. (Additionally, IEEE Std 7- 4.3.2-1993 addresses common-cause failures for digital computers.)

This criterion does not invoke coincidence (or multiple-channel) logic within a safety group; however, the application of coincidence logic may evolve from other criteria or considerations to maximize plant availability or reliability. An evaluation has been performed and documented in other standards to show that certain fluid system failures need not be considered in the application of this criterion. The performance of a probabilistic assessment of the safety systems may be used to demonstrate that certain postulated failures need not be considered in the application of the criterion. A probabilistic assessment is intended to eliminate consideration of events and failures that are not credible; it shall not be used in lieu of the SFC. IEEE Std 352-1987 and IEEE Std 577-1976 provide guidance for reliability analysis.

Where reasonable indication exists that a design that meets the SFC may not satisfy all the reliability requirements specified in clause 4, item i, of IEEE Std 603-1998, of the design basis, a probabilistic assessment of the safety system shall be performed. The assessment shall not be limited to single failures. If the assessment shows that the design basis requirements are not met, design features shall be provided or corrective modifications shall be made to ensure that the system meets the specified reliability requirements.

Independence and Redundancy

The principle of independence is basic to the effective utilization of the SFC. The design of a safety system shall be such that no single failure of a component will interfere with the proper operation of an independent redundant component or system.

Nondetectable, Cascaded, Common-Cause Failures

The detectability of failures is implicit in the application of the SFC. Detectability is a function of the system design and the specified tests. A failure that cannot be detected through periodic testing, or revealed by alarm or anomalous indication, is nondetectable. An objective in an analysis of safety systems is to identify nondetectable failures. When nondetectable failures are identified, one of the following courses of action shall be taken:

- Preferred course: The system or the test scheme shall be redesigned to make the failure detectable.
- Alternative course: When analyzing the effect of each single failure, all identified nondetectable failures shall be assumed to have occurred.

Whenever the design is such that additional failures could be expected from the occurrence of a single failure from any source (e.g., mechanical, electrical, and environmental), these cascaded failures, collectively, shall be considered to be a single failure.

Certain common-cause failures shall be treated as single failures when conducting the single-failure analysis. Such failures can be in dissimilar components and can have dissimilar failure modes. Failures resulting from cascaded failure and DBEs have already been discussed, and are those that shall be included in the analysis.

Common-cause failures not subject to single-failure analysis include those that can result from external environmental effects (e.g., voltage, frequency, radiation, temperature, humidity, pressure, vibration, and EMI), design deficiencies, manufacturing errors, maintenance errors, and operator errors. Design qualification and QAPs are intended to afford protection from external environmental effects, design deficiencies, and manufacturing errors. Personnel training, proper control room design, and operating, maintenance, and surveillance procedures are intended to afford protection from maintenance and operator errors.

Additionally, provisions should be made to address common-cause failures. Examples of techniques are detailed defense-in-depth studies, failure mode and effects analysis, and analyses of abnormal conditions or events. Design techniques, such as diversity and defense in depth, can be used to address common-cause failures.

Comprehensive guidance on using diversity to address common-cause failures in digital computers is provided in IEEE Std 7-4.3.2-1993.

Design Basis Events

Design basis events are postulated events used in the design to establish the acceptable performance requirements of the structures, systems, and components. A DBE that results in the need for safety functions may cause failure of system components, modules, or channels. In order to provide protection from these failures, the equipment should be designed, qualified, and installed so as to be immune to such anticipated challenges. When analysis indicates that failures in a safety system result from DBEs, these failures shall be considered a consequence of the event.

Shared Systems

The SFC is applied to units with shared systems as follows:

- The safety systems of all units shall be capable of performing their required safety functions with a single failure assumed within the shared systems or within the auxiliary supporting features or other systems with which the shared systems interface.
- The safety systems of each unit shall be capable of performing their required safety functions, with a single failure initiated concurrently in each unit within the systems that are not shared. Provisions shall be included in the design to ensure that single failures within one unit will not adversely affect (propagate to) the other unit, thereby preventing the shared systems from performing the required safety functions.

The failures in the criteria listed above need not be considered simultaneously in the performance of the single-failure analysis, (i.e., the single-failure analysis is conducted for the plant to demonstrate that the criterion listed first is met). The single-failure analysis is repeated to demonstrate that the criterion listed second is met.

IEEE Std 379-2000 includes a note that the above description is meant to "neither endorse nor forbid" the use of shared systems.

42. Electrical personnel shall demonstrate a familiarity level knowledge of electrical safety design requirements for emergency, standby, and UPS systems for VSS (IEEE Stds-387-1984, 650-1990, and 944-1986; DOE O 420.1B; DOE G 420.1-1; etc.).

a. Identify and discuss the principal design criteria for standby power supplies supporting VSS: capability, ratings, interactions, design and application considerations, and design features.

The following is taken from IEEE Std 387-1984.

Capability

When in service, each diesel-generator unit shall have the capability of performing as a redundant unit of a standby power supply, in accordance with the requirements stated in IEEE Std 308-1980.

The diesel-generator unit shall also have each of the following specific capabilities to meet design, application, and qualification requirements:

- Design Conditions. The unit shall be capable of operating during and after any DBE without support from the preferred power supply. The following design conditions, including appropriate margins as required by IEEE Std 323-1983, 6.3.1.5, shall be specified by those individuals responsible for the system application and, as a minimum, shall include
  - operational cycles (4,000 starts over a period of 40 years, unless otherwise specified)
  - operating hours (4,000 hours over a period of 40 years, unless otherwise specified)

- temperature at equipment locations (minimum and maximum with durations and average annual ambient)
- seismic response spectra
- radiation (1–10 rads of gamma integrated dose over a period of 40 years, unless otherwise specified)
- humidity (minimum and maximum with durations)
- load profile (including allowable voltage and frequency variations)
- absolute barometric pressure (altitude and tornado depressurization, duration, and magnitude)
- combustion air contaminants (salt, sand, etc.)
- fuel type and quality
- auxiliary electrical power supply requirements and quality
- effect of fire protection actuation
- service water quality

- Starting and Loading. The unit shall be capable of starting, accelerating, and being loaded with the design load within the time required by the equipment specification requirements and quality
  - from the normal standby condition
  - with cooling not available, for a time equivalent to that required to bring the cooling equipment into service with energy from the diesel-generator unit
  - on a restart with an initial engine temperature equal to the continuous rating full-load engine temperature

- Light Load or No Load Operation. The unit shall be capable of accepting design load following operation at light load or no load for the time required by the equipment specification.
- Design Load. The unit shall be capable of carrying the design load for the time required by the equipment specification.
- Quality of Power. The unit shall be capable of maintaining voltage and frequency at the generator terminals within limits that will not degrade the performance of any of the loads comprising the design load below their minimum requirements, including the duration of transients caused by load application or load removal.

The loads will usually dictate the size of the UPS system (usually rated in kVA at a given power factor). An important factor to consider in sizing the UPS system is the inrush current imposed on it. Since the UPS has very little overload capability, it is usually not practical or economical to size the UPS so that the unit is capable of furnishing inrush or short-circuit current requirements. The use of a transfer switch can compensate for the lack of this capability by providing a transfer of the transient load to the bypass source of power. Where no transfer capability exists, consideration should be given to selective loading of high inrush loads onto the UPS system. Consideration should also be given to the selection of fault-clearing devices to compensate for the lack of capability of supplying high short-circuit current.

Environmental capability of SC electrical equipment must be demonstrated by testing, analysis, and operating experience, or a combination of these methods.

Ratings

A diesel-generator unit shall have continuous and short-time ratings which shall reflect the output capabilities of the diesel-generator unit in accordance with all capability requirements mentioned in IEEE Std 387-1984, section 5.1, and the following rules:

- Inspections and scheduled maintenance shall be performed periodically using the manufacturer's recommendations and procedures.
- Unscheduled maintenance shall be performed in accordance with the need as indicated by the periodic inspections and operating experience.

The diesel-generator units may be utilized to the limit of their power capabilities, as defined by the continuous and short-time rating. Unless time and load parameters for light and no-load operation are established by tests and documentation, the following precautions shall be taken:

- When 4 hours of operation at 30% or less of the continuous rating have been accumulated without at least 0.5 hour of operation above 50% of the continuous rating, the unit shall be operated at a load of at least 50% of the continuous rating for a minimum of 0.5 hour.
- Operating at 30% or greater continuous rating shall be restricted to the manufacturers' recommendations.

Interactions

Mechanical and electric system interactions between a particular diesel-generator unit and other units of the standby power supply, the nuclear plant, the conventional plant, and the Class 1E electric system shall be coordinated in such a way that the diesel-generator unit's design function, and capability requirements, may be realized for any DBE, except failure of that diesel-generator unit.

Design and Application Considerations

Design and application considerations shall include, but not necessarily be limited to, the considerations listed in table 10.

Table 10. Design and application considerations

Considerations
1. Common failure mode between units of the standby power supply
2. Single failure criterion as applied to the standby power supply
3. Matching of diesel engine, alternator, excitation system, and voltage regulator
4. Energy for operation of the control, surveillance, and protection systems
5. Control, surveillance, and protection systems
6. Lubrication system and equipment
7. Selection of air, water, or other means of cooling
8. Supply of cooling medium
9. Cooling system and equipment
10. Selection of electric, pneumatic, or other means of starting
11. Supply of starting energy
12. Starting system and equipment
13. Supply and quality of combustion air
14. Combustion air system and equipment
15. Supply of fuel
16. Fuel supply system and equipment, ANSI N195-1976 [2]
17. Removal of products of combustion
18. Equipment design life
19. Service environment
20. Seismic design
21. Design load
22. Time available between receipt of start diesel signal and initiation of load sequence
23. Description of loading sequence with time durations of application of individual loads
24. Maximum time available between receipt of start diesel signal and acceptance of design load
25. Accommodation of loading sequence and time duration for application of individual loads
26. Load performance characteristics
27. Continuous rating
28. Short time rating
29. Light load and no load operation
30. Diesel-generator unit performance characteristics
31. Electric fault conditions
32. Electric transients
33. Insulation and temperature rating of electric equipment insulation systems for operating and quiescent conditions
34. Creepage and clearance distances for electric equipment contacts
35. Electrically induced thermal effects
36. Mechanically induced thermal effects
37. Thermal shock
38. Mechanical shock
39. Operating cycles that may cause thermally induced stresses
40. Physical configuration and mechanical support of attached auxiliaries, accessories, hardware, piping, wire and cable, and raceways
41. Handling during manufacture, shipping, storage and installation
42. Fire protection system: separation between units, and possible damaging effects by actual or inadvertent operation
43. Tornado depressurization
44. Separation criteria for Class 1E and Non-Class 1E wiring, IEEE Std 384-1981 [10]
45. Operational vibration
46. Monitoring diesel-generator units during accident and post-accident conditions
47. Design considerations for testability and synchronizing capability

Source: IEEE Std 387-1984

Design Features

Harmful vibration stresses shall not occur. Harmful torsional vibration stresses shall not occur within a range from 10% above to 10% below rated idle speed and from 5% above to 5% below rated synchronous speed. Moving parts shall be designed to withstand that level of overspeed that results from a short time rating load rejection. Margin shall be provided to allow the overspeed device to be set sufficiently high to guarantee that the unit will not trip on short-time rating load rejection. As a minimum, the generator rotor, exciter rotor (if used) and flywheel shall be designed to withstand an overspeed of 25% without damage. If the diesel engine is equipped to operate in both the isochronous and the droop mode, provisions shall be included to automatically place the engine governor in the proper mode of operation when the diesel-generator unit is required to operate automatically. If the voltage regulator is equipped to operate in paralleled and nonparalleled mode, provisions shall be included to automatically place the voltage regulator in the proper mode of operation when the diesel-generator unit is required to operate automatically.

The diesel-generator unit shall be provided with control systems, permitting automatic and manual control. Upon receipt of a start-diesel signal, the automatic control system shall provide automatic startup and automatic adjustment of speed and voltage to a ready-to-load condition. A start-diesel signal shall override all other operating modes and return control of the diesel-generator unit to the automatic control system. A start-diesel signal shall not override any manual non-operating modes such as those for repair and maintenance.

Provisions shall be made for control from the control room and external to the control room.

The diesel-generator unit shall be provided with surveillance systems permitting remote and local surveillance and indicating the occurrence of abnormal, pretrip, or trip conditions. As a minimum, the following conditions shall be surveyed:

- Unit not running
- Unit running, not loaded
- Unit running, loaded
- Unit out of service

The following systems shall have sufficient mechanical and electrical instrumentation to survey the variables required for successful operation and to generate the abnormal, pretrip, and trip signals required for alarm of such conditions:

- Starting system
- Lubricating system
- Fuel system
- Primary cooling system
- Secondary cooling system
- Combustion air system
- Exhaust system
- Generator
- Excitation system
- Voltage regulation system
- Governor system

The diesel-generator unit shall be automatically tripped on an engine overspeed or generator differential overcurrent or both. Protective features, other than engine overspeed and generator differential overcurrent, shall be

- blocked from automatically tripping the diesel-generator unit during an accident condition and shall annunciate the condition they monitor in the plant control room; or
- if protective features other than engine overspeed and generator differential overcurrent are retained during accident conditions, two or more independent measurements of each of these parameters with coincident trip logic shall be provided.

All protective devices shall remain effective during diesel-generator unit testing or operation during non-accident conditions.

b. Identify and discuss some of the design application requirements for UPS supporting VSS: performance requirements, UPS sizing and capacities, and UPS configurations.

The following is taken from IEEE Std 944-1986.

Performance Requirements

The UPS system must be capable of providing a reliable, regulated, and filtered source of uninterruptible power to the vital loads of a power-generating station. To support this goal UPS systems are designed to supply power during power supply outages and to provide power conditioning when supply voltages and frequency variations exceed those allowable for the load. A properly selected UPS system will provide continuous power to the load throughout most disturbances encountered in the power supply system. Under certain conditions up to a 4.17 millisecond interruption in the power supply to the load may occur as the load is transferred from the inverter output to the bypass source or vice versa.

UPS Sizing and Capacities

The loads will usually dictate the size of the UPS system (usually rated in kilovolt-amperes at a given power factor). An important factor to consider in sizing the UPS system is the inrush current imposed on it. Since the UPS has very little overload capability, it is usually not practical or economical to size the UPS so that the unit is capable of furnishing inrush or short-circuit current requirements. The use of a transfer switch can compensate for the lack of this capability by providing a transfer of the transient load to the bypass source of power. Where no transfer capability exists, consideration should be given to selective loading of high inrush loads onto the UPS system. Consideration should also be given to the selection of fault-clearing devices to compensate for the lack of capability of supplying high short-circuit current.

The following load data shall be used in the sizing of a UPS system:

- Total steady-state load
- Load power factor
- Continuous or short-duration load
- Inrush current requirements of load

The UPS real-power and reactive-power rating should respectively equal or exceed 125% of the total real-power and 125% of the total reactive-power requirements for all normal steady-state load configurations. The 25% margin should be included in the UPS capacity to account for the margin in calculating the maximum load. It should be recognized that the largest real-power requirements might occur for a load configuration that is different from that which results in the largest reactive-power requirements. Where the load power factor is unknown, a power factor of 0.8 lagging should be used. The UPS shall be designed to supply 100% of rated kilovolt-amperes over the entire AC and DC input-voltage ranges described in 5.7 of IEEE Std 944-1986, and for any load-current waveforms with a crest factor not greater than 2.0.

UPS Configurations

Typical configurations of UPS systems that are applicable to power generating station loads are described below.

Single UPS Unit with Rectifier/Charger, Inverter, and Battery

A single UPS is the simplest of configurations; it consists of a rectifier/charger, inverter, and battery. In the configurations shown, the units are dedicated systems. The configuration as shown in figure 70 is capable of providing continuity of load power as long as the UPS continues to operate within its specification. The AC output voltage supplied to the load is not disturbed by an AC input failure. The inverter is characterized by its ability to supply the power to the load and can take its power from either the AC input by way of the rectifier/charger or from the battery. When the AC input fails, the battery will provide energy to the inverter to maintain continuity of load power. The capacity of the battery determines the length of time the system can operate without an AC input supply. The primary advantages of this configuration are its simplicity and minimum cost when compared to other systems. The main disadvantage is that a failure of the inverter results in a loss of supply to the critical loads.

Single UPS Unit with Separate Battery Charger

In place of a rectifier/charger, a separate rectifier and battery charger may be used (see figure 71). In this case, the rectifier is used to provide load power to the inverter. The battery charger is controlled to recharge and maintain the battery in a charged condition. A blocking diode is used between the battery and the DC link to prevent the rectifier from charging the battery. This arrangement is suitable for applications where an existing charger and battery are required for power generating station loads and permits the removal of the UPS system from service without disturbing the DC load. The main disadvantage is that a failure of the inverter results in a loss of a supply to the critical loads.

Single UPS Unit with Alternate Source and Static Transfer Switch

When the continuity of load power is critical, the addition of an alternate source and static transfer switch should be used, as shown in figure 72. This configuration can operate in two modes:

- Continuous Operation. In the continuous operation mode, the load is connected to the UPS unit through the transfer switch. In case of UPS unit failure, or load current transients, such as inrush or fault current, the load is automatically transferred to the alternate source by the transfer switch.
- Standby Operation. In standby operation, the load is supplied by the AC input through the alternate source and transfer switch.

Standby Redundant UPS Units

The standby redundant UPS configuration is characterized by its ability to operate as a single UPS, and the provisions of single UPS will apply. The system configuration is equivalent to a single UPS configuration. Upon failure of the operating UPS unit, the load is transferred to the standby UPS unit by the transfer switch. This configuration is shown in figure 73.

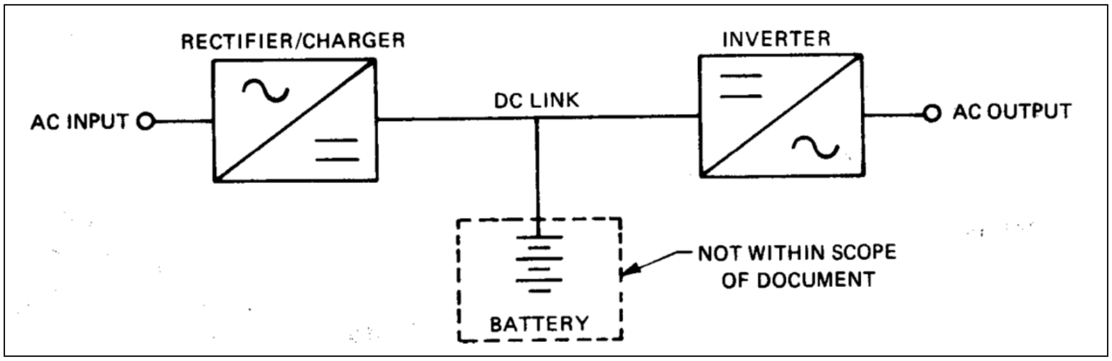


Figure 70. Single UPS unit with rectifier/charger, inverter, and battery

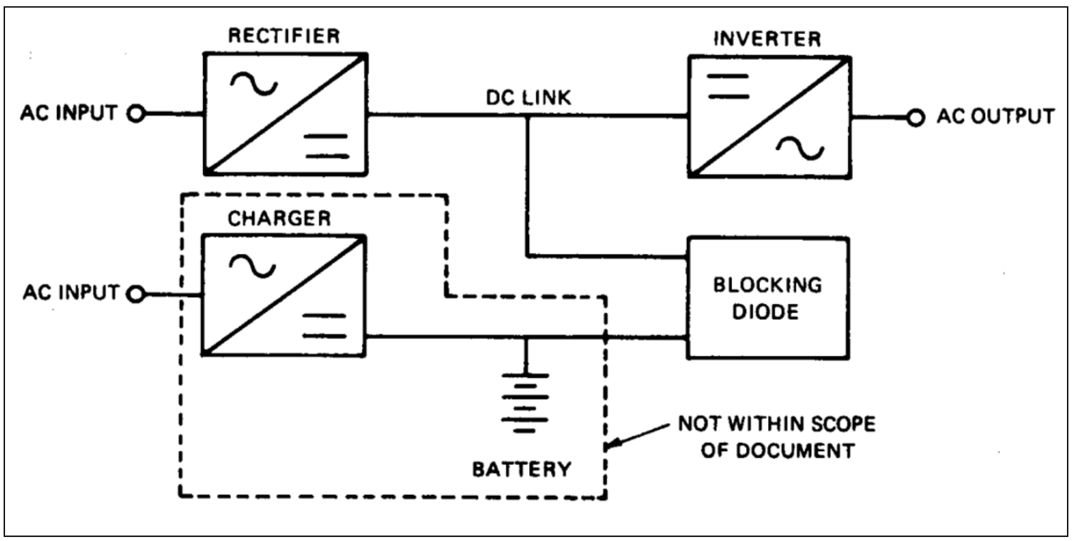


Figure 71. Single UPS unit with separate battery charger

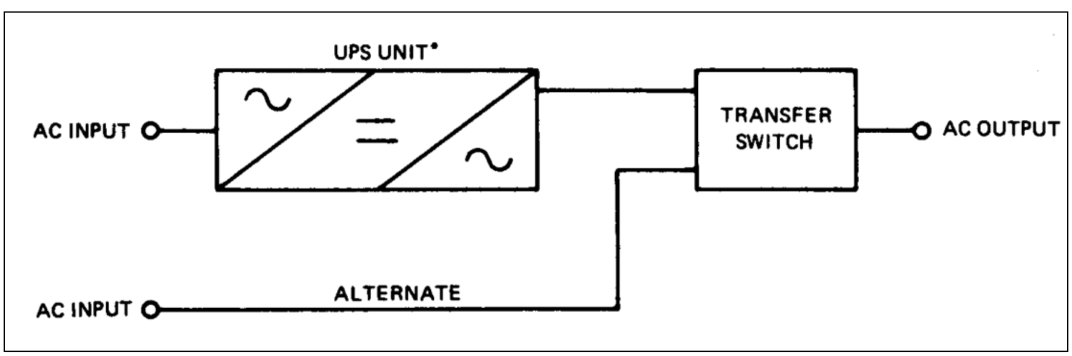
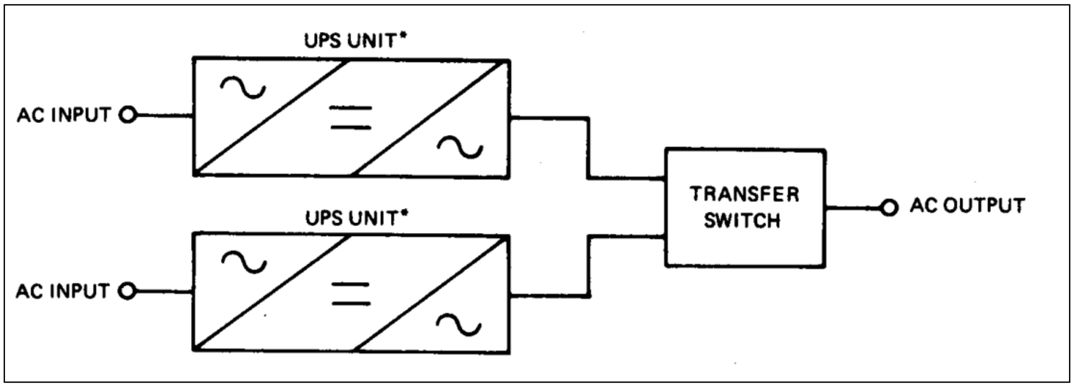


Figure 72. Single UPS unit with alternate source and static transfer switch



Source: Figures 70–73, IEEE Std 944-1986

Figure 73. Standby redundant UPS units

Uninterruptible power supply with Bypass/Maintenance Source and Transfer Switch

A UPS with bypass/maintenance source and a transfer switch is used for periodic maintenance and testing of the UPS system. The transfer switch, which may be of the manual type, connects the AC load to the AC supply while bypassing the UPS system. This switch should be selected on the basis of whether the load can be interrupted even for a short duration. If the load cannot be interrupted the switch should be make-before-break-type, and the UPS may be taken out of service for inspection and testing without affecting the loads.

c. Identify some of the key Class 1E performance characteristics for Class 1E static battery chargers and inverters supporting VSS: input conditions, output requirements, surge withstand capability, and reverse current flow prevention.

The following is taken from IEEE Std 650-1990.

Input Conditions

Primary input conditions for Class 1E static battery chargers and inverters supporting VSS are

- voltage
- frequency
- phase

Output Requirements

Primary output requirements for Class 1E static battery chargers and inverters supporting VSS are

- voltage and voltage regulation
- current (minimum and maximum)
- current limit
- frequency and frequency regulation (inverters only)
- load power factor (inverters only)
- ripple voltage (battery chargers only)
- harmonic distortion (inverters only)

Surge Withstand Capability

Surge withstand capability is mentioned but not elaborated on in primary references, including IEEE, NFPA, and DOE documents. See note below.

Reverse Current Flow Prevention

Reverse current flow prevention is mentioned but not elaborated on in primary references, including IEEE, NFPA, and DOE documents. See note below.

Note: Regarding surge withstand capability and reverse current flow prevention, IEEE Std 650-1990 notes the following: “The required Class 1E performance characteristics and the safety function shall be specified by those responsible for the design application of the equipment, and shall include, as a minimum, numerical values and durations for normal, abnormal, design-basis event, and post-design-basis event conditions.”

43. Electrical personnel shall demonstrate a familiarity level knowledge of electrical safety design requirements for VSS accident monitoring instrumentation (IEEE Std-497-2002, DOE O 420.1B, DOE G 420.1-1, etc.).

The information for KSA’s ‘a’ and ‘b’ is taken from IEEE Std 497-2002.

a. Identify and discuss the selection criteria used for identifying the “‘type variables” for accident monitoring instrumentation.

The variable types will be referred to as A, B, C, D, and E. Criteria for the selection of each type of variable are given below and summarized in table 11.

Type A variables are those variables that provide the primary information required to permit the control room operating staff to

- take specific, planned, manually-controlled actions for which no automatic control is provided and that are required for safety systems to perform their safety-related functions as assumed in the plant accident analysis licensing basis;
- take specific, planned, manually-controlled actions for which no automatic control is provided and that are required to mitigate the consequences of an AOO.

Type A variables provide information essential for the direct accomplishment of specific safety-related functions that require manual action. These variables are a subset of those necessary to implement the plant-specific emergency procedure guidelines (EPGs) or the plant specific emergency operating procedures (EOPs) or the plant abnormal operating procedures (AOPs). Type A variables do not include those variables that are associated with contingency actions that may also be identified in written procedures.

Type B variables are those variables that provide primary information to the control room operators to assess the plant critical safety functions. Any plant critical safety functions addressed in the EPGs or the plant-specific EOPs that are in addition to those identified above shall also be included. The Type B variables shall be those necessary to implement the plant functional restoration EPGs, plant-specific EOPs, and the plant critical safety function status trees, if applicable.

Type C variables are those variables that provide primary information to the control room operators to indicate the potential for breach or the actual breach of the three fission product barriers (extended range): fuel cladding, reactor coolant system pressure boundary, and containment pressure boundary. The selection of these variables represents a minimum set of plant variables that provide the most direct indication of the integrity of the three fission product barriers and provide the capability for monitoring beyond the normal operating range.

Type D variables are those variables that are required in procedures and licensing basis documentation (LBD) to

- indicate the performance of those safety systems and auxiliary supporting features necessary for the mitigation of DBEs
- indicate the performance of other systems necessary to achieve and maintain a safe shutdown condition
- verify safety system status

Type D variables shall be based upon the plant accident analysis licensing basis and those necessary to implement the following procedures (as applicable to the plant design):

- Event-specific EPGs or plant-specific EOPs
- Functional restoration EPGs or plant-specific EOPs
- Plant AOPs

Type E variables are those variables required for use in determining the magnitude of the release of radioactive materials and continually assessing such releases. These variables shall include, but not be limited to, monitoring the following:

- The magnitude of releases of radioactive materials through identified pathways (e.g., secondary safety valves and condenser air ejector)
- The environmental conditions used to determine the impact of releases of radioactive materials through identified pathways (e.g., wind speed, wind direction, and air temperature)
- Radiation levels and radioactivity in the plant environs
- Radiation levels and radioactivity in the control room and selected plant areas where access may be required for plant recovery

Documentation shall be developed and maintained for the selection bases of the accident monitoring variables consistent with the plant LBD.

Table 11. Summary of accident monitoring variable types/source documents

Referenced clause in standard	Selection criteria for the variable type	Source documents
4.1	Type A — Planned manually controlled actions for accomplishment of safety-related functions for which there is no automatic control.	— Plant accident analysis licensing basis — EPGs or plant-specific EOPs — Plant AOPs
4.2	Type B — Asses the process of accomplishing or maintaining plant critical safety functions.	— Functional restoration EPGs or plant-specific — Plant critical safety functions related EOPs — Plant critical safety function status trees
4.3	Type C — Indicate potential for breach of fission product barriers — Indicate an actual breach of fission product barriers	— Plant accident analysis licensing basis — Design basis documentation for the fission product barriers — EPGs or plant-specific EOPs
4.4	Type D — Indicate performance of safety systems — Indicate the performance of required auxiliary support features — Indicate the performance of other systems necessary to achieve and maintain a safe shutdown condition — Verify safety system status	— Plant accident analysis licensing basis — Event-specific EPGs or plant-specific EOPs — Functional restoration EPGs or plant-specific EOPs — Plant AOPs
4.5	Type E — Monitor the magnitude of releases of radioactive materials through identified pathways — Monitor the environmental conditions used to determine the impact of releases of radioactive materials through identified pathways — Monitor radiation levels and radioactivity in the plant environs — Monitor radiation and radioactivity levels in the control room and selected plant areas where access may be required for plant recovery	— Procedures for determining radiological releases through plant identified pathways — Procedures for determining plant environs radiological concentration — Procedures for determining plant habitability

Source: IEEE Std 497-2002

b. Identify some key performance criteria of accident monitoring instrumentation.

Range

The range of a monitoring channel shall be established to ensure that it covers the transients identified in the plant LBD. The range for Type C variables shall encompass, with margin, those limits that would indicate a breach in a fission product barrier. For example, measurement of reactor pressure shall include the capability of measuring, with margin, up to Level D service limits of the reactor vessel (see American Society of Mechanical Engineers 2007 Boiler and Pressure Vessel Code).

Accuracy

The required accuracy of accident monitoring instrument channels shall be established based on the assigned function.

Response Time

Accident monitoring instruments shall be designed to provide real-time and timely information. Typically, the displayed information will lag behind actual conditions because of sensor location, thermal heat transfer time lag, information processing cycle times, degree of severity of environmental conditions, and other potential effects on instrument response times. In general, these response times are not as critical as in the case when the instrument provides a signal for automatic reactor protection system or engineered safeguard system action. For computer driven displays, the indicated variable will additionally lag real-time conditions depending on the update frequency of the display. The update frequency shall be fast enough to avoid the potential of misleading the operator with respect to plant conditions. It is considered prudent that this update period be approximately 1 to 2 seconds.

Required Instrumentation Duration

The post-event operating time for each variable shall be defined and addressed in the development of the qualification program.

- The post-event operating time for Type A variable instrument channels shall be the duration for which the measured variable is required by the plant's LBD.
- The post-event operating time for Type B variable instrument channels shall be at least the duration associated with the longest-duration DBE for that variable.
- The post-event operating time for Type C variable instrument channels shall be at least 100 days for instrument channels monitoring the fission product barriers:
  - Fuel cladding
  - Reactor coolant system pressure boundary
  - Containment pressure boundary

  The qualification duration for other Type C variable instrument channels shall be the duration for which the measured variable is required by the plant's LBD.
- The post-event operating time for Type D and Type E variable instrument channels shall be based on the plant's LBD.

A shorter post-event operating time may be acceptable if equipment replacement or repair can be accomplished within an acceptable out-of-service time, taking into consideration the location and accessibility of the equipment.

Reliability

For those systems for which either quantitative or qualitative goals have been established, appropriate analysis of the design shall be performed to confirm that such goals have been achieved. IEEE Std 352-1987 and IEEE Std 577-1976 provide guidance for performing the reliability analysis.

Performance Assessment Documentation

An assessment for each of the performance criteria shall be conducted. This assessment shall be done to ensure that the as-designed performance meets or exceeds the performance criteria. The results of this assessment shall be documented and shall consider

- allowances for calibration uncertainties, loop errors, and drift (consistent with the methodology given in ANSI/Instrumentation, Systems, and Automation Society (ISA) Std 67.04.01-2000, *Setpoints for Nuclear Safety-Related Instrumentation*);
- the magnitude and direction of errors imposed on the accident monitoring instrumentation by environmental and/or seismic conditions during and after the postulated event.

44. Electrical personnel shall demonstrate a familiarity level knowledge of electrical safety design requirements for VSS Motor Control Centers (MCC) (IEEE Std 649-1991, DOE O 420.1B, DOE G 420.1-1, etc.).

a. Identify the three qualification alternatives for VSS MCC equipment.

The information for KSAs ‘a’ through ‘c’ is taken from IEEE Std 649-1991 (1991 edition archived; 2005 edition active).

The three qualification alternatives are testing, analysis, and the use of operating experience.

Equipment may be qualified by test, analysis, operating experience, or any combination thereof. Combined qualification shall be developed on a case-by-case basis by applying the procedures presented in the referenced standard. The qualification methods used shall provide auditable data by which they can be shown to constitute a complete qualification program.

Regardless of the method(s) used in the qualification program, the equipment is considered to be qualified when it meets the acceptance criteria listed in the equipment specification found in Section 9 of the referenced standard. Any failure to meet the acceptance criteria should be analyzed to determine its cause and overall effect on the equipment’s qualification.

b. Identify the three major elements of the qualification process for VSS MCC, equipment specification, the qualification program, and the documentation requirement.

Equipment Specification

The equipment specification for MCCs shall contain the criteria to be met to qualify the equipment for its intended application. This specification may be written by either the end user or the equipment manufacturer, depending on who has the responsibility for providing the qualification requirements to the organization performing the qualification program. As a minimum, the following shall be included:

- Equipment Description. The equipment specification shall describe the MCC in terms of physical and electrical configuration.
- Equipment Safety Functions. The specification shall describe the performance requirements and specific safety functions of the MCC equipment, including the required operating times; when in the DBE sequence these functions are required to occur; and the maximum allowable time that a contact subject to chatter can remain in its unintended state.
- Interfaces. Interfaces and loadings via physical attachments to the equipment at the equipment boundary shall be specified. These interfaces include mounting requirements, cable, and cable raceway connections, as well as bus duct connections.
- Design Standards. Specifications shall indicate, by number and date, applicable UL, NEMA, ANSI, IEEE, and other industry standards or sections of standards.
- Service Conditions. The range of values for operational and environmental parameters shall be specified for the application. They may include the following as applicable:
    - Supply and control voltages and frequency
    - Design ambient temperature
    - Ambient time/temperature profile
    - Ambient time/pressure profile
    - Duty cycle
    - Seismic requirements
    - Radiation
    - Percent relative humidity
    - Abnormal vibration or altitude
    - Spray or jet impingement
    - Electrical loading at rated voltage (inductive and/or resistive)

  Normal and abnormal service conditions and conditions resulting from DBEs shall be specified. The service conditions for these events should be expressed as a time history for each parameter that may affect equipment functions during the event.

- Margin. It should be indicated whether or not margin has been included in the specified values.
- Operational Aging Parameters. Operational aging parameters given in table 12 reflect typical requirements for a generic qualification program. Where specific applications require different values, the values shall be specified.
- Qualified Life Objective. The desired qualified life objective shall be stated for the MCC or its component(s) that are subject to significant aging mechanisms.
- Acceptance Criteria. Acceptance criteria shall be defined so that all failures to perform the specified safety function(s) in the service conditions for which the equipment is being qualified can be identified. The operational tests given in table 12 reflect typical requirements for a generic qualification program. Where specific applications require different values, the values shall be specified; however, care should be taken to ensure that the acceptance criteria selected are not overly restrictive or based on measurements not related to the specified safety functions.

Table 12. Typical operational aging parameters

Test per Five-Year Aging Period

Device	AC Application	DC Application
Contactor	750 operating cycles (maximum 6/min at nominal voltage and the following (1) Load currents per NFPA 70-1978(9) values through the power contacts. Typical values at 460 V are NEMA Size 1-14A NEMA Size 2-34A NEMA size 3-65A NEMA Size 4-124A NEMA Size 5-240A (2) Rated inductive load current through one auxiliary contact	Same as ac Typical values for reduced voltage starters at 240 V are NEMA Size 1-20A NEMA Size 2-38A NEMA Size 3-89A NEMA Size 4-140A NEMA Size 5-255A
Overload relay	5 Operations at 200% rated current	Same as ac
Molded case circuit breaker 100-600 A frame size	(1) 2 overload trips at 200-600% rated current for thermal magnetic breakers (2) 125 manual operations at 100% rated conditions (voltage and current: maximum 4/min	Same as ac
Above 600 A frame size	(1) 2 overload trips at 200-600% rated current for thermal magnetic breakers. (2) 60 manual operations at 100% rated conditions (voltage and current; maximum 1/min).	Same as ac
Fuse and fuse holder	See note	Same as ac
Transformers		
(1) Control power	No operational aging required	Not applicable
(2) Distribution	No operational aging required	
Auxiliary relay and timing devices	750 operating cycles (maximum 6/min at nominal voltage with rated inductive load on one contact).	Same as ac
Pushbuttons and selector switches	750 operating cycles at nominal voltage with rated inductive load on one contact.	Same as ac
Indicating light modules	No operational aging required	Same as ac
Solid state devices	Special consideration must be given to solid state devices. Supplier should be consulted for specific operational parameters	Same as ac
Ground fault-sensor/relay	Same as solid state devices	Same as ac
Undervoltage and overvoltage relays	Supplier should be consulted for specific operational aging parameters	Same as ac
Disconnect switches	125 manual operations at 100% rated conditions (voltage and current).	Same as ac
Resistors (power)	Not applicable	No operational aging required
Transfer switches	Supplier should be consulted for specific operational aging parameters	Same as ac
Stab-on-connections	Five insertions and removals	Same as ac

Note: Operational aging of fuses may be accomplished by either natural aging or accelerated aging techniques. Alternatively, manufacturer's or other documentation may be provided to verify that, subject to the application, age is not a factor to causing common mode failures of fuses.

Table 13. Typical functional tests

Operational Test

Device	AC Application	DC Application
Contactor*	Pick up at 110% and 85% of rated coil voltage Device shall not drop out at or a over 70% rated coil voltage	Pick up at 110% and 80% of rated coil voltage Device shall not drop out at or above 70% rated coil voltage
Overload relay*	Tripp on 200% overload within manufacturer's time current/curves	Same as ac
Molded case circuit breaker *	(3) Manual operation (4) Trip on 200% of rated current within manufacturer's time current/curves (5) Trip on 80-120% of maximum instantaneous trip setting (except molded case switches)	Same as ac
Fuse and fuse holder	Conduct rated current	Same as ac
Transformers (control power and distribution)	(1) Proper secondary voltage is present when rated voltage is applied to the primary leads (2) Check insulation strength by dielectric leakage current measurement	Not applicable
Auxiliary relays*†	Pick up at 110% and 85% of rated coil voltage. Device shall not drop out at or above 70% rated coil voltage	Pick up at 110% and 85% of rated coil voltage. Device shall not drop out at or above 70% rated coil voltage
Pushbuttons and selector switches*	Make and break at rated conditions (voltage and current)	Same as ac
Indicating light modules	No operational test required. Failure of the indicating light module shall not result in the degradation of the circuit in which the light is located (for example, no short circuit).	Same as ac
Solid state devices	Special consideration must be given to solid state devices. Supplier should be consulted for specific operational parameters.	Same as ac
Ground fault-sensor/relay*†	Same as solid state devices	Same as solid state devices
Undervoltage and overvoltage relays*†	Supplier should be consulted for specific operational aging parameters.	Same as ac
Disconnect switches*	Make and break at rated conditions (voltage and current)	Same as ac
Resistors (power)	Not applicable	Conducts rated current
Transfer switches*	Supplier should be consulted for specific operational aging parameters	Same as ac
Stab-on-connections	Check electrical and mechanical integrity of connections. No overheating while conducting rating current.	Same as ac

* Device contacts shall be monitored to verify make and break load conditions.

† Requirements for qualification of relays for other than motor control center application may be found in IEEE C37.98-1978. The user of this standard may wish, in development of a motor control center qualification program, to incorporate some of these other requirements to achieve broader qualification of relays than just for motor control centers. In any event, the requirements for qualification of relays in a motor control center program shall be at least as stringent as specified herein.

Source: Tables 12 and 13, IEEE Std 649-1991(R2005)

Not all of the acceptance criteria in table 13 can be demonstrated with the equipment inside a test chamber. Therefore, the specifier must determine which criteria are to be demonstrated during and after a harsh environment test. Alternative criteria such as the following may also be used:

- No unwanted tripping of thermal sensitive devices such as circuit breakers, fuses, and overload relays
- No dielectric breakdown that results in the permanent loss of control or main power voltage
- No spurious circuit operations

Qualification Program

The qualification program required by IEEE Std 649-1991 is conducted in the following sequence:

- Development of a Qualification Plan. The purpose of a documented qualification plan is to provide an auditable link between the equipment specifications and the results of the qualification program presented in the qualification report. A qualification plan is required. It shall describe the method(s) for identifying any significant aging mechanisms, the qualification program as determined from the identification of the significant aging mechanisms, the specified DBEs, and other requirements. It shall contain other information as specified in section 12 of IEEE Std 649-1991.
- Identification of Significant Aging Mechanisms. Motor control center equipment is composed of devices and components having a variety of materials, designs, and functions. Each device or component must be reviewed in terms of its materials, design, function, and specified environments to identify significant aging mechanisms that could prevent the performance of its required safety functions. The most likely aging mechanisms for MCC equipment are the effects produced by
    - operational cycling
    - temperature
    - radiation

  When other service conditions such as humidity, altitude, or normal vibration exist that could potentially produce aging mechanisms, the conditions shall be specified by the user and addressed in the qualification program. For MCC applications, the temperature and radiation effects apply primarily to nonmetallic materials. When it can be demonstrated and documented that these or other aging mechanisms are not significant, no further evaluation of aging is required.

- Implementation of the Qualification Plan. Qualification procedures described in section 10 of IEEE Std 649-1991 shall then be used to qualify the MCC and/or its components based on the results of the significant aging mechanism identification. Variations from the conditions specified in the qualification plan require alteration of the procedure and appropriate justification. The qualification sequence, when the test alternative is utilized, shall be as follows:
    - Device- (and component-) level qualification
        - Inspection
        - Baseline data measurement

    - Aging (if significant aging mechanisms are identified)
    - Functional tests (if aging is performed)
    - Seismic qualification
    - Other tests required by the qualification plan (see 10.6.2 of IEEE Std 649-1991)
    - Final functional test

  - Assembled MCC-level qualification (if required)
    - Device and component testing as required
    - Seismic qualification
    - Other tests required by the qualification plan (see 10.6.2 of IEEE Std 649-1991)
    - Final functional test

- Determination of Qualification. In the evaluation of the qualification program results, the MCC and its components are considered to have passed when they meet the acceptance criteria specified in the equipment specification. Any failure to meet the acceptance criteria shall be analyzed to determine appropriate modification(s) of the equipment or the limitation that shall be imposed on its use. Failures shall be documented as described in 12.2.4 of IEEE Std 649-1991.

  Failure during the qualification process does not mean that the equipment is disqualified for its intended safety application if it can be demonstrated that the failure was not common cause in nature or if the failure does not affect the MCC's safety functions. When such demonstration is possible, the failed device or component may be replaced by a similar, equivalently-aged device or component, and the qualification process may be continued or repeated, provided that the effect on interface connections can be shown to be insignificant.

  Section 11 of IEEE Std 649-1991 addresses modifications during the qualification program. Common cause failures may be addressed either by design changes to eliminate the cause of failure, by reducing the qualified life, or by specifying an appropriate component replacement interval, all in conjunction with repeating part or all of the qualification process. A common cause failure must be thoroughly analyzed and its resolution documented. Continued qualification is based on adherence to specified service conditions, maintenance schedules, and replacement schedules provided by the qualifier to maintain qualified life.

Documentation Requirement

The documentation shall be sufficient to provide justification that the MCC and its subcomponents can meet their specified safety functions for normal service conditions, abnormal service conditions, DBEs, and post-DBEs. The documentation shall be presented in an organized and auditable form.

The documentation shall include a tabulation of all normal, abnormal, DBE, and post-DBE specified service conditions, and the service conditions for which the equipment was qualified.

Specific features that were demonstrated by the equipment qualification program shall be identified.

The qualification plan shall contain sufficient details to identify the acceptance criteria, describe the required procedures, and correlate the qualification methods and results to the equipment specifications. The qualification plan shall contain the following:

- Equipment specification (as noted above)
- Number (quantity) of units to be tested
- Mounting, connection, and other interface requirements
- Aging simulation procedures, including the qualified life objectives
- Service conditions to be simulated
- Performance and environmental variables to be measured
- Test equipment requirements, including accuracies
- Environmental, operating, and measurement sequence in step-by-step detail
- Acceptance criteria
- Type test data
- Statement of nonapplicable portions of the specification
- Description of any conditions peculiar to the MCC and its subassemblies that are not covered above but that could affect the equipment during testing
- Method(s) for identification of significant aging mechanisms

The qualification report shall contain the following:

- Qualification plan
- Objectives (acceptance criteria)
- Detailed description of equipment tested
- Test facility description and identification of instrumentation
- Test procedures
- Test data
- Required periodic maintenance, surveillance, and/or testing
- Evaluation of any component failure or abnormality encountered during the test
- Summary and conclusions, including qualified life statement
- Supporting documentation
- Approval, signature of the qualifier, and date

Partial type tests of MCCs that are augmented by operating experience, analysis, extrapolation, or combinations thereof shall include the following items:

- Operating Experience Data
    - Equipment specification (as noted above)
    - Interface and boundary conditions of the equipment
    - Specification of equipment for which operating experience is available
    - Identification of the specific features to be demonstrated using operating experiences

    - Comparison of past application and specifications with the new equipment specification for each feature to be demonstrated using operating experiences
    - Summary and source of operating experience applicable to equipment qualification, including maintenance/repair history, environmental conditions, electrical loadings, and seismic/vibrational loadings
    - Basis on which the data have been determined to be suitable and the equipment qualified
    - Approval, signature of the qualifier, and date

- Analysis
    - Equipment specification (as noted above)
    - Interface boundary conditions of the equipment
    - Specific features, postulated failure modes, or failure effects to be analyzed
    - Assumptions, empirically derived values, and the mathematical models used, together with justification for their use
    - Test data that support the assumptions and mathematical models
    - Description of analytical methods or computer programs used
    - Summary of analytically established performance characteristics and their acceptability
    - Approval, signature of the qualifier, and date

When the test data or operating experience data have been extrapolated, the basis and justification of the validity for the extrapolation shall be provided.

c. Discuss the qualification procedural requirements for VSS MCCs relating to aging, seismic qualification, and harsh environment events.

Equipment may be qualified by test, analysis, operating experience, or any combination thereof. Combined qualification shall be developed on a case-by-case basis by applying the procedures presented in this section. The qualification methods used shall provide auditable data by which they can be shown to constitute a complete qualification program.

Regardless of the method(s) used in the qualification program, the equipment is considered to be qualified when it meets the acceptance criteria listed in the equipment specification (see section 9 of IEEE Std 649). Any failure to meet the acceptance criteria shall be analyzed to determine its cause and overall effect on the equipment's qualification as discussed in section 10.8.

Aging

Aging may be addressed by several methods. These methods include age conditioning (testing), analysis, operating experience, in-service surveillance and maintenance for extension of qualified life, or any combination thereof. An aging method shall be selected based on an evaluation of the materials and application of the specific device or component. Age conditioning or analysis need not be performed even if significant aging mechanisms exist if naturally aged equipment with proper documentation, which meets the requirements of section 6.3.3.1 of IEEE Std 323-1983 [6], is used as the test specimen.

Seismic Qualification

Motor control centers may be seismically qualified by test, combined analysis and testing, or use of operating experience. Seismic qualification of Class 1E MCCs shall meet the requirements of IEEE Std 344-1987 [7]. The procedures and guidelines of that document shall be followed in demonstrating that the Class 1E MCCs can meet their qualification requirements. In addition, some specific areas that are peculiar to MCCs are listed herein with recommended qualification procedures to be used. These procedures are intended to supplement those described in IEEE Std 344-1987 [7] and provide additional guidance for qualifying this kind of equipment. IEEE C37.98-l978 [3] may be useful in determining qualification of individual devices.

Harsh Environment Events

Motor control center equipment is normally furnished for use in a mild environment in which the seismic event is the DBE of major concern. Under certain conditions, MCC equipment is furnished for use in a harsh environment where post-LOCA [loss of coolant accident] or HELB [high energy line break] events are of major concern.

When equipment is furnished for use in a harsh environment, specified conditions such as temperature, pressure, humidity, dust, and radiation shall be addressed in the qualification program. For a given post-LOCA or HELB event, the conditions for which the MCC and its equipment must be qualified shall be included in the MCC specification developed in accordance with section 9 of IEEE Std 649. The acceptable methods for demonstrating equipment capability for these events or conditions are testing, use of operating experience, analysis, or any combination thereof.

45. Electrical personnel shall demonstrate a familiarity level knowledge of electrical safety design requirements for digital computers supporting VSS (IEEE Std 7-4.3.2-2003, Annex E; DOE O 420.1B; DOE G 420.1-1; etc.).

The following is taken from IEEE Std 7-4.3.2-2003.

a. Discuss some of the configuration requirements for communications independence relating to communications between computers in different safety channels.

Communication between computers in different safety channels may be desired for such purposes as voter logic or time-stamp synchronization. Upon a failure of the communication, the preferred failure state should be set if one has been identified. Figure 74 and figure 75 depict ways in which this can be accomplished.

Figure 74 depicts broadcast communication between a safety computer in channel A and a safety computer in channel B. The one-way communication path provides a point of software isolation. The physical links between the computers provide electrical isolation. This isolation may be accomplished optically (i.e., fiber optic cable or optical isolators).

Communications isolation is provided through the broadcast communication. The buffering circuit provides an interface allowing acknowledgment or no acknowledgment of data transfer between channels, collision avoidance, etc. It serves as a buffering feature between the communications link and the safety function to ensure integrity of the safety function. The buffering circuit should be separate (e.g., at a minimum on a different board) from the processor performing the safety function. The buffering circuit may be another processor, memory card(s), etc. Any V&V and validation activities should include the buffering circuit. The physical link between the buffering circuits should serve as the point of electrical isolation.

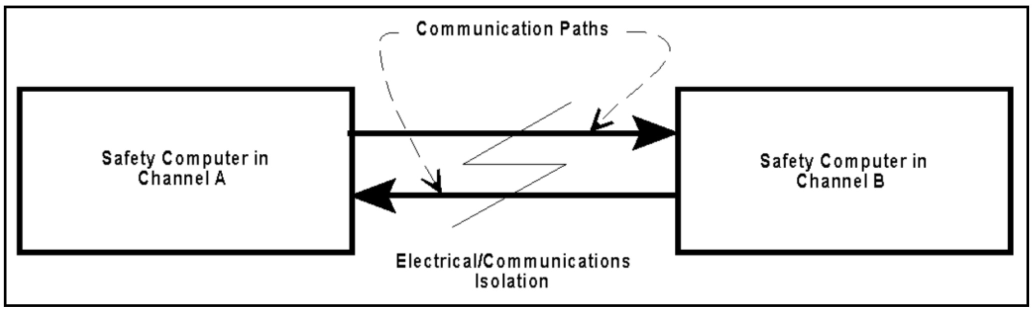
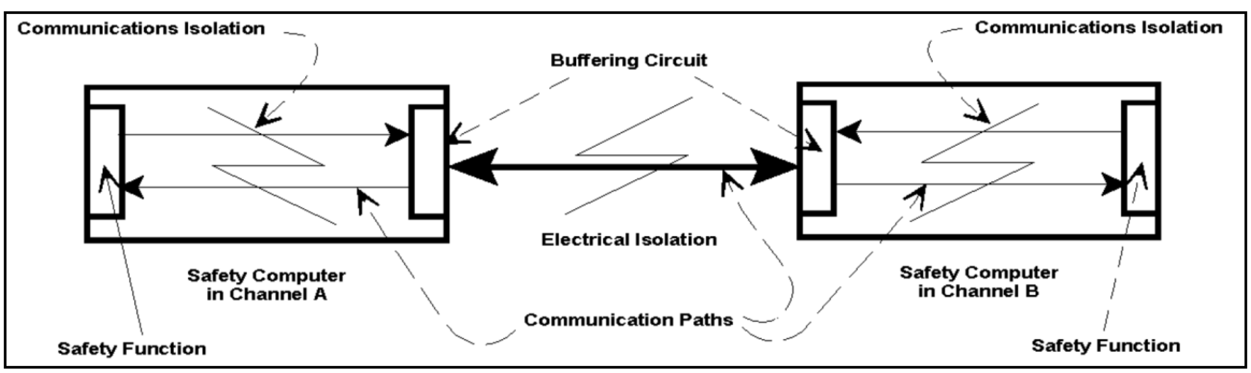


Figure 74. Communication between safety channels (one-way communication)

Figure 75 depicts a method with two separate points of isolation, one electrical and one for communications. This method allows two-way communication between safety computers, as long as a buffering circuit is employed.



Source: Figures 74 and 75, IEEE Std 7-4.3.2-2003

Figure 75. Communication between safety channels (two-way communication)

The broadcast communication link between the safety function and the buffering circuit serves as a route for data to be sent out by the safety computer. The separate communication from the buffering circuit allows the safety function processor to receive data from another channel. The process of requesting and receiving data from another channel should not result in loss of either of the safety functions.

b. Discuss some of the configuration requirements for communications independence relating to communications between safety and non-safety computers.

Communication between safety and nonsafety computers may be desired for purposes of time-stamp synchronization and installation of approved setpoint changes. However, at no time should the safety computer require input from the nonsafety computer in order to perform its safety function. Figures 76 and 77 depict ways communication between safety and nonsafety computers can be accomplished.

Figure 76 graphically shows a broadcast communication between the safety computer and the nonsafety computer. The one-way communication path provides for communication isolation. The physical link(s) between computers might provide both electrical and communications isolation as required. Electrical isolation may be accomplished optically (i.e., fiber optic cable or optical isolators). Communications isolation is provided through the broadcast communication path.

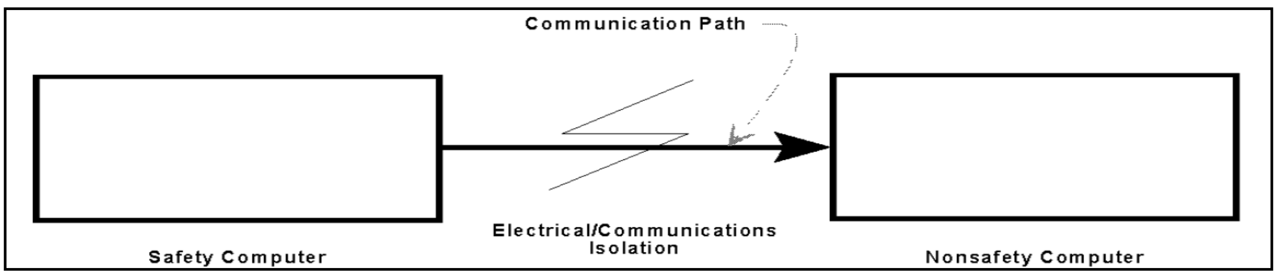
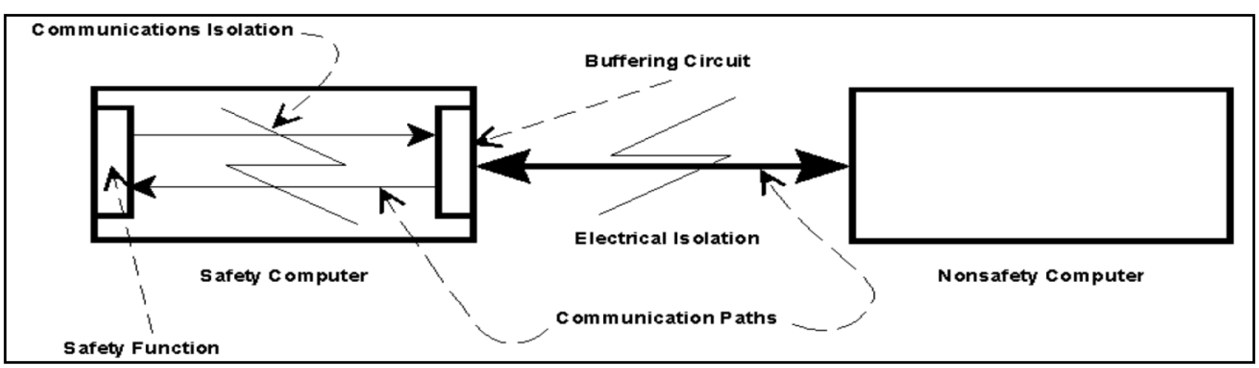


Figure 76. Communication between safety and nonsafety computers (one-way communication)

Figure 77 depicts a method with two separate points of isolation, one electrical and one communications. This method allows two-way communication between the safety computer and the nonsafety computer, as long as a buffering circuit is employed in the safety computer. Use of this method may be necessary when a separate computer is used for test and calibration purposes.



Source: Figures 76 and 77, IEEE Std 7-4.3.2-2003

Figure 77. Communication between safety and nonsafety computers (two-way communication)

The buffering circuit provides an interface allowing acknowledgment or no acknowledgment of data transfer between channels, collision avoidance, etc. It serves as a buffering feature between the communications link and safety function to assure the integrity of the safety function. The buffering circuit should be separate (i.e., at a minimum on a different board) from the processor performing the safety function. It may be another processor, memory card(s), etc. Any V&V activities should include the buffering circuit. As required, the link between the buffering circuit and the nonsafety computer provides electrical isolation.

The broadcast communication link between the safety function and the buffering circuit serves as a route for data to be sent by the safety computer. The process of sending data should not result in loss of the safety function. The broadcast communications link from the buffering circuit to the safety function is necessary when a separate test and calibration computer is employed.

46. Electrical personnel shall demonstrate a familiarity level knowledge of electrical safety design requirements for VSS protection systems (IEEE Stds 741-1997 and 833-1988, DOE O 420.1B, DOE G 420.1-1, etc.).

The information for this competancy statement is taken from IEEE Std 741-1997.

a. Identify the key general design criteria for VSS protection systems (IEEE Std-741, Section 4.)

As used in IEEE Std 741, protection refers to the sense, command, and execute features with their associated interconnections (see IEEE Std 603-1991) that are provided to minimize equipment damage and any interruption of electrical service resulting from mechanical or electrical failures or other unacceptable conditions. Protection includes equipment required to support the Class 1E power system in the performance of its safety function, and components whose function is to increase the availability and reliability of the safety-related equipment. The protection shall be capable of the following:

- Preventing failures in safety systems and equipment from disabling safety functions to below an acceptable level. The protective actions of each load group shall be independent of the protective actions provided by redundant load groups (see IEEE Std 308-1991)
- Operating the required devices upon detection of unacceptable conditions to reduce the severity and extent of electrical system disturbances, equipment damage, and potential personnel and property hazards
- Monitoring the connected preferred power supply and, where an alternate preferred power supply is provided by the design, of automatically initiating a transfer or alerting the operator to manually transfer to the preferred alternate power supply
- Providing indication and identification of the protective operations
- Periodic testing to verify logic schemes and protective functions
- Monitoring the availability of protection control power

- Periodic testing to verify setpoints. This requirement is not applicable to fuses

Those parts of the protection that have a safety function shall meet the requirements of IEEE Std 603-1991 and IEEE Std 308-1991. Documentation requirements for the protection of Class 1E power systems and equipment are found in IEEE Std 308-1991. Those parts of the protection whose function is nonsafety related shall be designed such that their failure does not degrade the Class 1E power system below an acceptable level.

b. Identify the major criteria for establishing bus voltage monitoring schemes (IEEE Std-741, Section 5.1.2 a) – h)).

Bus voltage monitoring schemes that are used for disconnecting the preferred power source, load shedding, and starting the standby power sources are part of the protection and shall meet the criteria that follow. Voltage monitoring schemes that are used only for alarms do not have to meet these criteria.

a) Bus voltage shall be detected directly from the Class 1E bus to which the standby power source is connected.
b) Upon sensing preferred power supply degradation, the condition shall be alarmed in the main control room. On sensing preferred power supply degradation to an unacceptable low-voltage condition, the affected preferred power supply shall be automatically disconnected from the Class 1E buses.
c) Each division shall have an independent scheme of detection of degraded voltage and loss-of-voltage conditions. Within each division, common equipment may be used for the detection of both conditions.
d) Each scheme shall monitor all three phases. The protection system design shall be such that a blown fuse in the voltage transformer circuit or other single phasing condition will not cause incorrect operation, nor prevent correct operation, of the scheme. Means shall be provided to detect and identify these failures.
e) The design shall minimize unwanted operation of the standby power sources and disconnection of the preferred power supply. The use of coincident logic and time delay to override transient conditions is a way to accomplish this.
f) Capability for test and calibration during power operation shall be provided.
g) The selection of undervoltage and time delay setpoints shall be determined from an analysis of the voltage requirements of the Class 1E loads at all onsite distribution levels.
h) Indication shall be provided in the control room for any bypass incorporated in the design.

c. Identify the major requirement for selecting protective devices for direct-geared valve actuator motors (IEEE Std-741, Section 5.5, first paragraph, first sentence).

The selection of a protective device for the direct geared valve actuator motor (VAM) shall ensure that the time current characteristic of the protective device is coordinated with the time current characteristic of the motor, as derived from motor time temperature data.

47. Electrical personnel shall demonstrate a familiarity level knowledge of electrical safety design requirements for Instrumentation and Control (I&C) equipment grounding of VSS (IEEE Std 1050-1996, DOE O 420.1B, DOE G 420.1-1, etc.).

The information for this competancy statement is taken from IEEE Std 1050-1996.

a. Discuss some design considerations for electrical noise minimization, noise sources, noise-coupling methods, and techniques for electrical noise minimization.

Design considerations for electrical noise minimization include the identification of the different types of noise sources, noise-coupling or transmission methods, and techniques that may be utilized that minimize the impact that electrical noise can have on vital safety systems. IEEE Std 1050-1996, *IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations,* devotes an entire chapter to this topic. A summary is provided below.

Noise Sources

Noise sources can be divided into the following categories:

- Natural sources—these happen independently of human activity, but their effects can be controlled.
- Incidental sources—these are caused by human activity, but they are not intentional.
- Intentional sources—these are emissions of potentially interfering energy produced for specific purposes unrelated to the equipment or systems under consideration.

Noise-Coupling Methods

Noise can be coupled into (or transmitted from) control circuits by any one of the following four different methods:

1. Conductive (direct contact)
2. Capacitive (electric)
3. Inductive (magnetic)
4. Radiative (electromagnetic)

Both capacitive and inductive coupling refer primarily to near field coupling. A control circuit or cable is considered to be in the near field of an electromagnetic source when the source to circuit distance is less than 0.167 of the wavelength ($\lambda/2\pi$) of the highest source frequency. Radiative coupling refers to circuits located in the far field of a source where the source's emissions are seen as a true propagating wave.

Techniques for Electrical Noise Minimization

There are five primary techniques for electrical noise minimization:

1. Suppression at the source
2. Positioning and isolating control cables
3. Shielding
4. Grounding
5. Filters

Other electrical noise minimization techniques include

- use of isolation and/or neutralizing transformers
- use of differential amplifiers
- increasing the signal-to-noise ration
- use of fiber optic cable

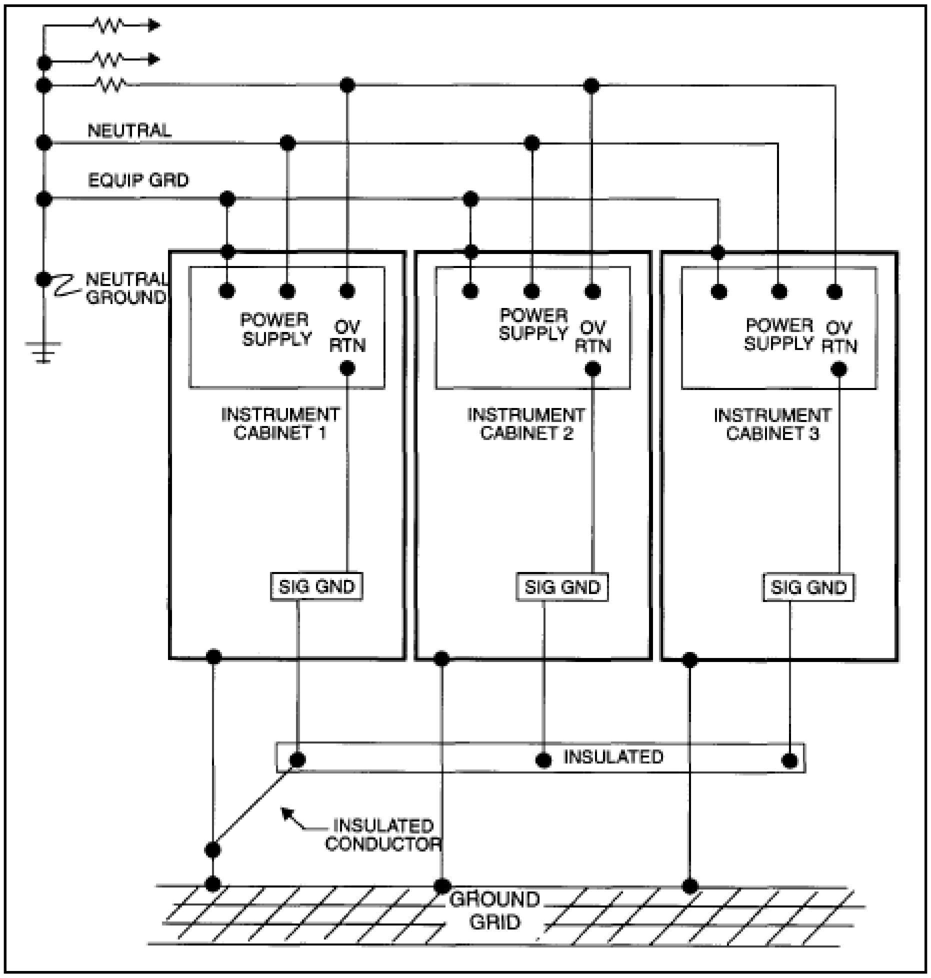
b. Describe the purpose or use, and advantages and disadvantages, of single-point ground systems, multi-point ground systems, and floating ground systems.

Single-Point Ground System

The single-point ground system is used to eliminate circulation of ground currents that cause common mode noise. This is the most commonly used system in an industrial environment. It is implemented by connecting the signal circuit to the station ground at only one point. This grounding method is very effective and is adequate when dealing with equipment operating at frequencies below 300 kHz. (Various sources place this frequency at anywhere between 100 kHz and 10 MHz. The equipment manufacturer should be consulted for each specific installation.)

A disadvantage of the system is that it is ineffective at high frequencies where signal wavelengths approach the equipment enclosure dimensions or the ground cable length. As equipment dimensions or ground cable lengths approach 0.15 of the signal wavelength, the cable can no longer be considered a low-impedance ground. Single-point reference grounds should be differentiated from signal return conductors, which do carry current under normal conditions.

In a distributed control system the equipment may be widely scattered throughout the station, and it is impractical to implement a single-point grounding arrangement. An I&C system is considered a distributed system when the individual control station cabinets are widely separated from each other. Such a system has special problems since the impedance in the signal reference conductors will result in a ground potential difference between the cabinets. Figure 78 illustrates an approach to providing a single-point ground system for this condition. The communications circuits between the cabinets should have appropriate protection for the common mode noise that is likely to result from the impedance of the long, insulated signal grounds.



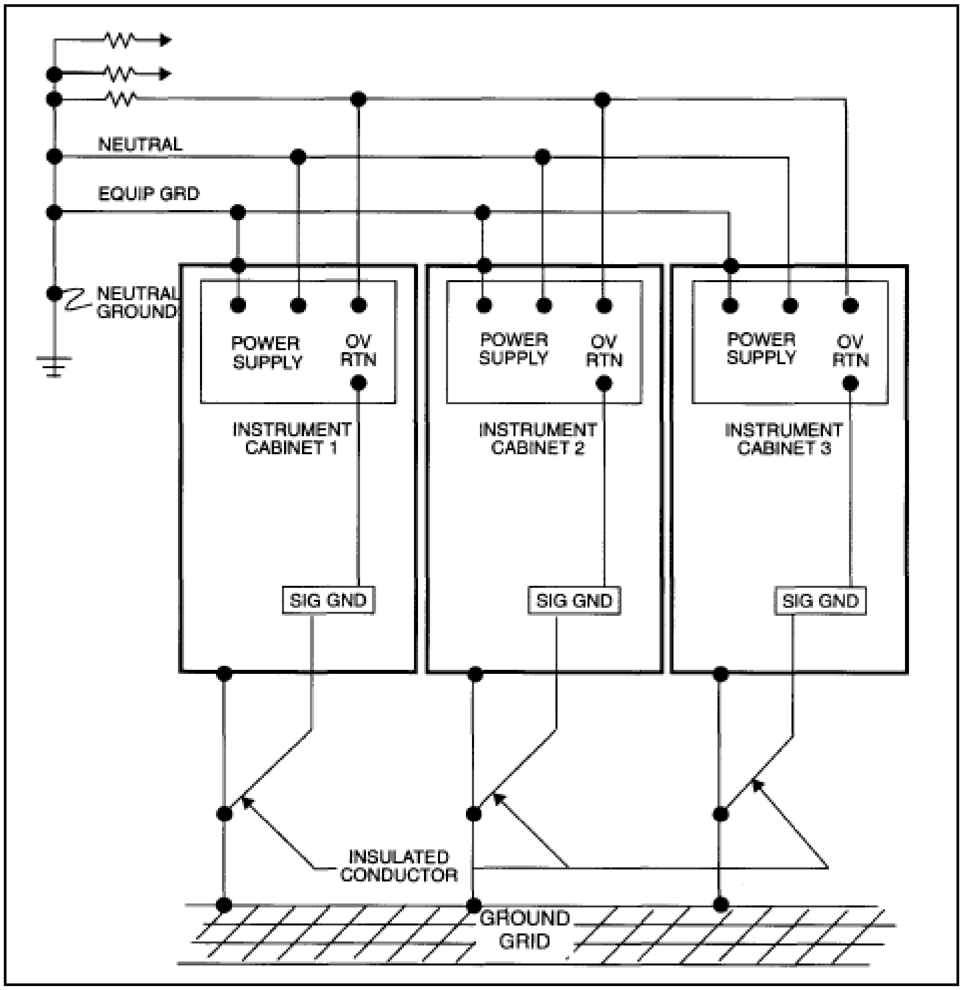
Source: IEEE Std 1050-1996

Figure 78. Single-point ground system for low-frequency signals with cabinets widely separated

Multi-point Ground System

A multiple-point ground system should be considered when grounding equipment that operates at frequencies over 300 kHz or when long ground cables are used. Each circuit is connected to ground at the closest point rather than routing all ground conductors to a single ground point. The advantages of this system are that circuit construction is easier, and that standing wave effects in the ground system at high frequencies are avoided. However, the system needs to be well maintained to overcome the effects of corrosion, vibration, and temperature change. Another disadvantage is that the system may create multiple ground loops that may cause inadvertent common mode noise. A multiple-point ground system is an option for low-frequency signals, as shown by figure 79.

This configuration accepts that a ground voltage difference will exist between the signal references and that the appropriate degree of protection should be provided for the resulting common mode noise.

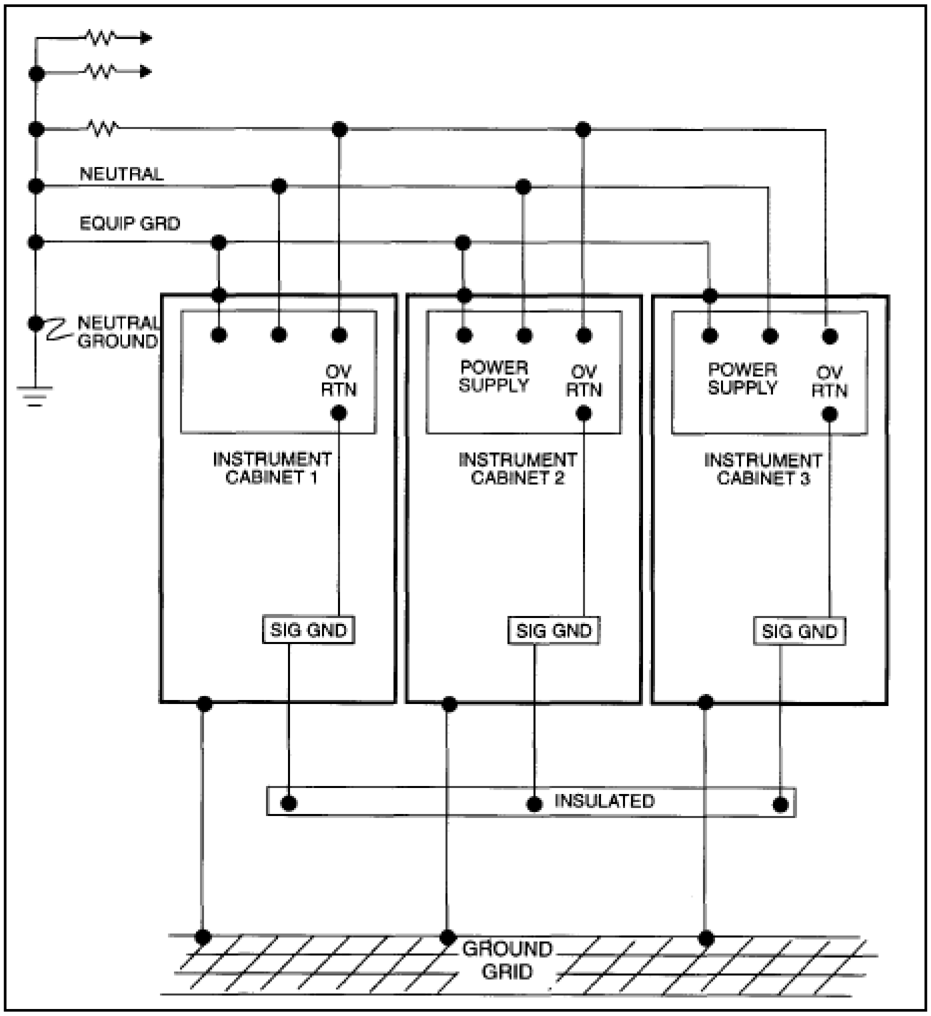


Source: IEEE Std 1050-1996

Figure 79. Multiple-point ground system for low-frequency signals with cabinets widely separated

Floating Ground System

The floating ground system is used to isolate circuits or equipment electrically from a common ground plane or from common wiring that might introduce circulating currents and produce common mode noise. It is implemented by electrically interconnecting the signal grounds, yet isolating them from a common ground plane (see figure 80). A hazard of this system is that static charges may accumulate and eventually cause a destructive or noise-producing discharge current to flow. It is usually advisable to implement this system with a bleeding resistor connected to ground to avoid the buildup of static charges.



Source: IEEE Std 1050-1996

Figure 80. Floating ground system

c. Identify the IEEE Standard citing requirements for VSS I&C equipment signal cable shield grounding requirements (IEEE Std 1050-1996).

IEEE Std 1050-1996 contains information about grounding methods for generating station I&C equipment. The identification of I&C equipment grounding methods to achieve both a suitable level of protection for personnel and equipment is included, as well as suitable noise immunity for signal ground references in generating stations. Ideal theoretical methods and accepted practices in the electric utility industry are presented.

48. Electrical personnel shall demonstrate a familiarity level knowledge of electrical safety design requirements for VSS Motor Operated Valves (MOV) (IEEE Std 1290-1996, DOE O 420.1B, DOE G 420.1-1, etc.).

a. Identify the IEEE Standard, citing requirements for motor applications, protection, and control for MOV motor applications (IEEE Std-1290).

The following is taken from IEEE Std 1290-1996.

Applications

Valve actuator motors (VAMs) have a unique design that can result in significantly different operating characteristics than NEMA Design B motors. Continuous duty motors, such as NEMA Design B Motors, are rated in HP, which implies a constant torque. VAMs are neither continuous duty nor constant torque at rated speed. They can be characterized as short duty time, high starting torque motors.

Protection

In general, protection schemes shall consider the design function of the VAM and its ability to perform this function. The protection scheme shall also consider the protection of the VAM. However, protection cannot always be designed to enable the valve to perform this design function and to protect the valve actuator. When this occurs, VAM protection should be established to encompass one of the following options:

- Protect the VAM at the expense of its design function to ensure that later VAM operation is possible. However, protection should not be provided that infringes on the design basis safety function of the VAM.
- Provide as much VAM protection as possible without limiting its chances of accomplishing its design function. Providing limited VAM protection may allow undetected VAM degradation.

Protection can be provided by various types and combinations of devices. This guide discusses thermal overload relays; fuses; thermal contacts; resistance temperature detector—resistors; molded case circuit breakers; and DC VAM surge protection. This guide is concerned only with VAM coordination with upstream power sources. As VAMs frequently have not been fuse protected, this guide provides some detail on fuse application.

Control

This clause includes considerations to be addressed in designing an MOV control circuit. Each block represents an individual portion of the control scheme that will be discussed in detail in the following subclauses. This clause provides suggestions for integrating the individual blocks into a complete control circuit such that the MOV can perform the required function for its application. The Electric Power Research Institute application guide NP-6660-D also provides guidance for selecting control, protection, and alarm functions that are consistent with typical MOV applications.

The first step in designing a control circuit is to obtain the specific system design requirements. The MOV system requirement data sheet can be used to document the valve functional requirements needed to develop the control circuit. The design of a control scheme is based on the valve application, system design requirements, valve design and type (including design limits), vendor requirements, and limitations of control devices.

Subclauses 6.1 through 6.6 provide brief descriptions of each block of the control logic, including advantages, disadvantages, and design considerations for each. These descriptions, in combination with the MOV system requirements, give the parameters necessary to select a control configuration appropriate for the MOV control circuit.

Protection can be provided by various types of devices. For examples of these devices, see clause 5.

VII. ELECTRICAL SAFETY REQUIREMENTS AND PRACTICES

This section is optional and should be used by the program and/or field offices to assist them with specific technical qualifications for that office.

49. Electrical personnel shall demonstrate a familiarity level knowledge of electrical safety requirements and practices in the following list of regulatory and consensus standards documents, including the relationship between these documents and which are "enforceable" in your site's contractors contract, such as OSHA (29 CFR 1910 and Subpart S, and 29 CFR 1926 Subparts K and V); NFPA 70E, Standard for Electrical Safety in the Workplace/Maintenance; NFPA-70B, Recommended Practice of Electrical Equipment Maintenance; DOE-HDBK-1092-2004, Electrical Safety Handbook; and 10 CFR 851, Worker Safety and Health Program.

[Note: The title of NFPA 70E does not contain the term "Maintenance."]

[Note: The 2004 version of NFPA 70E has been superseded by the 2009 revision and is archived but still available. Because the 2009 revision was drastically reduced in scope it is not used as a reference in this guide.]

a. Describe the purpose, scope, and application of the requirements detailed in the listed standards and Orders.

29 CFR 1910

The Williams-Steiger Occupational Safety and Health Act of 1970 (84 Stat. 1593) states that

> Without regard to chapter 5 of title 5, *United States Code*, or to the other subsections of this section, the Secretary shall, as soon as practicable during the period beginning with the effective date of this Act and ending 2 years after such date, by rule promulgate as an occupational safety or health standard any national consensus standard, and any established Federal standard, unless he determines that the promulgation of such a standard would not result in improved safety or health for specifically designated employees.

The legislative purpose of this provision is to establish, as rapidly as possible and without regard to the rule-making provisions of the Administrative Procedure Act, standards with which industries are generally familiar, and on whose adoption interested and affected persons have already had an opportunity to express their views. Such standards are either national consensus standards on whose adoption affected persons have reached substantial agreement, or Federal standards already established by Federal statutes or regulations.

29 CFR 1910 carries out the directive to the Secretary of Labor under section 6(a) of the Act. It contains occupational safety and health standards that have been found to be national consensus standards or established Federal standards.

29 CFR 1926

29 CFR 1926, beginning with subpart A, sets forth the safety and health standards promulgated by the Secretary of Labor under section 107 of the Contract Work Hours and Safety Standards Act. The standards are published in subpart C of this part and following subparts. Subpart B of this part contains statements of general policy and interpretations of section 107 of the Contract Work Hours and Safety Standards Act having general applicability.

NFPA 70E, Standard for Electrical Safety in the Workplace

NFPA 70E addresses those workplace electrical safety requirements that are necessary for the practical safeguarding of employees in their pursuit of gainful employment. This standard covers the installation of electric conductors, electric equipment, signaling and communications conductors and equipment, and raceways for the following:

- Public and private premises, including buildings, structures, mobile homes, recreational vehicles, and floating buildings
- Yards, lots, parking lots, carnivals, and industrial substations
- Installations of conductors and equipment that connect to the supply of electricity
- Installations used by the electric utility, such as office buildings, warehouses, garages, machine shops, and recreational buildings, that are not an integral part of a generating plant, substation, or control center

NFPA-70B, Recommended Practice of Electrical Equipment Maintenance

NFPA-70B applies to PM for electrical, electronic, and communication systems and equipment and is not intended to duplicate or supersede instructions that manufacturers normally provide. Systems and equipment covered are typical of those installed in industrial plants, institutional and commercial buildings, and large multifamily residential complexes. Consumer appliances and equipment intended primarily for use in the home are not included.

The purpose of this recommended practice is to reduce hazards to life and property that can result from failure or malfunction of industrial-type electrical systems and equipment.

DOE-HDBK-1092-2004, Electrical Safety Handbook

The *Electrical Safety Handbook* presents the DOE safety standards for DOE field offices or facilities involved in the use of electrical energy. It has been prepared to provide a uniform set of electrical safety guidance and information for DOE installations to effect a reduction or elimination of risks associated with the use of electrical energy. The objectives of this handbook are to enhance electrical safety awareness and mitigate electrical hazards to employees, the public, and the environment.

This handbook provides general information to enhance understanding of DOE Orders, national codes, national standards, and local, state, and Federal regulations. This handbook shall not supersede more stringent requirements in those applicable codes, standards, and regulations.

10 CFR 851

Title 10 CFR 851, "Worker Safety and Health Program," codifies the Department's worker protection program requirements established in DOE O 440.1B, *Worker Protection Program for DOE (Including the National Nuclear Security Administration) Federal Employees.* Consistent with the intent of Congress, DOE O 440.1B forms the basis for the rule's substantive requirements. The Conference Committee for the National Defense Authorization Act recognized that contractors currently operate under this Order, "which provides an adequate level of safety." (Conference Report 107–772, November 12, 2002, at 797.)

b. Discuss the graded approach process that Department line management uses to determine an appropriate level of coverage by electrical personnel. Include in this discussion the factors that may influence the level of coverage.

The following is taken from DOE O 5480.20A.

A graded approach means a process by which the level of analysis, documentation, and action necessary to comply with a requirement are commensurate with the relative importance to safety, safeguards, and security; the magnitude of any hazard involved; the life-cycle stage of a facility; the programmatic mission of a facility; the particular characteristics of a facility; and any other relevant factor.

The following is taken from DOE O 420.1B.

A graded approach considers the following factors:

- Remaining Facility Lifetime and the Safety Significance of Remaining Operations. Facilities undergoing deactivation, and decontamination and decommissioning, may be undergoing frequent changes, modifications, and in some cases, removal of systems no longer needed to support the safety basis of those operations. After deactivation or when a facility is in long-term surveillance and maintenance, there may be less need for attention.
- Safety Importance of the System. Not all systems are equal as measured by the likelihood and consequences of the hazard and the accidents that they prevent or mitigate. The level of system documentation detail in CM should be tailored to the importance of the system.

c. Determine contractor compliance with the listed documents as they apply to contract design requirements and electrical system activities at a defense nuclear facility.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

50. Electrical personnel shall demonstrate a familiarity level knowledge of DOE O 414.1C, Quality Assurance, as it pertains to electrical systems.

a. <u>Mandatory Performance Activity</u>: Describe how electrical equipment is procured based upon its safety function and/or nuclear-related activity using quality assurance criteria and appropriate national or international consensus standards.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

b. Describe what is meant by implementing quality assurance criteria using a graded approach.

The following is taken from DOE O 414.1C.

Each DOE organization must develop and implement a QAP that implements QA criteria using a graded approach. The QAP must address the following management, performance, and assessment criteria:

- Management/Criterion 1—Program: Establish an organizational structure, functional responsibilities, levels of authority, and interfaces for those managing, performing, and assessing work. Establish management processes, including planning, scheduling, and providing resources for work.
- Management/Criterion 2—Personnel Training and Qualification: Train and qualify personnel to be capable of performing assigned work. Provide continuing training to personnel to maintain job proficiency.
- Management/Criterion 3—Quality Improvement: Establish and implement processes to detect and prevent quality problems. Identify, control, and correct items, services, and processes that do not meet established requirements. Identify the causes of problems, and include prevention of recurrence as a part of corrective action planning. Review item characteristics, process implementation, and other quality-related information to identify items, services, and processes needing improvement.
- Management/Criterion 4—Documents and Records: Prepare, review, approve, issue, use, and revise documents to prescribe processes, specify requirements, or establish design. Specify, prepare, review, approve, and maintain records.
- Performance/Criterion 5—Work Processes: Perform work consistent with technical standards, administrative controls, and hazard controls adopted to meet regulatory or contract requirements using approved instructions, procedures, etc. Identify and control items to ensure their proper use. Maintain items to prevent their damage, loss, or deterioration. Calibrate and maintain equipment used for process monitoring or data collection.
- Performance/Criterion 6—Design: Design items and processes using sound engineering/scientific principles and appropriate standards. Incorporate applicable requirements and design bases in design work and design changes. Identify and control design interfaces. Verify/validate the adequacy of design products using individuals or groups other than those who performed the work. Verify/validate work before approval and implementation of the design.
- Performance/Criterion 7—Procurement: Procure items and services that meet established requirements and perform as specified. Evaluate and select prospective

suppliers on the basis of specified criteria. Establish and implement processes to ensure that approved suppliers continue to provide acceptable items and services.

- Performance/Criterion 8—Inspection and Acceptance Testing: Inspect and test specified items, services, and processes using established acceptance and performance criteria. Calibrate and maintain equipment used for inspections and tests.
- Assessment/Criterion 9—Management Assessment: Ensure that managers assess their management processes and identify and correct problems that hinder the organization in achieving its objectives.
- Assessment/Criterion 10—Independent Assessment: Plan and conduct independent assessments to measure item and service quality and the adequacy of work performance and to promote improvement. Establish sufficient authority and freedom from line management for independent assessment teams. Ensure that persons conducting independent assessments are technically qualified and knowledgeable in the areas to be assessed.

The criteria listed above are implemented using a graded approach that accounts for the following factors:

- The relative importance to safety, safeguards, and security
- The magnitude of any hazard involved
- The life-cycle stage of a facility or item
- The programmatic mission of a facility
- The particular characteristics of a facility or item
- The relative importance to radiological and nonradiological hazards
- Any other relevant factors

c. Describe the types of documents related to electrical systems that should be controlled by a document control system.

The information for KSAs ‘c’ and ‘d’ is taken from DOE G 414.1-2A.

Records should be compiled in a records management system. Typical records include procedures, plans, and manuals; training and qualification results; acceptance test results; technical/regulatory correspondence; operational records; design basis descriptions, design review results, design revisions, and CM data; and quality problem resolutions. Records may be in a variety of forms (e.g., electronic, written, or printed; microfilm; photographs; radiographs; or optical disks).

A document control system should be in place to control the preparation, review, approval, issuance, management, and revision of documents. Documents are required by organizations, projects, or programs to control policy and administrative and/or technical information. A document may describe work to be done, data to be used at different locations or by different people, or, in changing situations, data to be controlled from time to time for reference purposes. The document control system should be established to supply the documents necessary for personnel to safely and correctly perform their assigned responsibilities.

DOE-HDBK-1092-2004, *Electrical Safety,* notes that the following must be documented and maintained in records:

- Performance of work
- Personnel training
- Work instructions
- Equipment testing data
- LOTO procedures
- Maintenance inspections and servicing
- Manufacturer's recommendations
- Hazardous location evaluations
- Dielectric test results
- Safety determinations
- Accepted risk determinations
- Decisions to forgo grounding or bonding
- Equipment design data
- Self-assessments
- Electrical deficiencies noted
- Maintenance and care of PPE

d. Discuss the requirements for revision and distribution of controlled documents.

A document control system should be in place to control the preparation, review, approval, issue, control, and revision of documents. Documents are required by organizations, projects, or programs to control policy and administrative and/or technical information. A document may describe work to be done, data to be used at different locations or by different people, or, in changing situations, data to be controlled from time to time for reference purposes. The document control system should be established to supply the documents necessary for personnel to safely and correctly perform their assigned responsibilities. Document control systems ensure that the mechanisms developed to implement the safety management functions of DOE P 450.4 are properly prepared, controlled, and available for use.

e. Discuss the determination of calibration frequency for electrical test equipment.

The following is taken from DOE-HDBK-1092-2004.

Instrumentation shall be calibrated per manufacturers' instructions. A record of calibration should be maintained for each instrument, by serial number or an equivalent method, showing dates of inspection, calibration data as received, the date when it should be recalled from the field and a recalibration check made, and any interim repairs. After a period of time, it should become obvious what frequency needs to be established for calibrating each instrument.

Calibration schedules and procedures for calibrating testing apparatus are recommended to be in accordance with ANSI C39.1.

The following is taken from NFPA 70B, ch 21.7.

In general, any test equipment used for the calibration of other equipment should have an accuracy at least twice the accuracy of the equipment under test. The test equipment should be maintained in good condition and should be used only by qualified test operators.

f. Describe the effect of using inappropriate calibration standards on electrical test equipment.

The following taken from NFPA 70B.

Data loss and unsafe work conditions can result from the use of inappropriate calibration standards. All test equipment should be calibrated at regular intervals to ensure the validity of the data obtained. In order to get valid test results, it might be necessary to regulate the power input to the test equipment for proper waveform and frequency and to eliminate voltage surges.

g. Discuss the key elements of the procurement process for electrical systems as described in DOE O 414.1C, Quality Assurance.

Key elements of the procurement process, as delineated in DOE O 414.1C, are as follows:

- Procure items and services that meet established requirements and perform as specified.
- Evaluate and select prospective suppliers on the basis of specified criteria.
- Establish and implement processes to ensure that approved suppliers continue to provide acceptable items and services.

51. Electrical personnel shall demonstrate a familiarity level of knowledge of DOE O 430.1B Chg 1, Real Property Asset Management, with regard to life-cycle asset management.

a. Explain the Department's role in the oversight of contractor maintenance operations.

The information for KSAs 'a' and 'b' is taken from DOE O 430.1B Chg 1.

Delineated below is a summary list of the responsibilities and authorities for effective management of DOE real property assets and the accountabilities for real property asset management, from planning and acquisition through operations and disposal:

- Lead Program Secretarial Offices (LPSOs) issue program missions, budgets, and planning estimates covering a 10-year planning horizon for site infrastructure and LPSO-related real property assets and approve 10-year site plans and land-use management plans for their sites.
- Cognizant Secretarial Offices (CSOs) and Program Secretarial Offices (PSOs) issue program missions, budgets, and planning estimates covering a 10-year planning horizon for their program-related work and/or real property assets and approve elements of TYSPs related to their programmatic responsibilities at related sites.
- Site/field managers ensure mission resource requirements for real property assets, including their plans and budgets, are prepared to meet the program missions, budgets, and planning estimates, and the results are documented in the TYSP. Site/field managers perform a key role coordinating program and tenant activities and real property asset needs at the site.

- TYSPs are submitted by site/field managers to the LPSOs/CSOs/PSOs as the plans for real property assets at the sites. TYSPs support LPSO/CSO/PSO programming decisions regarding real property assets and subsequent site budget requests.
- The Office of Engineering and Construction Management develops policies and procedures for real property asset management and provides corporate oversight for implementation.

b. Identify the key elements of a contractor maintenance plan as required by the DOE Order referenced above.

The contractor must maintain real property assets in a manner that promotes operational safety, worker health, environmental compliance, property preservation, and cost-effectiveness while meeting the program missions. This requires a balanced approach that not only sustains the assets but also provides for their recapitalization and includes the following as a minimum:

- A maintenance management program that includes a condition assessment of the real property assets, a work control system, management of deferred maintenance, a method to prioritize, and systems to budget and track maintenance expenditures.
- Identification of 5-year maintenance and repair requirements (sustainment) and funding for deferred maintenance reduction.
- Identification of 5-year recapitalization requirements to replace or modernize existing facilities.
- Condition assessments that must be performed on real property assets at least once within a 5-year period, and may be required more frequently for mission-essential facilities and infrastructure. The condition assessment program shall utilize a tailored approach based on facility status, mission, and importance and the magnitude of the hazards associated with facilities and infrastructure. Inspection methodology shall be consistent with industry practice and shall include identification of safety and health hazards. Deferred maintenance estimates will be based on nationally recognized cost-estimating systems or the DOE Condition Assessment Information System. The condition assessment program will support the reporting requirements of the Facilities Information Management System.

c. Describe configuration control and its relationship to the maintenance work control process and the maintenance history file.

The following is taken from DOE G 433.1-1

Configuration management is a discipline that applies technical and administrative direction and surveillance to identify and document the physical characteristics of a facility. It is a method of doing business that maintains consistency among design requirements, physical configuration, and facility documentation. It audits to verify conformance to specifications and related documentation. Basically, it boils down to doing all those things that should be done all along to properly manage and control physical and functional items at a facility.

Such a program can be broken down into five basic programmatic elements:

1. Program management
2. Design requirements

3. Document control
4. Change control
5. Assessments

An important aspect of a CM program is the assurance that the design basis of a DOE nuclear facility is established, documented, and maintained. The facility SSCs and computer software should conform to approved design requirements and any changes to them must be minimized through an integrated management review process with established approval criteria. This will help to establish that the operations of the facility are reliable if personnel operating the facility are knowledgeable about changes through timely review and training. Proposed changes should be thoroughly evaluated to determine their impact on other hardware and documents. Such changes should be reviewed and approved by appropriate, responsible managers before implementation. This way, the program maintains a consistency between the documents of all departments and organizations (i.e., design, inspection, operations, maintenance, testing, or training). Safety, mission, economic impact, and benefit can be fully analyzed through the full range of review and approval contained in the program (see DOE-STD-1039-93 and DOE-STD-1073-2003).

The work control process should be integrated with the planning process and should include provisions for equipment repair history.

d. Describe the mechanisms for feedback of relevant information, such as trend analysis and instrumentation performance/reliability data, to identify necessary program modifications.

The following is taken from DOE O 226.1A. Additional detail is available from that source.

Mechanisms anchored in a contractor assurance system will provide a variety of feedback types, as follows:

- Assessments (including self-assessments or management assessments, operational awareness or management walk-throughs, QA assessments, and internal independent assessments)
- Event reporting (including reporting, analyzing, and trending operational events, accidents, and injuries)
- Worker feedback mechanisms
- Issues management (including analysis of causes, identification of corrective actions, corrective action tracking, monitoring and closure, verification of effectiveness, trend analysis, and identification of continuous improvement opportunities)
- Lessons learned
- Performance measures

e. Review a contractor preventive maintenance activity and describe the preventive maintenance factors to be considered as the activity is planned.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

f. Discuss the importance of post-maintenance testing and the elements of an effective post-maintenance testing program.

The following is taken from DOE G 433.1-1.

Post-maintenance testing should be performed to verify that components will fulfill their current, authorized design function when returned to service after maintenance.

Post-maintenance testing includes all testing performed after maintenance activities. An effective post-maintenance testing program should apply to all maintenance activities and should address each organization's responsibilities, equipment to be included, degree and type of testing, procedure needs, acceptance requirements, testing control, and documentation of results. Post-maintenance testing could be as simple as checking a manual valve for leaks at normal operating pressure after packing adjustment or as detailed as an in-depth diesel generator performance test.

The objective of post-maintenance testing is to verify that SSCs are capable of performing their intended function when returned to service following maintenance and to ensure that the original deficiency is corrected. Post-maintenance testing requires close coordination among various facility groups and contract personnel. Post-maintenance testing integrates with the work-control system and the health and safety permit system.

Post-maintenance testing involves the following key elements:

- Responsibilities of each group are clearly defined.
- Scope of equipment tested includes all facility equipment.
- Input from maintenance, owner/operator, and technical support groups is included in the specification of appropriate tests.
- Guidance is available to planners for identifying appropriate tests.
- Testing is conducted with owner/operator's authorization, uses approved procedures or instructions, and is performed and reviewed by qualified personnel.
- Tests are conducted under the appropriate system operating parameters.
- A form is used to authorize, document, and review the results of post-maintenance testing.
- Post-test system restoration is formally controlled (restoring system to normal and/or standby modes following completion of post-maintenance testing).

g. Review the results of post-maintenance testing activities and discuss the acceptance of post-maintenance testing.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

h. Discuss the importance of maintaining a maintenance history.

The following summary is taken from DOE G 433.1-1, section 4.15. Additional detail is available from that source.

A maintenance history and trending program should be maintained to document data, provide historical information for maintenance planning, and support maintenance and performance trending of facility systems and components. The documentation of complete, detailed, and usable history will be increasingly important as plant-life extension becomes an issue.

One objective of a good equipment maintenance history program is the ability to readily retrieve equipment maintenance, performance, and reference information to improve facility reliability.

The work-control system may be useful as a maintenance history data collection tool. The maintenance history program should provide a system to document component identification and description, vendor reference information and correspondence, diagnostic monitoring data, corrective and PM or modification information, and spare parts information. This system may be maintained centrally or locally by the group responsible for collecting the data. In either case, easy access should be provided to all groups needing the information. The historical data, combined with operating experience at similar facilities, operating logs and records, and facility performance monitoring data, can be effective in analyzing trends and failures in equipment performance and making adjustments to the maintenance program. The maintenance history program should clearly define systems and equipment to be included, data to be collected, methods for recording data, and uses for the data.

i. Review a maintenance history file and discuss the potential implications of repeat maintenance items.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

j. Explain how various problem analysis processes can be used to enhance maintenance programs (DOE G 433.1-1, Nuclear Facility Maintenance Management Program Guide for Use with DOE O 433.1).

The following is taken from DOE G 433.1-1.

Root-cause analyses of unplanned, recurring, and persistent maintenance problems, incidents, and outages that impact safe and reliable operations, although historically performed, have only recently adopted formal methodologies to systematically and clearly lead to their effective resolution. The root cause is seldom a single factor.

Individuals at all levels should be trained in the use of one or more of a variety of formal problem analysis and solving methodologies, including

- Kepner-Tregoe;
- job hazard analysis;
- function analysis;
- total quality management—performance improvement process;
- reliability, availability, and maintainability analysis;
- single-failure analysis;
- root-cause analysis;
- facility safety analysis and review;
- risk assessment (including failure modes and effects analysis);
- value engineering.

The interaction and effects of one or more of the following factors should be considered:

- Design
- Drawings
- Procedures
- Training
- Qualification verification
- Tools
- Attitude
- Supervision
- Human error
- Management control
- Communication

When the nature of specific concerns warrants (based upon uniqueness, warranty, complexity, time-constraints, state-of-the-art technology, special skills/equipment/tools, etc.) outside expertise may need to be contracted to ensure the appropriate focus.

Root-cause categories should be established to facilitate future analyses, correlate proven corrective actions, and focus management action on the critical few.

These methods result in value-added and knowledge-based correction plans that should be followed to validated resolution and documented in the maintenance history files. Applicable information should be shared as lessons learned for broad-based benefit from local actions.

Selected Bibliography and Suggested Reading

Code of Federal Regulations

10 CFR 830, "Nuclear Safety Management". January 1, 2009.
10 CFR 830, Subpart A, "Quality Assurance Requirements."
10 CFR 830, Subpart B, "Safety Basis Requirements."
10 CFR 835.602, "Controlled Areas."
10 CFR 851, "Worker Safety and Health Program."
29 CFR 1910, "Occupational Safety and Health Standards."
29 CFR 1910.67, "Vehicle-Mounted Elevating and Rotating Work Platforms."
29 CFR 1910.120, "Hazardous Waste Operations and Emergency Response."
29 CFR 1910.137, "Electrical Protective Devices."
29 CFR 1910.147, "The Control of Hazardous Energy (Lockout/Tagout)."
29 CFR 1910.268, "Telecommunications."
29 CFR 1910.269, "Electric Power Generation, Transmission, and Distribution."
29 CFR 1910.305, "Wiring Methods, Components, and Equipment for General Use."
29 CFR 1910.331–335, "Electrical safety-related work practices."
29 CFR1910.1200, "Hazard Communication."
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