Microgrids, SmartGrids, and Resilience Hardware 101

Jim Reilly, Electrical Engineer - Microgrid Deployment

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REVIEW DRAFT – NOT FOR CITATION, QUOTATION, OR DISTRIBUTION

- ❖ **Grid Overview**
- ❖ **What is a Microgrid?**
- ❖ **What is a SmartGrid?**
- ❖ **Variable Generation**
- ❖ **Batteries**
- ❖ **NREL CORE Microgrid Design Process**
- ❖ **NREL Overview**

All info in this deck is oversimplified to help a broad baseline understanding, please consult with the experts before fully pursuing a microgrid or SmartGrid

Common Energy Terms

- ❖ **Distributed Generation**
  - o Distributed Electric Resource (DER), Decentralized Generation, Dispersed Storage & Generation (DSP), Decentralized Energy, Distributed Energy, Independent Power Producer (IPP), Non-Utility Generator (NUG), etc.

- ❖ **Dispatchable Generation Source**
  - ❖ Generation sources that can be dispatched at request of operators
  - ❖ Baseload – Slow ramping up or down – Roughly 1-12 hours
    - ❖ Coal, Nuclear, Geothermal, Biomass, etc.
  - ❖ Peaking – Quick ramping up or down – seconds to minutes
    - ❖ Natural Gas, Hydropower, Geothermal, Biomass, Diesel, etc.

- ❖ **Variable Generation**
  - ❖ Generation sources driven by variable energy resource
    - ❖ Wind power, solar power, Marine and Hydrokinetic, etc..
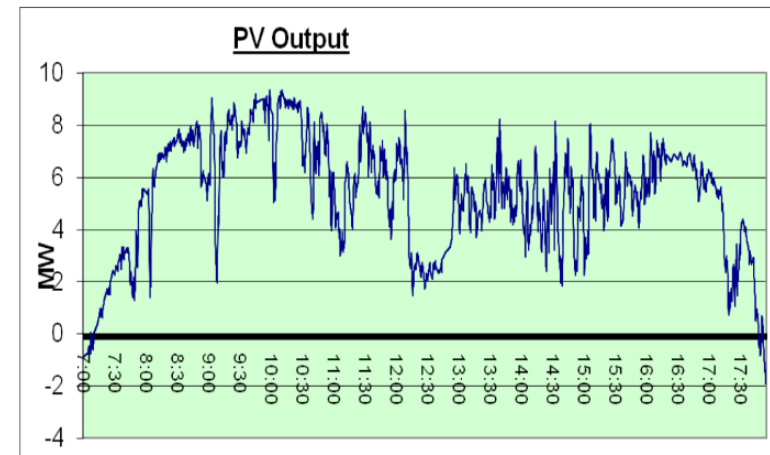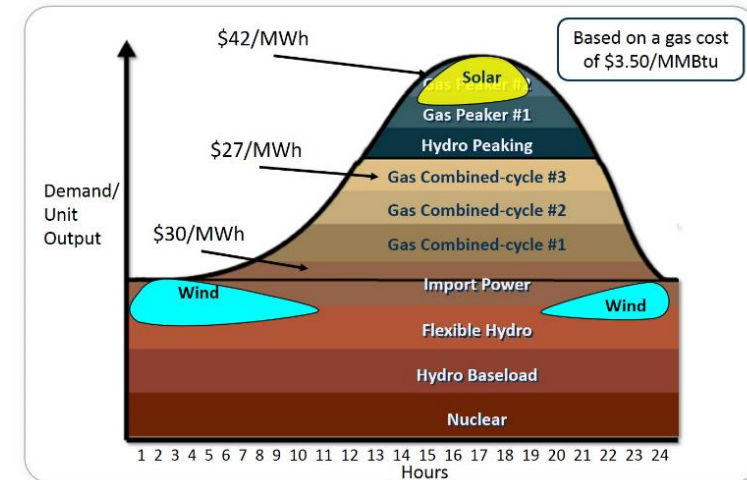
- ❖ **Reliability**
  - ❖ Ability of a system to avoid a disruption in quality service
  - ❖ System Average Interruption Frequency Index (SAIFI)
    - ❖ $\text{CAIFI} = \dfrac{\text{Number of Customer Interruptions}}{\text{Customers Served}}$

- ❖ **Resilience**
  - ❖ Ability of a system to adapt, withstand, and recover from a disruption
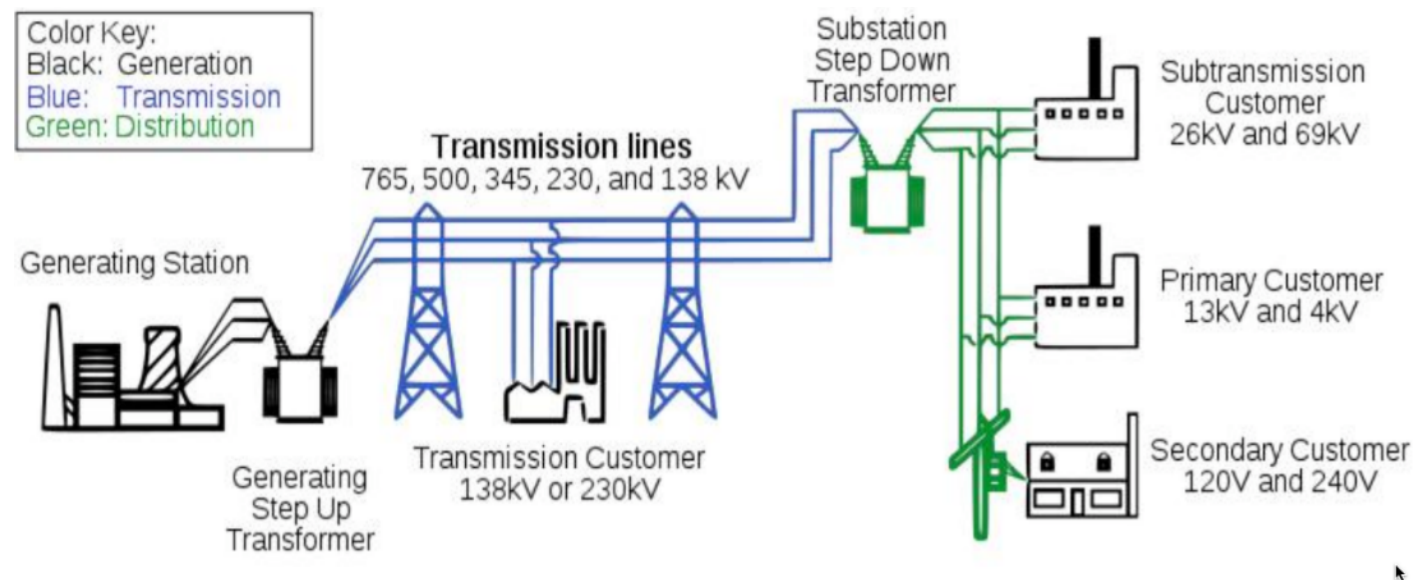 - ❖ System Average Interruption Duration Index (SAIDI)
    - ❖ $\text{CAIDI} = \dfrac{\text{Duration of Customer Interruptions}}{\text{Customers Served}}$

Electric Grid Overview

Historically all power flowed from transmission to distribution, distributed generation is creating potential bi-directional power flows and forcing utilities to implement more intelligent distribution networks.
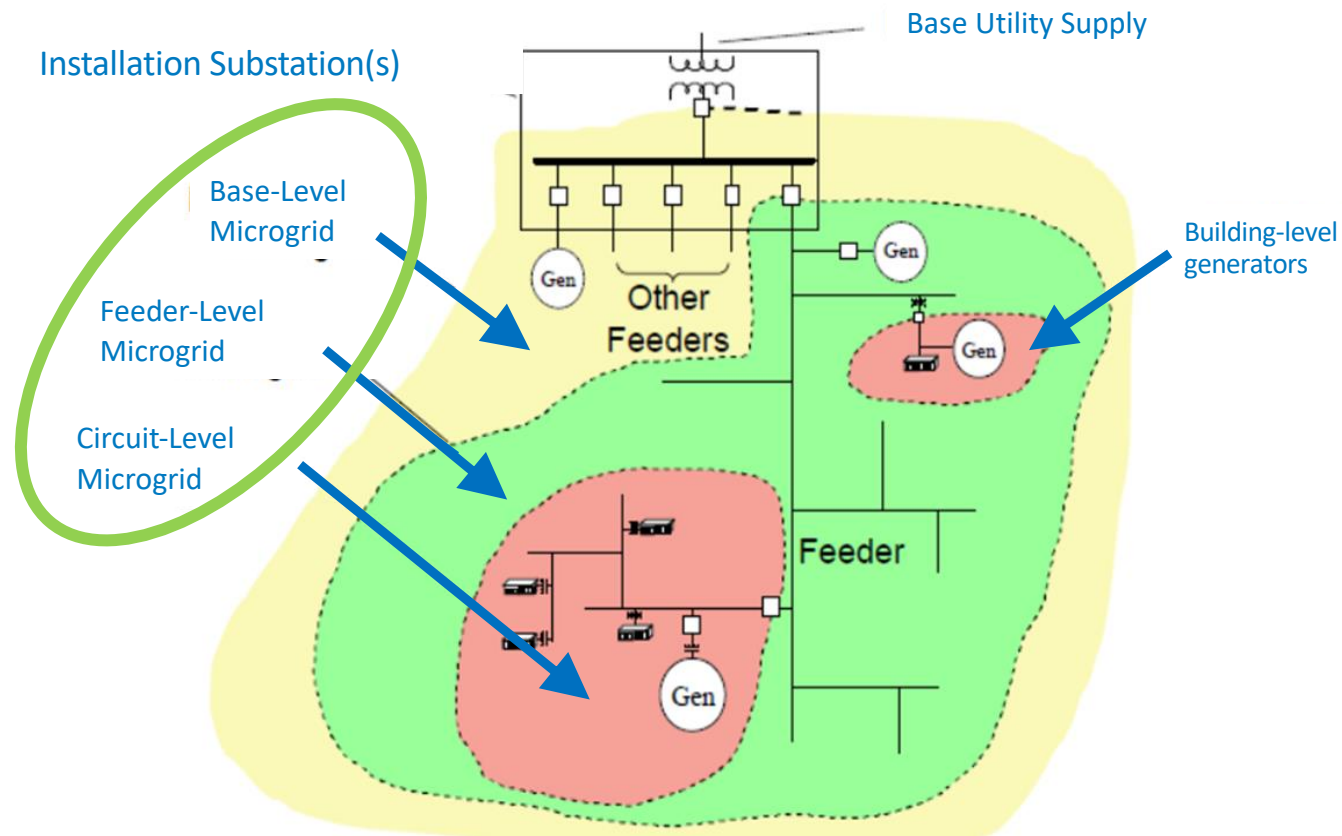
❖ **Transmission** – high capacity back-bone lines that carry energy from generation to distribution across long distances

  ❖ Common voltages are 115 kV, 138 kV, 230 kV, 315 kV, 500 kV (typically metal poles)

❖ **Distribution** – localized network that delivers energy from the transmission substation to loads

  ❖ Common voltages are 12.47 kV, 22 kV, 34.5 kV, 46 kV, 69 kV (typically wood poles)

Microgrid – DOE Definition

❖ Group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid….and can operate in both grid-connected or island-mode.
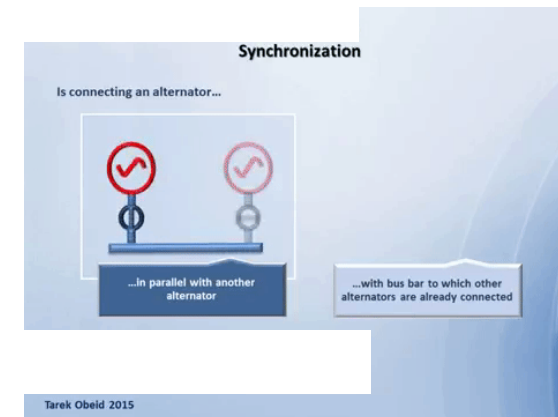

Installation Substation(s)

Base Utility Supply

Base-Level Microgrid

Feeder-Level Microgrid

Circuit-Level Microgrid

Building-level generators

A microgrid can be operated in two major modes;

- Grid-tied
  - Peak Shaving
  - Frequency Regulation
  - Demand Response
  - Etc…
- Islanded
  - Load Isolation - Planned outage
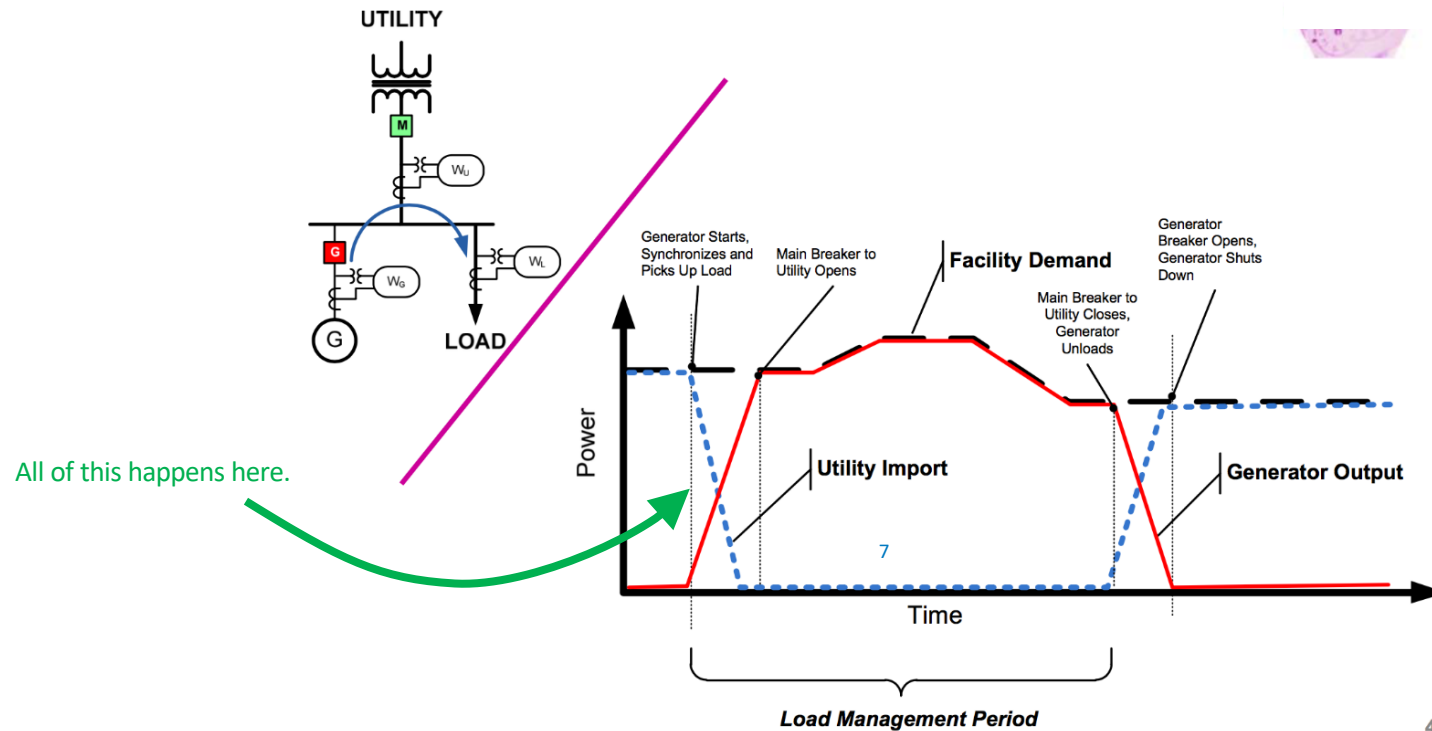 - Emergency Power - Unplanned outage

http://www.publicpower.com/library/committee_forum2011/Wayne%20Hartman.pdf

Load Isolation - Planned Microgrid Transition

1. Generators or battery storage are brought online with intertie-breaker open
   - Generators are spinning, but not connected to either grid
2. Generators and Batteries are synchronized with the public grid and breakers are closed
3. Breaker/Disconnect to island base is opened
   - Generators and storage transition to begin serving load
     – Can be as quickly as 22ms
4. Loads are shed, if necessary.
     – (1-20 cycles for disconnects/breakers to open)
5. Generator ties are closed and loads begin to be brought back online
6. ****Power restored to selected loads***
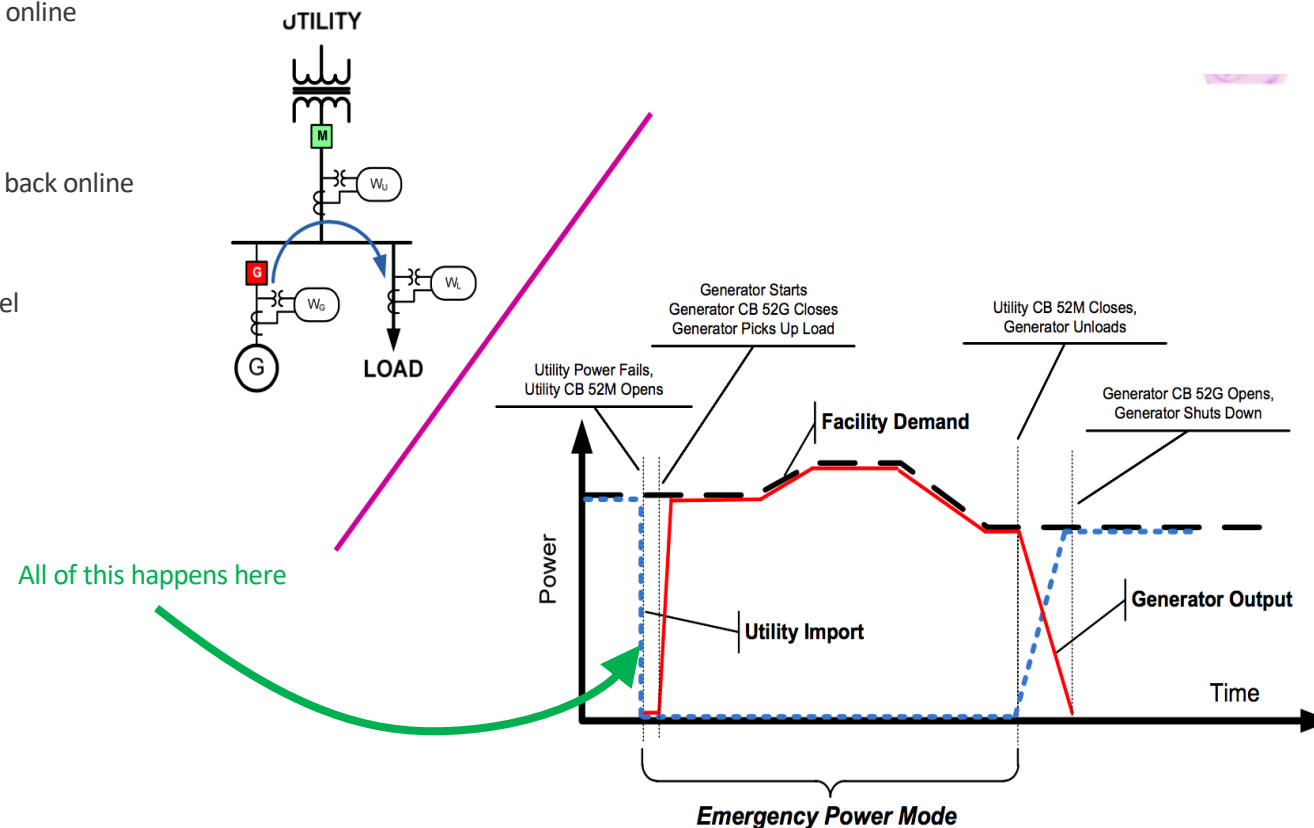7. Controls balance voltage and frequency at microgrid level

➢ Planned transition from Utility-feed to microgrid
➢ Backup generators are "Spinning" and are ready to serve loads at time of isolation
➢ Seamless transition can occur with proper coordination

All of this happens here.

1. Protection system senses a fault – breakers trip
   – (1-20 cycles)

2. ***Power outage***

3. Central control system sees tripped breaker and begins islanding sequence
   – (Intracycle)

4. Generators are ramped up or battery storage is brought online
   – (intracycle -10 minutes)

5. Loads are shed, if necessary.
   – (1-20 cycles)

6. Generator ties are closed and loads begin to be brought back online

7. ****Power restored to selected loads***

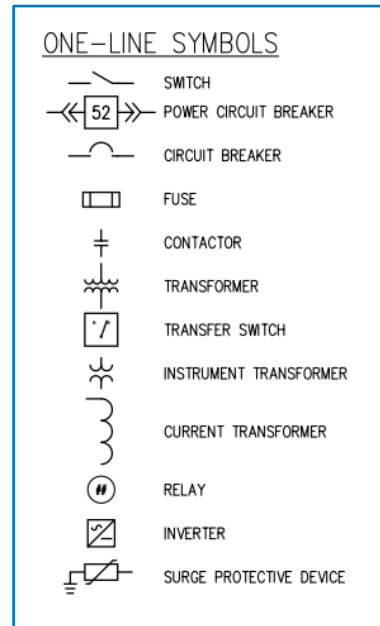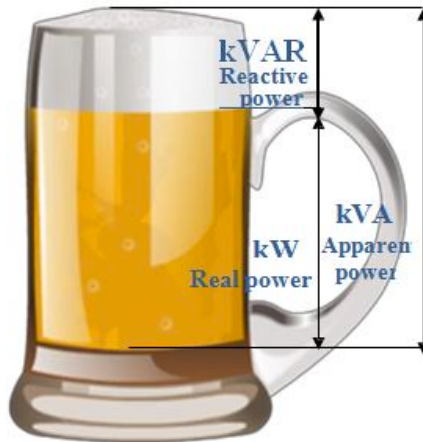8. Controls balance voltage and frequency at microgrid level

- Unplanned transition from utility-fed to microgrid
- Backup generators are not "Spinning"
- Short duration outage – 1 sec to 10 mins

All of this happens here

Components of Microgrids

Components

- ❖ Generation
- ❖ Energy storage
- ❖ Loads
- ❖ Transmission and Distribution Lines
- ❖ Switching and Protection Devices (manual and/or motor actuated)
  - ❖ Circuit Breaker
  - ❖ Disconnect Switch
  - ❖ Automatic Transfer Switch (ATS)
  - ❖ Reclosers
  - ❖ Fuses
- ❖ Power/voltage Correction
  - ❖ Voltage Regulator
  - ❖ Capacitor

Opening HV Air-break disconnect under load
(Not supposed to happen, but still cool!)

SmartGrid - DOE Definition

❖ Interconnected generation and loads enabled with remote **monitoring and controls** capabilities

   ❖ Enabled through fiber, relays, central control system

   ❖ Allows for central monitoring and controls

   ❖ Workforce management to deploy personnel for O&M

   ❖ Some functions can be automated based on set-points and desired operating conditions

Components that Enable SmartGrid

- ❖ **Hardware**
  - ❖ [Current Transformer (CT)](#) and [Potential Transformer (PT)](#)
    - ❖ Transform high current/voltage to low current/voltage to become easier and cheaper to measure
  - ❖ [Relay](#)s
    - ❖ Terminal point to convert data signal into action (ex open breaker, or ramp generator)
- ❖ **Communication**
  - ❖ Fiber Optic/Cat 6/radio or line signals
    - ❖ Carrier for signals between terminals
- ❖ **Software**

- ❖ SCADA/Hardware Machine Interface (HMI)
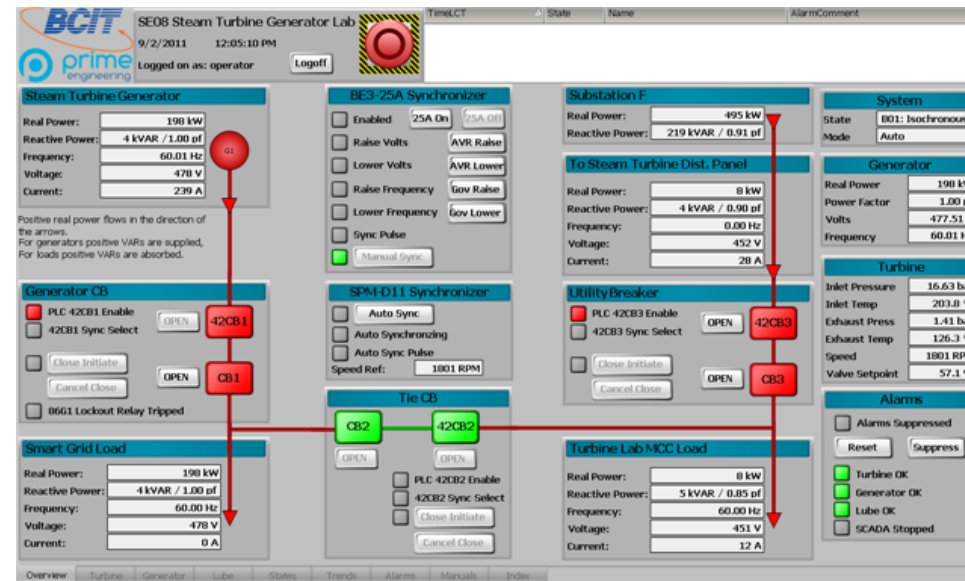- ❖ Energy Management System
- ❖ Battery Management System
- ❖ Microgrid Controller
- ❖ Programmable Logic Controllers (RTACs)

Old Analog Relays

New Digital Relays

Examples of levels…there are a limitless number of configurations

Basic

Grid-level generators that can island groups of loads from grid

- ❖ Connected generators can parallel
- ❖ Manual operation of all switching and generation

Intermediate

Grid-level generators that can remotely island loads from grid

- o System is half-automated, requires manual load shedding or isolation
- o Generators can be remotely controlled once loads are shed

Advanced

- ❖ Full Smart Microgrid capability
  - o Entire installation can be islanded
  - o Central control of load shedding
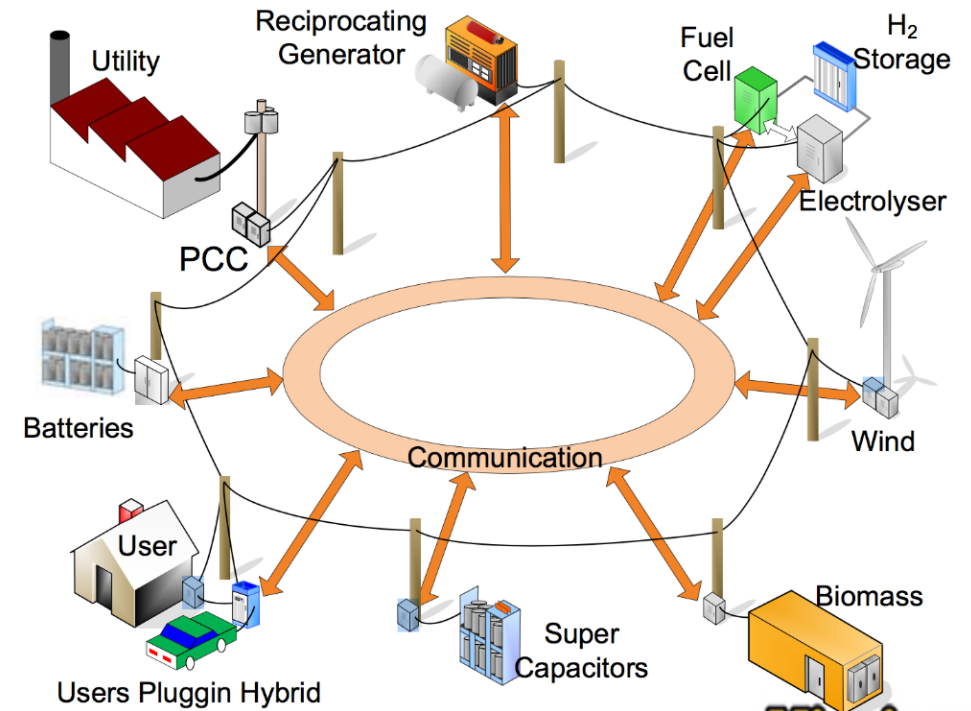 - o Central control of generator output

❖ **"Smart Microgrid"** – Interconnected generation and loads capable of being operated and monitored remotely as an island from the public utility system

- o Smart Microgrids consist of two major layers
  - **Microgrid layer** – electrical distribution
  - **SmartGrid layer** – controls and monitoring

Smart microgrids can enable participation in markets for;

- ❖ Frequency Regulation
- ❖ Demand Response
- ❖ Peak Shaving
- ❖ Price Arbitrage/Load Shifting
- ❖ Conservation Voltage Reduction (CVR)
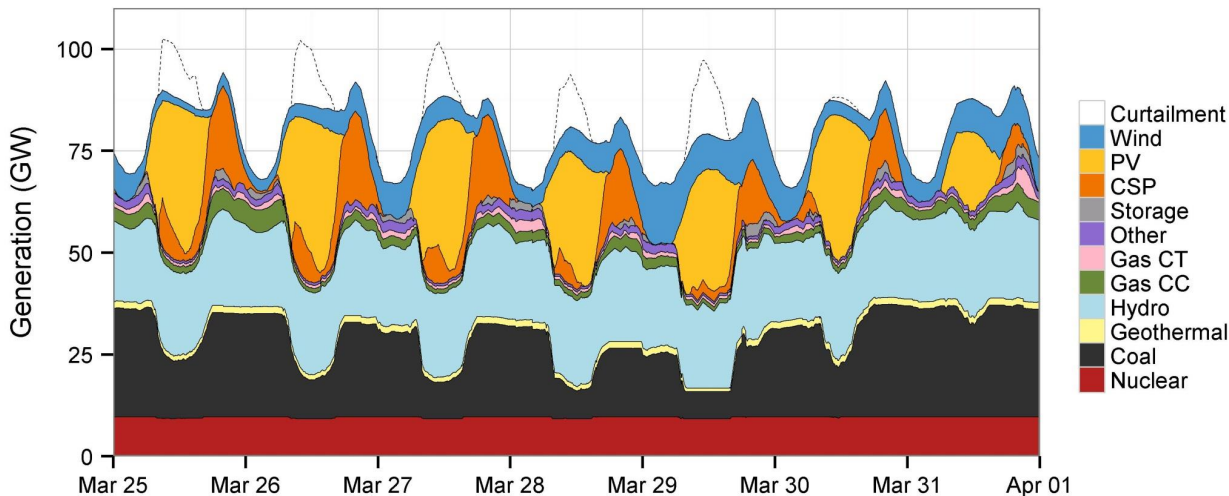- ❖ Volt/VAR Support
- ❖ Etc..

Variable Generation in a Microgrid

Microgrid Planning: Ensure that adequate capacity exists to serve peak load and blackstart the microgrid
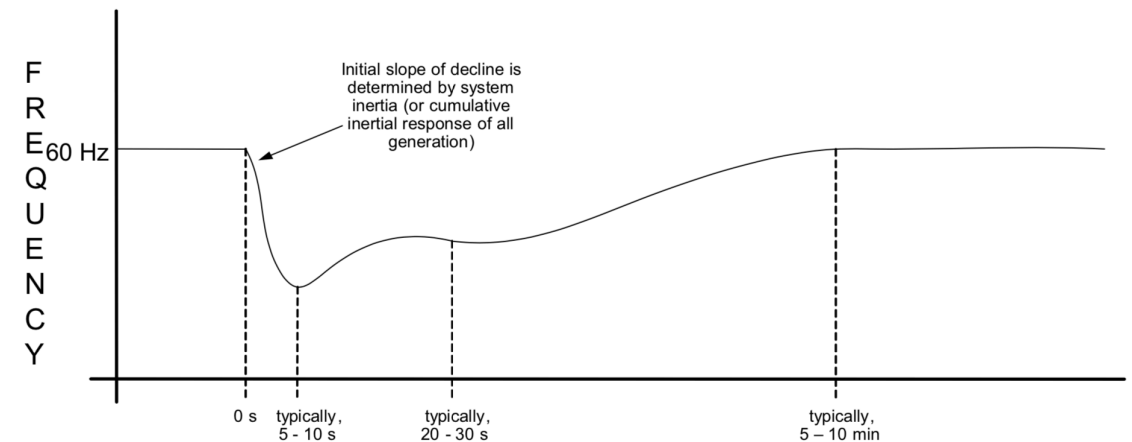
- ❖ Peak load and average load are a large factor of generation capacity sizing
  - ❖ Generation should be sized with consideration of the efficiency of the system
- ❖ Generation capacity must be capable of supporting in-rush currents during blackstart
- ❖ Capacity and Energy resources
  - – Variable energy resources should be viewed as an energy resource (kWh)
  - – 10 MW of solar PV and 10 MW of diesel cannot serve 20 MW of load, this can serve 10 MW of load with PV offsetting fuel use

Operation: Generation will be dispatched based on system needs

- ❖ As load varies, generation will be adjusted to maintain a balanced system
- ❖ Variable generation should be maximized to reduce fuel consumption when available, but may need to be curtailed to ensure adequate power quality

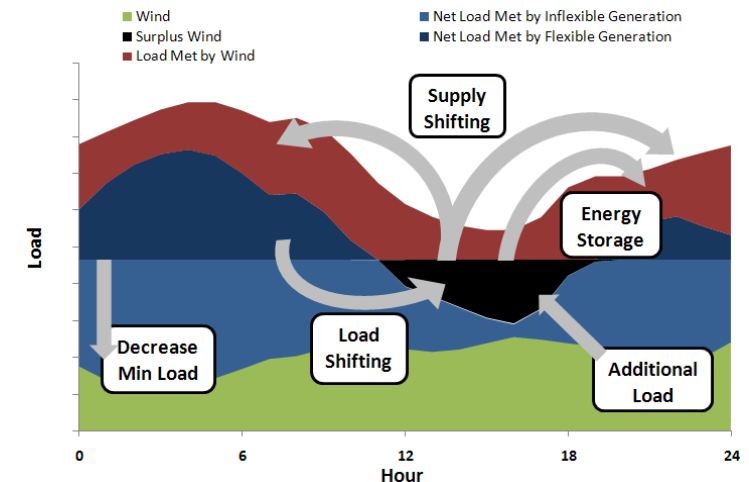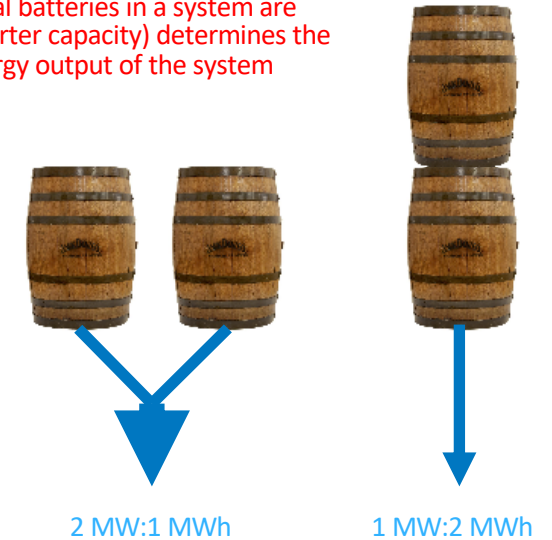Denholm, "High Penetration VG and the Potential Role of Energy Storage " 2014

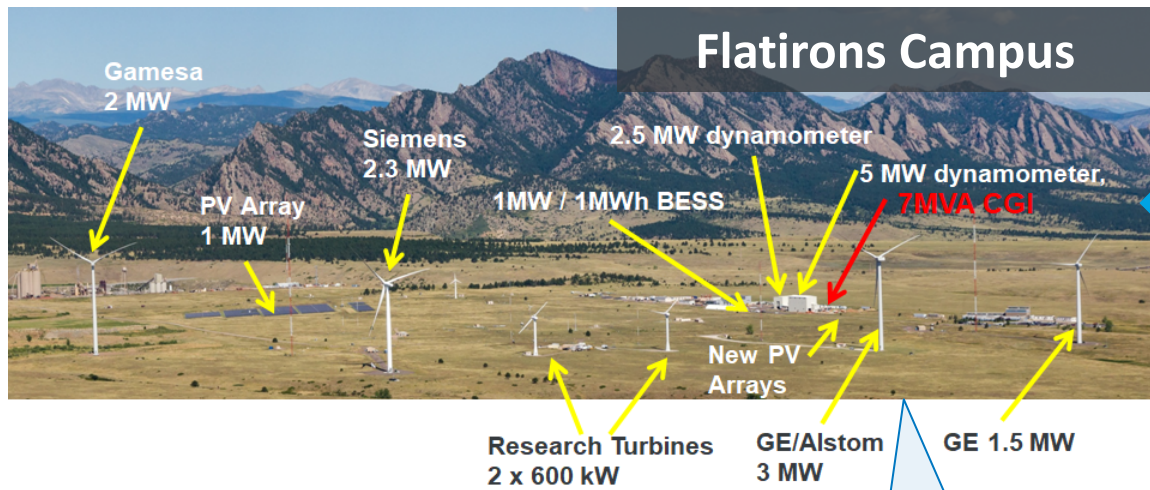E. Ela, "Active Power Control From Wind Turbines" 2014

Battery Energy Storage System (BESS)

- ❖ Capacity of a BESS = MW
  - ❖ Similar to peak output of a diesel – the most power that can be injected
  - ❖ Output can be controlled through inverters up to specified capacity

- ❖ Energy of a BESS = MWh
  - ❖ Similar to the fuel storage for a diesel generator

- ❖ Simplified run-time of a BESS
  - ❖ MWh / MW_{load} = # of hours
  - ❖ 5 MWh BESS injecting 2 MW can run for 2.5 hours
  - ❖ 5 MWh BESS injecting 0.5 MW can run for 10 hours
  - ❖ 20 MWh BESS injecting 10 MW can run for 2 hours
    - ❖ At $1M per MWh, this gives **2 hours** of backup for a 10 MW load for $20M

- ❖ Batteries output DC power and require an inverter to convert DC to AC
  - ❖ For BESS, inverters have a constant source of power and can be used to full ability. Until empty
  - ❖ Certain battery chemistries are better are quick response grid-services than others

How the individual batteries in a system are configured (and inverter capacity) determines the power and energy output of the system

2 MW:1 MWh   1 MW:2 MWh

■ Wind
■ Surplus Wind
■ Load Met by Wind
■ Net Load Met by Inflexible Generation
■ Net Load Met by Flexible Generation

Supply Shifting

Energy Storage

Decrease Min Load

Load Shifting

Additional Load

Load

Hour

Flatirons Campus

- Gamesa 2 MW
- Siemens 2.3 MW
- 2.5 MW dynamometer
- 5 MW dynamometer, 7MVA CGI
- PV Array 1 MW
- 1MW / 1MWh BESS
- New PV Arrays
- Research Turbines 2 x 600 kW
- GE/Alstom 3 MW
- GE 1.5 MW

Energy Systems Integration Facility (ESIF)

Virtual Emulation Environment (HPC @ ESIF + PHIL @ ESIF and Flatirons)

20MW

115kV

13kV

13-34kV

<2MW

HEMS

PV Inverter

Smart Meter

Thermostat

Electric Vehicle

Water Heater

Battery

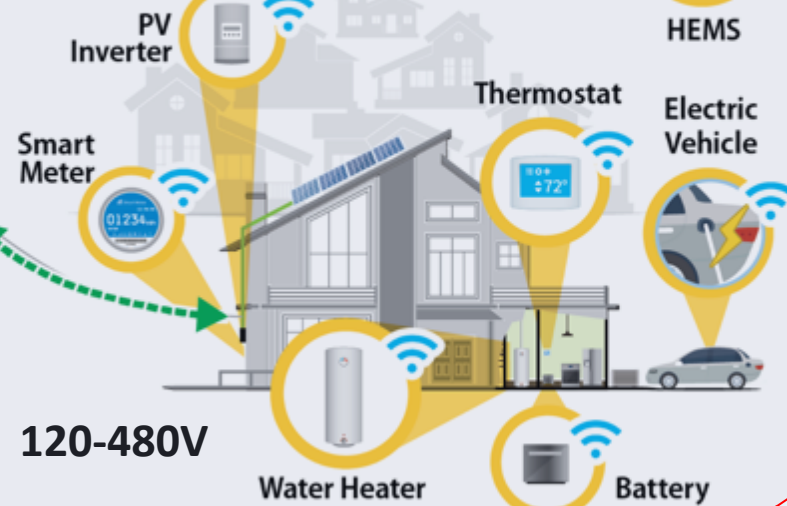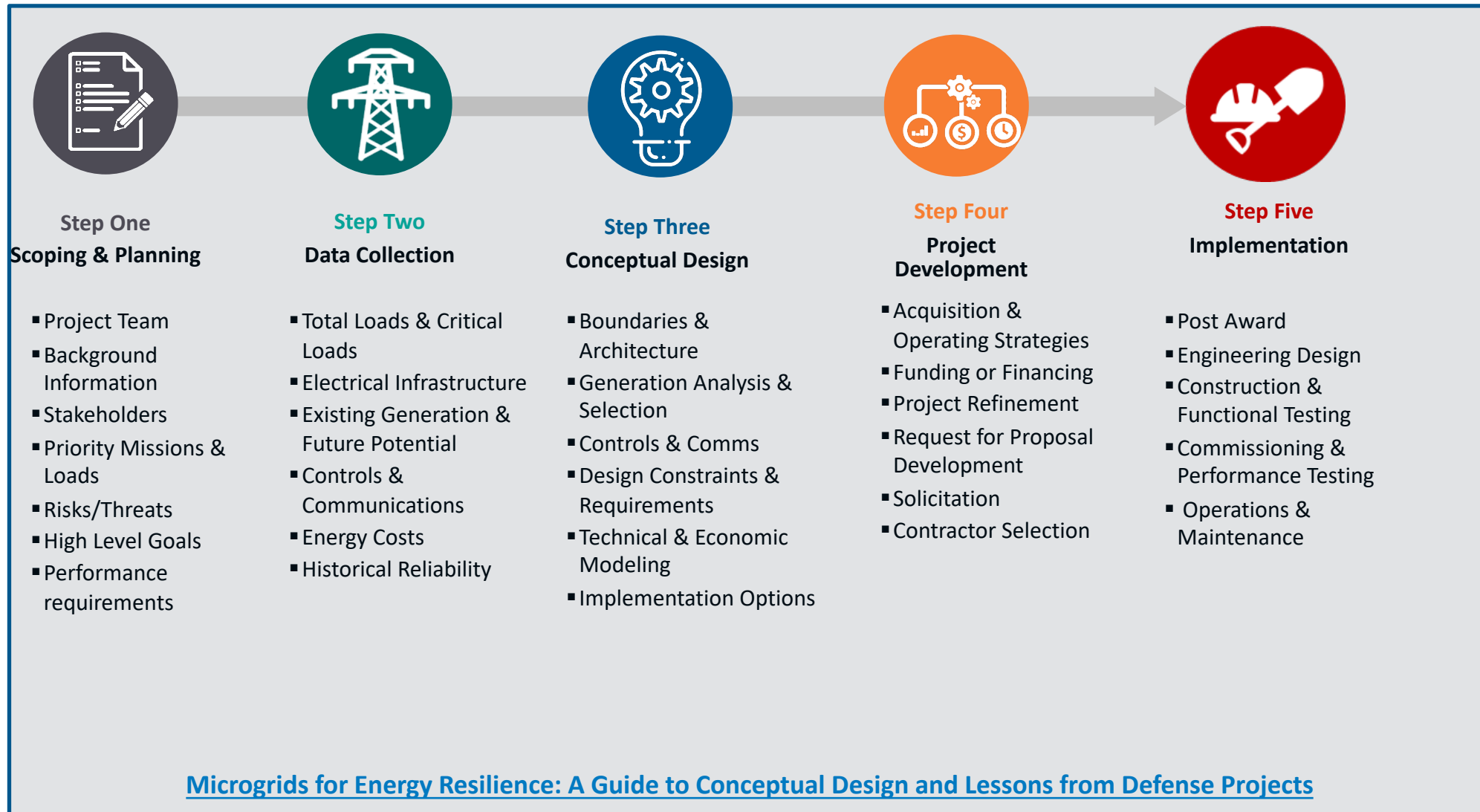120-480V

Bulk Generation, Storage, and MD/HD Mobility

Transmission/ Distribution & Storage
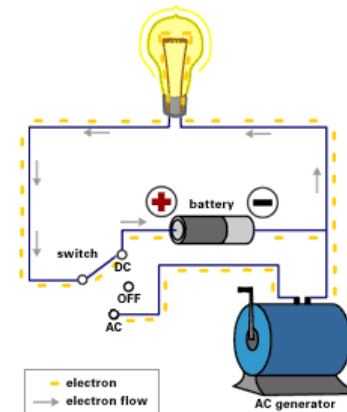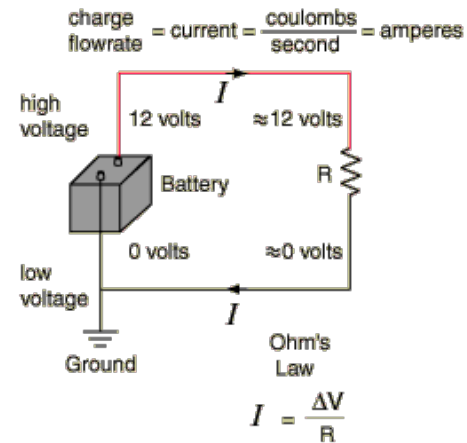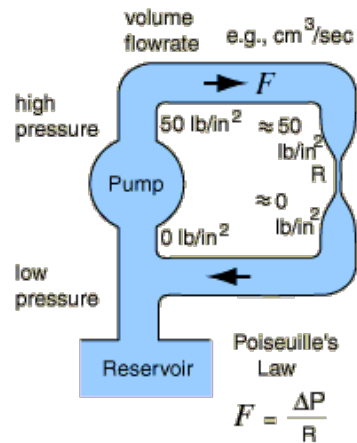
Distributed Generation, Storage, Loads, and LD Mobility

NREL Microgrid Design Process

CORE
Continuously Optimized Resilient Energy

Step One
Scoping & Planning

- Project Team
- Background Information
- Stakeholders
- Priority Missions & Loads
- Risks/Threats
- High Level Goals
- Performance requirements

Step Two
Data Collection

- Total Loads & Critical Loads
- Electrical Infrastructure
- Existing Generation & Future Potential
- Controls & Communications
- Energy Costs
- Historical Reliability

Step Three
Conceptual Design

- Boundaries & Architecture
- Generation Analysis & Selection
- Controls & Comms
- Design Constraints & Requirements
- Technical & Economic Modeling
- Implementation Options

Step Four
Project Development

- Acquisition & Operating Strategies
- Funding or Financing
- Project Refinement
- Request for Proposal Development
- Solicitation
- Contractor Selection

Step Five
Implementation

- Post Award
- Engineering Design
- Construction & Functional Testing
- Commissioning & Performance Testing
- Operations & Maintenance

Microgrids for Energy Resilience: A Guide to Conceptual Design and Lessons from Defense Projects

Thank you!

In DC circuits, electrons travel in one direction causing voltage and current to remain constant over time
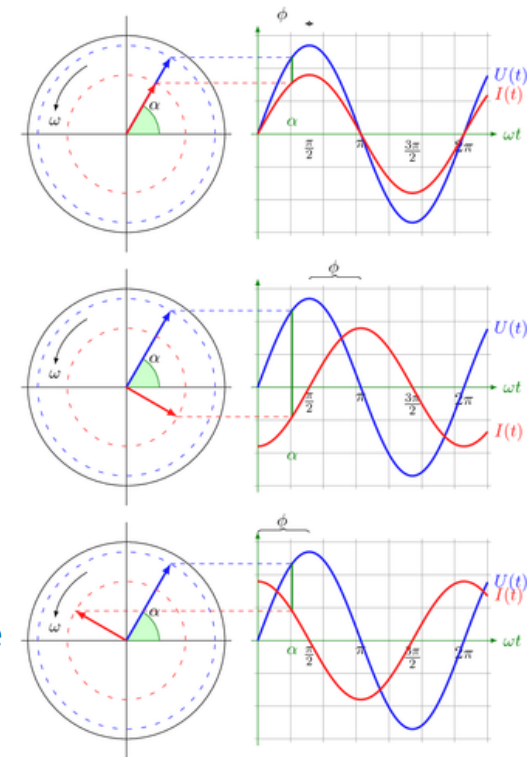
- **P** = **VI**, **P** = Power
- **V** = Voltage, the electrical potential energy between two points
- **I** = Current, the flow of electric charge through a conductor
- **R** = Resistance

In AC circuits, electrons move back and forth through the circuit causing the voltage and current to fluctuate with time

- Voltage and Current will travel out of phase with each other when inductance and capacitance are introduced to the circuit
- An inductive circuit is considered "lagging." The current peaks after the voltage
- A capacitive circuit is considered "leading." The current peaks before the voltage

Inductive
-Lagging

Capacitive
-Leading

Switching and Protection Devices

Overhead High-Voltage Disconnect Switches

High Voltage Fuses

Underground Switching Cabinet

High Voltage Circuit Breakers

Pad-mount switch cabinet (PMH)

Photos courtesy Mike Coddington - NREL

Protection and Power Transformation Equipment

Single-Phase Overhead Transformer

Three-Phase Overhead Transformers

Three-Phase Pad-mount transformer

Solar PV inverter
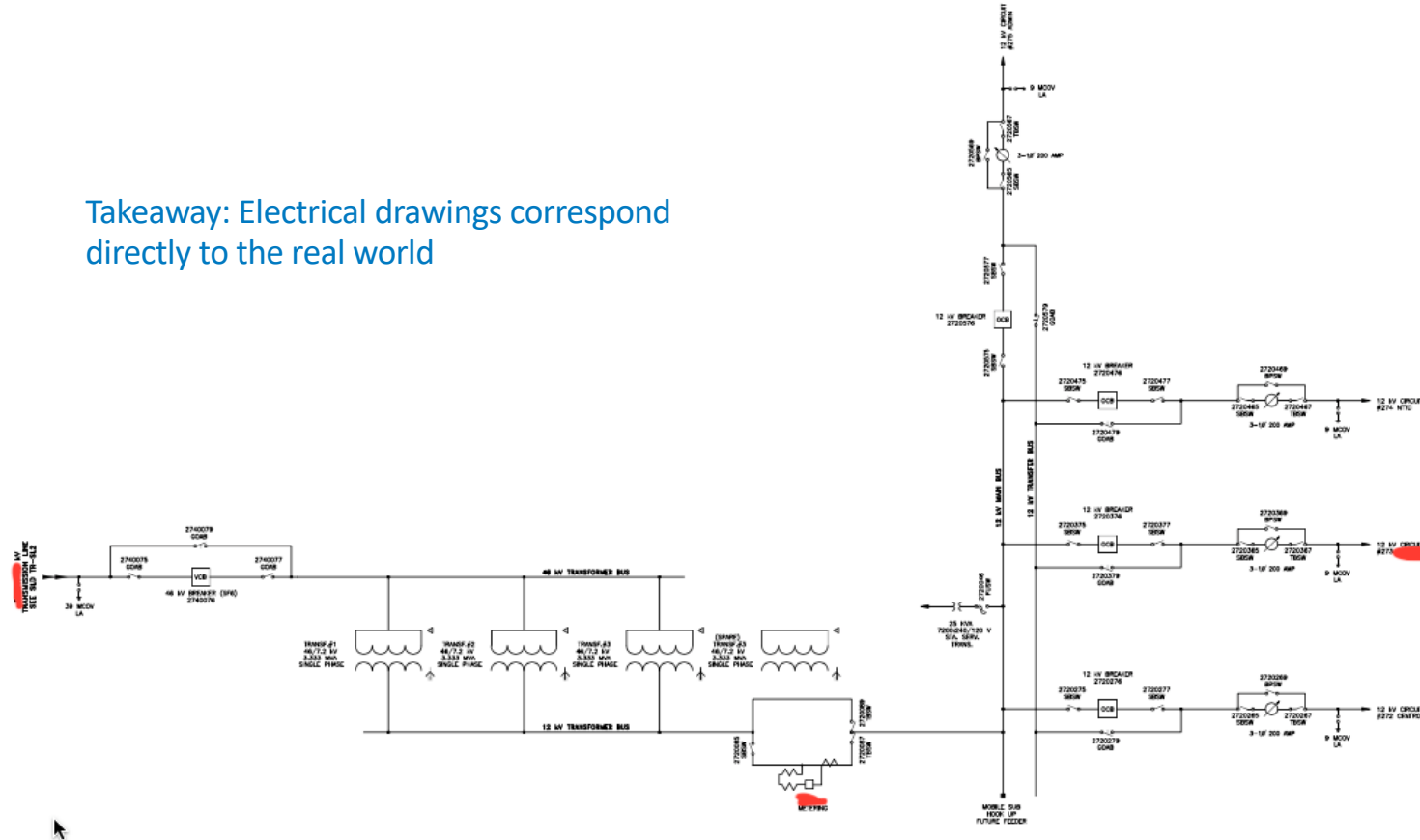
Recloser

Single-Phase Pad-mount transformer

2.5MW & 3.8kW Wind Inverters

Photos courtesy Mike Coddington - NREL

Takeaway: Electrical drawings correspond directly to the real world

Substation Example(page 3 of 3)

1. Data is gathered through hardware on the system.
   - Current Transformer (CT)
   - Potential Transformer (PT)
2. Receivers accept and convert signals
   - Relays connected to CTs and PTs
3. Signals sent through communication medium
   - Fiber – Fast communication speed
   - Ethernet – Medium communications speed
   - Radio – slowest communication speed
   - Infared – fast communication speeds
4. Central control facility/servers
   - SCADA system/microgrid controller
5. Signal sent through communication medium
   - Fiber – Fast communication speed
   - Ethernet – Medium communications speed
   - Radio – slowest communication speed
   - Infared – fast communication speeds
6. Receivers accept signals from communication medium
   - Relay, RTAC, RTU
7. Signal triggers hardware to perform a function
   - Generator ramp up/down
   - Switch open/close
   - Shed loads
   - Volt/VAR compensation

1 & 2

3

4

5

6 & 7

High Voltage Disconnect Arc