Assessment of Large Power Transformer Risk Mitigation Strategies

October 2016

Prepared for:
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Systems Analysis,
US Department of Energy

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Suggested Citation:

ICF. Assessment of Large Power Transformer Risk Mitigation Strategies. Fairfax, VA. 2016.

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Acronyms and Abbreviations

Acronym / Abbreviation	Stands For
BPS	bulk-power system
CAISO	California Independent System Operator
CDI	critical defense infrastructure
CEII	critical electric infrastructure information
CNP	CenterPoint Energy
DHS	Department of Homeland Security
DOE	Department of Energy
DPA	Defense Production Act of 1950
EEI	Edison Electric Institute
EHV	extra high voltage
EMP	electromagnetic pulse
EPA	Environmental Protection Agency
EPSA	Office of Energy Policy and Systems Analysis
ERCOT	Electric Reliability Council of Texas
ERO	Electricity Reliability Organization
ESCC	Electricity Sector Coordinating Council
FACA	Federal Advisory Committee Act of 1972
FAST	Fixing America's Surface Transportation Act of 2015
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FOIA	Freedom of Information Act
FPA	Federal Power Act
GCC	Government Coordinating Council
GMD	geomagnetic disturbance
GSU	generator step-up (transformer)
HILF	high-impact, low-frequency
HV	high voltage
IEEE	Institute of Electrical and Electronics Engineers
ISO	Independent System Operator
LPT	large power transformer
MISO	Midcontinent Independent System Operator

Acronym / Abbreviation	Stands For
MVA	megavolt amperes
NERC	North American Electric Reliability Corporation
NIPP	National Infrastructure Protection Plan
OE	Office of Electricity Delivery and Energy Reliability
PPD	Presidential Policy Directive
QER	Quadrennial Energy Review
RecX	Recovery Transformer
RFT	recovery flex transformer
R&D	research & development
RTO	Regional Transmission Organization
SCC	Sector Coordinating Council
SED	Spare Equipment Database
SSA	Sector-Specific Agency
SSP	Sector-Specific Plan
STEP	Spare Transformer Equipment Program
TRIP	Transformer Recovery Inventory Program

Executive Summary

Critical electric infrastructure in the United States faces a wide variety of threats which could negatively impact the reliability of the grid. These occurrences range from natural weather-related events to man-made hazards such as terrorist attacks, physical attacks, and cyber attacks. In addition, certain high-impact, low-frequency (HILF) events, including severe geomagnetic disturbance (GMD) or electromagnetic pulse (EMP), could damage equipment that is difficult to replace.[1] Such threats have the potential to cause a severe power outage that may last for an extended period of time.

Large power transformers (LPT) are an especially critical component of the transmission system. A damaged or destroyed transformer could affect the transmission capacity of a regional electric power grid. In particular, the loss of multiple high-voltage (HV) transformers may overwhelm the system and cause widespread power outages, possibly in more than one region, increasing vulnerability and the potential for cascading failures. A timely replacement of multiple, failed LPTs is a challenge, due to the complex and lengthy process involving the procurement, design, manufacturing, and transportation of LPTs. Therefore, the operational failure of multiple LPTs could result in a long-term service interruption and considerable economic loss.

The electricity sector has worked with federal authorities to identify risks, including those associated with losing multiple LPTs, and to develop strategies to mitigate such risks. In addition to legislation outlining emergency response measures, such as the Stafford Act, Defense Production Act, and Fixing America's Surface Transportation (FAST) Act, several types of private sector spare transformer sharing programs have been established, and new initiatives continue to be developed in the United States. While the ultimate objective of these programs is the same—mitigate risk to the grid as a result of impaired transformer equipment or loss of LPTs— each of these programs was created to address various types of risks in the electricity sector. Three key industry transformer sharing programs currently exist in the United States—the North American Electric Reliability Corporation's Spare Equipment Database Program (SED), the Edison Electric Institute's Spare Transformer Equipment Program (STEP) and the industry-funded SpareConnect. Another program, Recovery Transformer (RecX), which was co-funded by DHS & EPRI, developed and successfully demonstrated a prototype transformer designed to accelerate the replacement of the most common extra-high voltage (EHV) transformers.[2] In addition to these, two more industry programs, Grid Assurance and Wattstock, have been proposed to complement existing programs.

The key question is what the government needs to do to mitigate the risks associated with multiple transformer loss not already covered by industry programs. To undertake such an assessment requires a data-driven evaluation of relevant threats, vulnerabilities, and consequences. The policies and programs described in this report are a diverse group with a wide range of applications to the mitigation of risks applicable to large power transformers. Each has its own focus and approach, as well as limitations. Two current North American Electric Reliability Corporation (NERC) reliability standards and one pending, not actually specific to transformers, require owners and operators to address physical security (CIP-014-2) and geomagnetic disturbances (EOP-010-1 and TPL-007-1) but leave the particular methods and criteria up to those entities. EEI's STEP program covers transformer loss from terrorist attacks for participants when the President has declared an emergency. The SED and SpareConnect programs provide vehicles for participants to discuss sharing equipment but are voluntary and do not provide for any inventory. Additional research is required to estimate the extent to which the programs mitigate different types of risks.

1. Purpose and Scope of the Study

The Office of Energy Policy and Systems Analysis (EPSA), in consultation with the Office of Electricity Delivery and Energy Reliability (OE), of the U.S. Department of Energy (DOE) directed this study to begin addressing the requirements of the 2015 Fixing America's Surface Transportation (FAST) Act, as well as to satisfy one of the recommendations of the Quadrennial Energy Review (QER): Energy Transmission, Storage, and Distribution Infrastructure (released in April 2015). The FAST Act directs DOE to develop a plan to establish a strategic transformer reserve (STR) in consultation with various industry stakeholders. The QER recommended that DOE "analyze the policies, technical specifications, and logistical and program structures needed to mitigate the risks associated with loss of transformers."[3] It also identified as a priority "increasing the security and resilience of the electric grid, including the development of an integrated national plan to mitigate challenges pertaining to aging power transformers, the cyber and physical security of transformers, and the vulnerabilities of large power transformers."[4]

The work in this paper—an assessment of existing industry, regulatory, and institutional arrangements for mitigating the disruption caused by the loss of multiple LPTs—supports the development of DOE/OE's response to the requirements of the FAST Act's §61004 to "prepare and submit to Congress a plan to establish a Strategic Transformer Reserve (STR)."[5] This Report to Congress, among other things, must discuss the degree to which utility sector actions or initiatives, including utility individual or joint ownership of spare equipment, sharing agreements, or other spare equipment reserves or arrangements, satisfy the need to establish a STR. This report provides an analysis of the structure and focus of industry-led transformer parts sharing programs, and the current regulatory environment as it pertains to the maintenance and reliability of the electric grid. This work is limited to this topic, and does not address other questions or requirements of the FAST Act, including the number, type, and location of transformers required; ease and speed of transportation of transformers; policy mechanisms or implementation issues; or funding mechanisms.[a]

Parallel to this study, DOE is conducting analyses to evaluate the necessity of forming a Federal Strategic Transformer Reserve, including the appropriate number of spare LPTs and total capacity in MVA, locations of critical substations, spare equipment development and design, and the logistics of storage, maintenance, transportation, installation, and energization of spare LPTs, among others.[b] In addition, in the summer of 2015, DOE also issued a request for information on the possible establishment of a national transformer reserve.[c]

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[a] The transformers that are the subject of this work, it should be noted, are those 100 MVA and above that are part of the bulk power system. Power transformers in the distribution system or strictly within the limits of state regulatory authority are outside of the scope of the study and therefore excluded from this analysis.

[b] The consideration of national strategic transformer reserve is a part of DOE's grid modernization laboratory call. Task 6.5.4 - Strategic Transformer Research of the Department of Energy's Grid Modernization Laboratory Call, http://www.netl.doe.gov/File%20Library/Business/solicitations/2016GMLabCall.pdf (accessed December 4, 2015).

[c] Responses to that request for information can be found at http://energy.gov/oe/comments-received-rfi-possible-establishment-reserve-large-power-transformers.

2. Background

2.1. Power Transformers and Electric Power System

Table 2-1. Transmission Voltage Classes and Ratings

Class	Voltage Ratings (kV)
Medium Voltage	34.5, 46, 69, 115/138
High Voltage	115/138, 161, 230
Extra High Voltage	345, 500, 765

Source: DOE, 2006. Modified based on industry review.

The electric power system consists of an integrated system of generators, bulk-power transmission lines, substations, and lower voltage distribution lines that provide power to consumers (see Table 2-1). [6] The highly interconnected nature of this system allows for economies of scale and increased reliability; however, the highly interconnected system also means that a disturbance to any part of the system has a greater potential for affecting the system as a whole. The U.S. bulk-power grid consists of approximately 390,000 miles of transmission lines, including more than 200,000 miles of high-voltage (HV) lines, connecting to more than 6,000 power plants.[7]

Figure 2-1[8] is a simplified representation of the U.S. electric power transmission and distribution grid. The transmission system is extensive, consisting mainly of transformers, switches, transmission towers and lines, control centers, and computer controls. Power transformers are a critical component of the transmission system. They adjust the electric voltage to a suitable level on each segment of the power transmission system from the generator to the end user. Power transformers step up the voltage at generation for efficient, long-haul transmission of electricity and step it down for distribution to the level used by customers. Power transformers are also needed to step the voltage either up or down at every point where there is a change in voltage in the power transmission system. The electric power grid could not function without them.

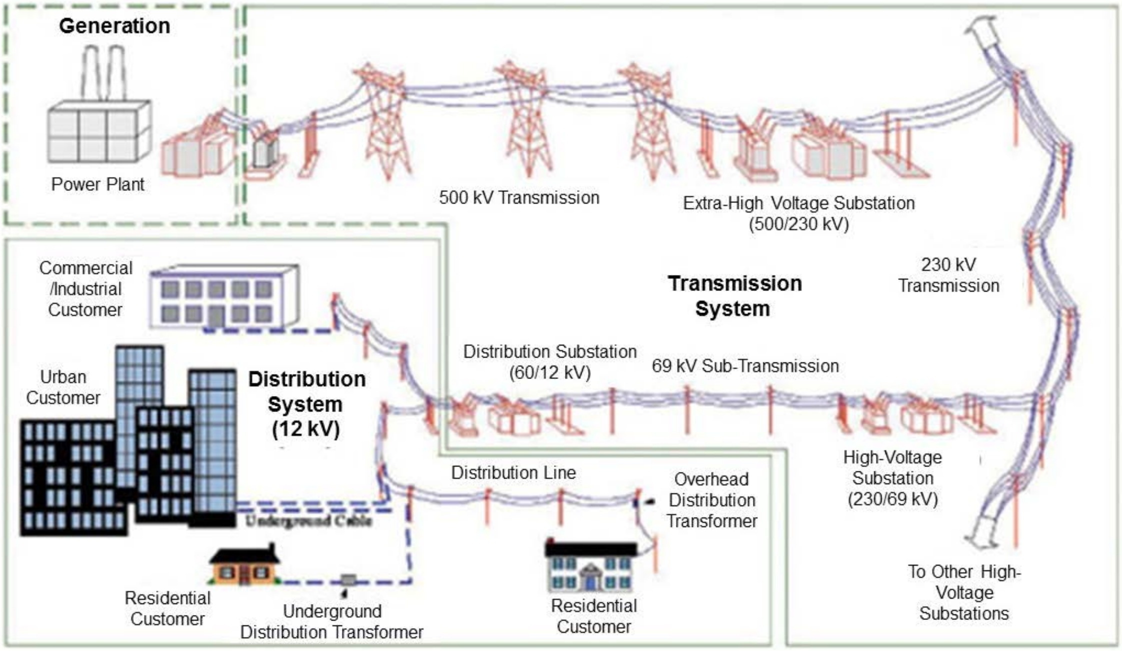

Figure 2-1. Representation of the Electric Power Transmission and Distribution Grid

The size of a power transformer is determined by the primary (input) voltage, the secondary (output) voltage, and the load capacity measured in MVA. In addition to the capacity rating, voltage ratings are often used to describe different classes of power transformers. LPTs with voltage ratings of 115 kV and above are considered HV, and LPTs with voltage ratings of 345 kV and above are considered extra high voltage (EHV) (see Table 2-1).[9]

HV and EHV transformers carry a substantial amount of electricity. Therefore, a damaged or destroyed transformer can affect the transmission capacity of a regional electric power grid, leading to extended power outages. Transmission operators can typically anticipate the loss of a single HV or EHV transformer station or substation and can reroute electricity.[10] The U.S. electricity industry has long embraced resilience as part of continuity of operations planning and risk management, and has built reliability and redundancy into the system. However, this critical infrastructure faces a wide variety of threats which could negatively impact the reliability of the grid. The following section discusses some of the key risks and threats.

2.2. Threat Environment

The threats faced by transformers are the same as those faced by the electric power grid at large, including those both natural and man-made. Weather events, such as lightning, tornadoes, derechos, and tropical storms, have historically been the biggest threat to the reliability of the grid and critical infrastructure.[11] In addition, certain high-impact, low-frequency (HILF) events, including severe geomagnetic disturbance (GMD) or electromagnetic pulse (EMP), could damage transformers and other difficult-to-replace equipment, causing a cascading effect on the system.[12] The main risk from such threats against the electric power industry is a widespread power outage that may last for an extended period of time.[13]

A recent incident highlighted the importance of physical security of electric infrastructure, including substations and LPTs. In April 2013, attackers used high-powered rifles to incapacitate a number of power transformers at the Metcalf transmission substation in California. According to media reports, although the targeted utility avoided a blackout through a re-dispatch, the incident caused more than $15 million in physical damages that required nearly a month to repair.[14] Media sources further reported that a 2013 power flow analysis by the U.S. Federal Energy Regulatory Commission (FERC) identified critical transmission substations in the United States and asserted that disabling a number of these substations could result in a significant power outage lasting 18 months or more.[15]

While not all industry experts agree on the potential severity and duration of a blackout from a multi-transformer attack, such claims heightened the concern of losing multiple LPTs. Electric infrastructure vulnerabilities, particularly of LPTs or transformers with a high-side voltage rating of 345 kV and above, have been a concern and discussed in a number of studies as well as by industry stakeholders and policy makers.[d] That is because LPTs are custom-engineered, tailored to utilities' technical specifications, and

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[d] Many sources exist. A few examples include the following: "A Framework for Establishing Critical Infrastructure Resilience Goals," the National Infrastructure Advisory Council, October 16, 2010, http://www.dhs.gov/xlibrary/assets/niac/niac-a-framework-for-establishing-critical-infrastructure-resilience-goals-2010-10-19.pdf (accessed December 8, 2015); Parfomak, P.W., "Electric Utility Infrastructure Vulnerabilities: Transformers, Towers, and Terrorism," Congressional Research Service, April 9, 2004, https://www.fas.org/sgp/crs/homesec/R42795.pdf (accessed May 9, 2016); High-Impact, Low-Frequency Event Risk to the North American Bulk Power System, NERC, June 2010, http://www.nerc.com/pa/CI/Resources/Documents/HILF%20Report.pdf (accessed May 9, 2016).

not produced in sufficient number to allow for spare inventories.[16] A timely replacement of multiple, failed LPTs is a challenge, due to the complex and lengthy process involving the procurement, design, manufacturing, and transportation of LPTs.[17] Therefore, multiple LPT failures could potentially result in long-term service interruptions and considerable economic losses.[18]

3. Regulatory and Policy Overview

The U.S. electricity sector is dispersed over 3,000 public, private, and cooperative utilities and more than 1,000 independent power generators, connected by hundreds of thousands of transmission and distribution lines in three regional interconnections. About two-thirds of the electricity consumed in the United States is served by transmission systems administered by an Independent System Operator (ISO) or Regional Transmission Operator (RTO), of which there are seven in the United States.[19] The reliability of bulk-power systems in the contiguous 48 states is governed by a set of federally-enforceable standards developed by NERC but subject to FERC approval. Various government authorities also oversee different aspects of the U.S. electricity industry. This section provides an overview of key policies and regulations pertaining to the transmission system or the bulk-power system (BPS), particularly as they relate to risk mitigation of LPTs as per the scope of this study.

3.1. Federal Policy and Regulatory Authorities

A number of federal entities have authority over electricity infrastructure-related matters depending on location and market structure, including the Federal Energy Regulatory Commission. FERC is an independent federal agency led by a board of appointed commissioners, and was established by the Federal Power Act of 1920 (originally as the Federal Power Commission).[20] FERC regulates on a national level and oversees many interstate activities.

FERC regulates public utilities, the transmission of electricity, and wholesale sales of electricity in interstate commerce. This includes electric facilities and power lines that transmit electricity across state borders, and utilities that sell electricity in states other than where the electricity was generated.[21]

However, FERC regulates primarily investor-owned utilities and does not have jurisdiction over the market activities or tariffs of federal entities (such as the Bonneville Power Administration and the Tennessee Valley Authority), cooperatives, or municipal utilities. The Electric Reliability Council of Texas (ERCOT) is also outside of FERC's regulatory jurisdiction for market and tariff matters, as its transmission system operates solely within the state of Texas and is not synchronously interconnected to the rest of the United States. States are responsible for regulating retail sales and distribution of electricity. Most state regulatory commissions have major responsibility to assure that retail electric consumers have adequate and reliable electric service.

FERC jurisdiction includes authority over certain equipment and facility transactions. Section 203(a)(1) of the Federal Power Act prohibits public utilities from selling, leasing, or disposing of any facilities, including transmission facilities, valued at more than $10 million without prior FERC approval.

FERC jurisdiction also extends to reliability. Under authority granted by the Energy Policy Act of 2005, FERC certified NERC as the Electric Reliability Organization (ERO). The responsibilities of the ERO include developing reliability standards, which must also be approved by FERC before becoming mandatory for users, owners, and operators of the bulk-power system. Enforcement of standards is a responsibility shared by NERC, eight Regional Entities[e] delegated authority by NERC, and FERC, with most of the front-line work undertaken by the Regional Entities. FERC's reliability jurisdiction applies to the bulk-power system (generally high-voltage transmission lines and associated facilities) but explicitly excludes facilities used in the local distribution of electricity. FERC's reliability jurisdiction covers all users, owners, and operators of the bulk power system, including municipal utilities, cooperatives, federal power administration, and power companies in ERCOT. The reliability standards address a wide range of issues, including vegetation management, coordination of protection systems, the development of emergency plans, and cybersecurity.[22]

Additional government agencies have jurisdiction over various aspects of the bulk power system. The Department of Agriculture/Forest Service and Department of Interior/Bureau of Land Management have roles in rights-of-way and land use management. The Environmental Protection Agency (EPA) oversees environmental and pollution concerns on a federal level; state agencies with environmental protection authority regulate air, water, and land resources within a state, including emissions and other effluents, sometimes under federal requirements. There are also several federal utilities that directly own and operate transmission and generation facilities.

Many agencies—whether through maintenance standards, siting procedures, environmental and safety regulations, or by operating the equipment themselves—have some influence over the operation of LPTs. There is no single agency, however, nor any unified regulatory scheme, with specific responsibility for policies related to transformers.

3.2. Policies and Regulations Pertinent to Electric Grid Resilience

Under the auspices of these federal authorities, several key laws exist in the United States that directly impact the resilience of the electric power grid. The Energy Policy Act of 2005 gave FERC certain authority over the reliability of the bulk power system through enforceable reliability standards. Such standards address a variety of aspects of the reliable operation of the grid, including physical security. In a restructured market, various federal and state policies and regulations address ways in which utilities' investments may be recovered; however, obtaining cost recovery for investments made for security and resilience can be difficult in some jurisdictions. In the event of an emergency, federal policies and programs exist to facilitate necessary response and recovery efforts, including obtaining critical materials and resources as well as the transportation of energy supplies and equipment.

In addition to these policies and regulations specific to the electricity industry, a set of federal policies are focused at managing risk to national critical infrastructure, including energy. These policies, in the context of national preparedness, provide a framework for critical infrastructure risk management, which entails prevention, protection, mitigation, response, and recovery. Further, such policies provide a framework under which infrastructure owners and operators may collaborate and share information with government entities in a secure environment. The following section describes in detail these current policies and regulations in the following broad categories: electricity reliability; rate making; emergency response and recovery; and critical infrastructure protection, security, and resilience. Finally,

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[e] The eight Regional Entities are: Florida Reliability Coordinating Council, Midwest Reliability Organization, Northeast Power Coordinating Council, ReliabilityFirst, SERC Reliability Corporation, Southwest Power Pool, Texas Reliability Entity, and Western Electricity Coordinating Council.

the last discussion in this section describes the new public law 114-94, which provides additional measures aimed at firming the U.S. electric grid against a variety of attacks and outages.

Together, these sets of policies and regulations provide legal authorities by which the government may influence and shape the electricity industry's risk mitigation strategies.

3.2.1. Electric Reliability Standards

The electric reliability standards enacted under FERC authority, commonly referred to as the "NERC reliability standards," are meant to prevent instability, uncontrolled separation, and cascading failures on the bulk-power system. Toward this end, NERC standards establish a range of operations and planning requirements covering such issues as performance under contingency conditions, the maintenance and coordination of protection systems, publishing of interconnection requirements, and capacity rating of transmission facilities.

NERC organizes standards drafting teams comprised of subject matter experts—volunteers from industry and other organizations (e.g., Regional Entity staff) with relevant expertise. The teams develop new standards and modifications to existing ones. However, before becoming mandatory and enforceable as federal regulations, a new or modified standard must be approved by open stakeholder ballot, by the NERC Board of Trustees, and finally by FERC.[23]

Currently, there are 116 reliability standards in 14 subject-area groups. Each standard is comprised of a number of individual requirements. Though two of the standards, described below, address risks of particular concern to large power transformers, none of the standards are specifically focused on LPTs. Furthermore, to the extent they can be said to address risks, it is only by requiring utilities to address the risks, not by providing particular solutions or strategies.

3.2.1.1. NERC Standard CIP-014-2: Physical Security

One of the standards pertaining to transformers in the Critical Infrastructure Protection (CIP) family of Reliability Standards is CIP-014-2, Physical Security. The goal of this standard is to protect transmission stations, substations, and primary control centers from physical attacks. A major component, of course, of any substation is transformers. In general, the standard applies to the owners and operators of three or more transmission lines of 200 kV or greater voltage, though even a single line of 500 kV or greater, or a line of any size declared critical, also triggers the standard.[24]

CIP-014-2 requires that transmission owners and operators identify their stations and substations critical to grid stability, evaluate the vulnerability of their facilities to physical attack, and develop and implement "documented physical security plans." The required elements of a plan are some manner of "resiliency and security measures," "law enforcement contact and coordination information," a timeline for executing the plan, and provisions for addressing evolving threats. CIP-014-2 also requires the transmission owners and operators subject to the standard to engage unaffiliated third-parties to verify their analyses and review their plans.

3.2.1.2. NERC Reliability Standard EOP-010-1: Geomagnetic Disturbance Operations

Reliability standard EOP-010-1, Geomagnetic Disturbance Operations (one of the Emergency Preparedness and Operations group of standards), was instituted to address solar events (i.e., storms or flares) that alter the electric currents in the earth's magnetic field and can have a large impact on the reliability of electric systems. In extreme cases, geomagnetically-induced currents from a solar storm could flow through transmission lines, damaging essential equipment, including large power transformers, and causing a collapse of the power system.[25]

As with the Physical Security standard, EOP-010-1 requires entities to develop and implement appropriate operating procedures to mitigate potential impacts from a GMD. The standard applies to transmission operators with an operation area that includes high side wye-grounded power transformers with terminal voltage greater than 200 kV and to reliability coordinators. Transmission operators are required to develop, maintain, and implement operating procedures "to mitigate the effects of GMD events."[26] Reliability coordinators are required to develop, maintain, and implement plans that coordinate the procedures of the operators within their areas.

A new reliability standard, TPL-007-1 Transmission System Planned Performance for Geomagnetic Disturbance Events, provides specific performance criteria for entities assessing the potential impacts of geomagnetic disturbances and preparing corrective action plans. The standard has been submitted to FERC, but not yet approved by the commission.

3.2.2. Rate Making

Rate recovery is of course a primary concern to public utilities and therefore a valuable policy tool for regulatory authorities trying to encourage such entities to address risks. Important factors to consider include who will pay for deployment of emergency equipment (e.g., transportation and installation) and how consumer rate structures may be adjusted to cover the cost of spare transformer usage.

Additionally, policy and regulatory frameworks require careful consideration. For instance, for those entities subject to the commission's jurisdiction, some rate recovery mechanisms must be filed with and approved by FERC before a rate may be implemented.[27]

According to FPA Section 205, all rates filed with FERC must be "just and reasonable" in order to be approved.[28] This language applies just as well to rate recovery for the cost of responding to emergency situations, such as LPT failure.[29] Additionally, Section 206 of the FPA states that if a complaint regarding rates is filed and FERC rules that a rate was, in fact, unjust and unreasonable, FERC can establish a new rate from the date of the complaint and enforce refunds of the overcharges.[30] This makes it especially important for spare transformer programs to establish FERC-approved funding structures before deployment.

Generally, if a utility seeks to change one aspect of its rates, it opens up all other aspects of its rates for simultaneous review. However, under single issue ratemaking, an approach FERC authorized for participation in the Edison Electric Institute's (EEI's) Spare Transformer Equipment Program (STEP), a utility can propose a change only to one aspect of its rates (i.e., on a single issue) and not open up any other aspect of its rates for review.[31] By allowing a utility to change its rates on a single issue, the utility may be more willing to make the investment knowing that it will not subject all aspects of its rates for review. Trackers (also called riders or surcharges) are a non-traditional rate mechanism typically employed for the purpose of add-on cost recovery for a single issue, helping to mitigate financial strain on a utility and its customers, i.e., in the case of an emergency.[32] However, some regulators feel this type of mechanism lacks transparency.[33] EEI also argued that any expenses incurred by customers as a result of the program are nonetheless in the public interest as the program serves to improve system reliability, and that rate impacts in STEP are actually "offset… by the value of the reliability gains" because the participating utilities jointly pay for the spare transformers, lowering the costs for each individual entity.[34]

3.2.3. Emergency Response and Recovery

In the event of an emergency that results in the impairment or loss of critical infrastructure, federal authorities facilitate and enable certain response and recovery actions during and after a disaster. Specifically, the Stafford Act allows for federal aid to be given to states and regions that do not have enough resources for emergency response.[35] The Stafford Act provides a framework for Presidential declaration of an emergency or a major disaster and its scope includes critical infrastructure and energy facilities that serve important national defense functions. Under the Stafford Act, the federal government is authorized to supplement state and local resources in major disasters or emergencies where those resources are overwhelmed.[36] Specifically, it outlines a process and timeline for declaring an emergency and the role of the Federal Emergency Management Agency (FEMA) which is responsible for coordinating administration of disaster relief to states.

Section 101 of the Stafford Act describes the need that Congress has identified in disaster relief for "aid, assistance, and emergency services, and the reconstruction and rehabilitation of devastated areas."[37] The Act contains a number of sections that could cover public power and in some cases possibly even private utilities. For instance, Section 201 indicates that state plans for recovery, to which the federal government provides technical assistance and grants, cover public and private facilities that have suffered damage. The President can directly order the repair or restoration of any critical federally-owned facility, as well as provide assistance to a private nonprofit facility responsible for "critical services," including power.[38] The President can also authorize grants for the removal of debris or wreckage from public and private lands.

The process of declaring an emergency is "made by the Governor of the affected State," who requests assistance from the federal government when dealing with an emergency that is beyond local and state capabilities.[39] The President can declare a national emergency (even without a prompt from a Governor) and provide aid to the region, including "technical and advisory assistance" for recovery activities.[40] In these situations, "emergency work" may be required, which includes "temporary restoration of essential public facilities and services," an area under which electricity could fall.[41] In Section 427, the definition of "essential service provider" includes entities that provide electrical power and contribute to emergency response; these entities are authorized greater accessibility during an emergency event, meaning that federal agencies cannot "impede … [their] restoration or repair."[42]

Title VI of the Stafford Act outlines the development of a "comprehensive emergency preparedness system" in response to natural disasters and man-made events.[43] Measures include emergency repairs or restoration of "vital utilities and facilities" affected by a hazard, procurement and stockpiling of resources, arranging for adequate warning systems, and establishing reliable control centers, all items that could apply to electricity delivery.[44] Specifically, FEMA has authority over provisions of Section 603 of the Stafford Act, also referred to independently as the Critical Infrastructures Protection Act of 2001.

The Act is designed to protect critical infrastructure, whether public or private, including energy services. Under the Act, a National Infrastructure Simulation and Analysis Center (NISAC) was established to "address critical infrastructure protection" and support "counterterrorism, threat assessment, and risk mitigation."[45] Here, critical infrastructure is defined as "systems and assets" that contribute to "security, national economic security, [or] national public health or safety."[46] While this section does not specifically mention LPTs, LPTs could fall under the Act's definition of "critical infrastructure," depending on factors such as location, size, ownership, or vulnerability of the unit. Particular NISAC activities include modeling and simulation of critical infrastructure systems, analysis of emergency event implications, and enhancing critical infrastructure stability. Again, since the language in this legislation strongly implies the inclusion of at least some LPTs, further information is required to understand which facilities are covered by Stafford Act provisions.

The Defense Production Act (DPA) of 1950 serves as the primary vehicle through which the federal government may influence domestic industry to provide essential materials for national defense. Enacted during the Korean War, DPA provides the President with a set of authorities to influence domestic industry in the interest of national defense and civil emergency preparedness and response.[47] The importance of DPA extends beyond national defense, however. With the act amended and reauthorized a number of times over the years, the term national defense has expanded to encompass activities related to critical infrastructure protection and restoration, as well as homeland security. Authorities provided in DPA can play an important role in LPT risk mitigation through the facilitation of the production of LPTs and key raw materials, including specialty electrical steel, for example. DPA authorities can be used to facilitate the transportation of LPTs during an emergency.

DPA authorities are available for activities/measures undertaken in preparation for, during, or following a disaster event—both man-made and natural. The Secretaries of Energy and Commerce have been delegated the president's authorities under sections 101(a) and 101(c) so that the Secretaries can give orders to require priority of contracts/orders relating to critical materials, including equipment, services, transportation, and energy supplies/sources.[48] Specifically, Secretary of Energy has authority with respect to all forms of energy; Secretary of Commerce has authority with respect to most materials, equipment, and services.

Under Title III, the President can order to create, maintain, expedite, expand, protect, or restore production and deliveries of services essential to the national defense. Finally, Section 304 provides the Defense Production Act Fund which can be allocated toward carrying out DPA provisions. The U.S. Treasury has $750 million in the DPA fund.[49] To receive an award from the fund, an entity must be unable to meet its needed production capacity without federal assistance, and the request for funding must be approved by the President.

3.2.4. Critical Infrastructure Protection, Security, and Resilience

A number of federal policies are directed at managing risk to critical infrastructure. After 9/11, the Homeland Security Act of 2002 assigned the Department of Homeland Security (DHS) with the responsibility of developing a comprehensive national plan for securing critical infrastructure.[50] Subsequently, Homeland Security Presidential Directive 7 (HSPD-7)—Critical Infrastructure

Identification, Prioritization, and Protection—established a national policy to identify and prioritize critical infrastructure and to protect it from terrorist attacks.[51] HSPD-7 was later replaced by Presidential Policy Directive 21 (PPD-21)—Critical Infrastructure Security and Resilience, which broadened the scope of the national policy on critical infrastructure, including the inclusion of resilience policy and an increased focus on cybersecurity issues.[52] PPD-21 "identifies energy and communications systems as uniquely critical due to the enabling functions they provide across all critical infrastructure sectors." Per PPD-21, DOE, as the Sector-Specific Agency (SSA), is responsible for risk management activities in the energy sector. Energy sector risk management activities entail identification and assessment of risks and various activities to mitigate and deter the impacts of such risks as outlined in the 2013 National Infrastructure Protection Plan (NIPP) and the 2015 Energy Sector Specific Plan (SSP).[53] As shown in Figure 3-1, critical infrastructure risk management entails prevention, protection, mitigation, response and recovery in the context of national preparedness.[54]

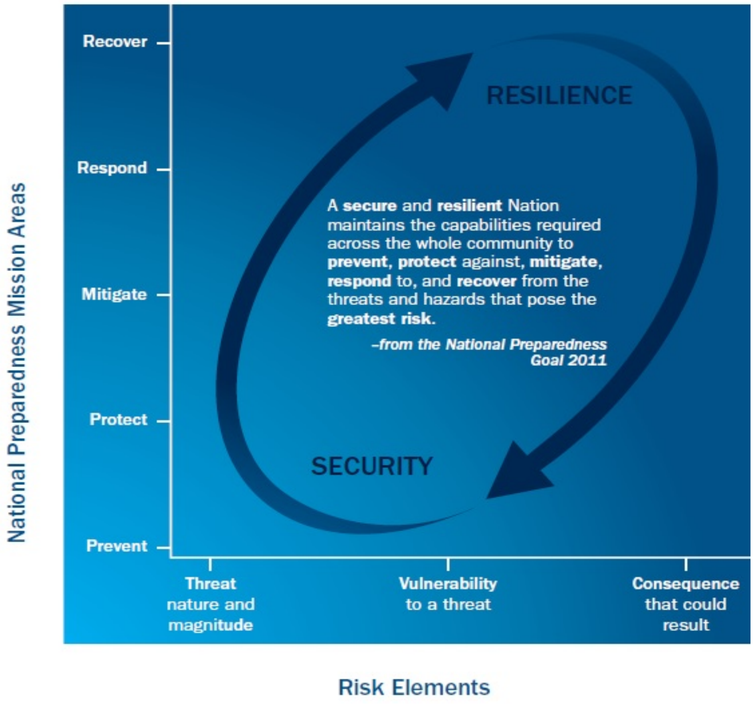

Figure 3-1. Critical Infrastructure Risk in the Context of National Preparedness

As stated in the Energy SSP, private-public partnership is the cornerstone of the Energy Sector's critical infrastructure security and resilience efforts.[55] Specifically, the Energy Government Coordinating Council (GCC) and Sector Coordinating Councils (SCCs) are the coordinating bodies carrying out risk management activities for government entities and industry stakeholders, respectively.[56] Thus DOE, as the chair of the Energy GCC, and the Electricity Subsector Coordinating Council (ESCC) have been working together to address various risks facing the U.S. electricity industry, including insufficient LPT spares during an emergency.

To facilitate open and secure information sharing, the discussion between GCC- and SCCs-related critical infrastructure are held under the Critical Infrastructure Partnership Advisory Council (CIPAC), which is exempt from the Federal Advisory Committee Act of 1972 (FACA).[57] FACA was created to make advisory bodies transparent and their meetings and written material available to the public; however, concerns regarding FACA requirements were becoming a hindrance to vital communications between government and critical infrastructure sectors, which led to the creation of CIPAC.[58] To further protect information pertaining to critical energy infrastructure, FERC established procedures for designating critical energy infrastructure information (CEII). CEII is defined as "specific engineering, vulnerability, or detailed design information about proposed or existing critical infrastructure (physical or virtual) that:

(1) relates details about the production, generation, transportation, transmission, or distribution of energy; (2) could be useful to a person planning an attack on critical infrastructure; (3) is exempt from mandatory disclosure under the Freedom of Information Act; and (4) gives strategic information beyond the location of the critical infrastructure."[59]

It is through this institutional framework and these federal authorities that the electricity sector has worked together to identify risks, including the risk associated with losing multiple LPTs, and to develop strategies to mitigate such risks. To further the efforts related to energy security and resilience, a new Act—the FAST Act—was signed into law in December 2015 and is discussed further in the next section.

3.2.5. Public Law 114-94 or the FAST Act

On December 4, 2015, President Obama signed into law the Fixing America's Surface Transportation (FAST) Act, Public Law 114-94, which includes amendments to the Federal Power Act and other actions aimed at improving the security and resilience of energy infrastructure in the face of emergencies.[60]

Specifically, Section 61003: Critical Energy Infrastructure Security, amends the FPA by adding a new section, 215A, which authorizes the Secretary of Energy to order emergency measures if the President finds a grid security emergency. "Grid security emergency" is defined as "the occurrence or imminent danger of events impacting the reliability of the critical electric infrastructure (CEI)"[61]; such events can include EMP, GMD, cyber or physical attacks. This new law provides that if the President declares a "grid security emergency," the Secretary of Energy can issue any order necessary to protect or restore the reliability of critical electric infrastructure. DOE has been directed to establish procedures for exercising the new emergency authority within 180 days of the enactment of the law.[62]

The new section, 215A of the FPA, also addresses the protection and voluntary sharing of critical electric infrastructure information (CEII). CEI is broadly defined to include both physical and virtual "systems and assets" of the bulk-power system, whose destruction or incapacity would have a negative impact on national or economic security, or public safety. CEII could mean potentially any information related to CEI that is generated by or submitted to any other federal agency. The new section exempts CEII from public disclosure requirements under the Freedom of information Act (FOIA) and other federal, state, local and tribal laws. It also directs FERC to adopt regulations to establish criteria and procedures for designating CEII, prohibit unauthorized disclosure, and facilitate voluntary sharing of CEII. The full impact and the specifics of these provisions will depend on the new FERC rules, for which FERC recently issued a notice of proposed rulemaking.[63] It is important to note, however, that no federal agency can force or require disclosure of CEII by anyone who has it and that the FAST Act does not create a cause of action to force such sharing.

As explained earlier, the FAST Act, specifically §61004, also directs the preparation of a report to Congress for a plan to establish a strategic transformer reserve. This report is one step in that effort.

3.3. RTOs/ISOs

There is no uniform position on spare transformers among Independent System Operators and Regional Transmission Organizations.[64] Most indicated no involvement in addressing the issue. Those that are involved, however, approach it from the perspective of establishing policies and rules for their market participants to implement.

One ISO, PJM, directs the purchase of spares by transmission owners through its Regional Transmission Expansion Plan (RTEP) process, with the number of spares required based on a probabilistic risk assessment.[65] The assessment incorporates the state or health of transformers, as well as the probability of natural disasters, such as hurricanes and tornados. It also weighs reliability impacts against cost implications and as of May 2014 has resulted in the purchase of seven spares.[66] Further, in addition to power transformer spares, PJM's direction to transmission owners provides that other equipment critical to the integrity of the grid also known to have long lead times should be supported by spares.[67]

Other ISOs with less forceful policies are the Midcontinent Independent System Operator (MISO), whose planning protocol requires transmission developers to provide documentation of "spare parts, spare structures, and/or spare equipment inventories for substations and/or transmission lines, as applicable, including descriptions of any agreements to share spare equipment, spare parts, and/or spare structures with other transmission entities"[68] and the California Independent System Operator (CAISO), whose developer application inquires as to the entity's resources for responding to major problems and asks for samples of emergency operating plans.[69]

4. Industry Strategies for Reducing Risks

A variety of industry efforts are underway in the United States to respond to risks associated with losing LPTs. In addition to the policy and regulatory provisions, the U.S. electricity industry has developed diverse strategies to address this risk. They include industry consortium-led transformer and electric equipment sharing programs and various LPT spare strategies implemented by individual utilities. The remainder of this study discusses the structure and arrangement of industry transformer and equipment sharing programs and provides a high level summary of other related activities in the U.S. electricity industry to mitigate risk associated with losing multiple LPTs.

4.1. Established Industry Consortium-Led Transformer Sharing Programs

Three key transformer sharing programs currently exist in the United States—NERC's Spare Equipment Data (SED) program, EEI's Spare Transformer Equipment Program (STEP), and SpareConnect. Another program, Recovery Transformer (RecX), developed a rapidly deployable prototype transformer designed to replace the most common HV transformers, which DHS successfully funded in partnership with EPRI and completed in 2014.[70] Two additional programs, Grid Assurance and Wattstock, are in development as of March 2016. The fact that several types of transformer sharing programs currently exist, and new initiatives continue to be developed, is an indication that industry recognizes the risk posed to grid reliability from the potential loss of LPTs.

Table 4-1 summarizes the key characteristics of the three existing programs: STEP, SED, and SpareConnect. The two additional transformer sharing offerings still in development, Wattstock and Grid Assurance, are discussed in the next section. As can be seen from this table, the qualifying events (the events that would trigger deployment) for each program differ. For example, the mandatory sharing of spare transformers under STEP is activated when there is a declaration of a state of emergency by the President as a result of an act of terrorism, while for SpareConnect any non-routine failure qualifies, and for SED the event is supposed to be one recognized as HILF.[71]

Table 4-1. Summary of Transformer Sharing Programs

Program	Administrator/ Organization	Qualifying Events	Type of Program	Number of Participants	Available Spare Categories	Number of Spares
STEP	EEI	Terrorist attack followed by presidential declaration of emergency	Obligatory sharing of individually held reserves. Also serves as a potential mechanism for voluntary sharing of transformers in other emergencies.	56	Large power transformers (LPTs) up to 500 kV	50,000 MVA (in the range of 71-105)
Spare Connect	EEI	Any emergency or non-routine failures	Communication channel that identifies participants with resources matching need	126	LPTs and related equipment (bushings, fans, auxiliary components)	N/A
SED	NERC	HILF events (coordinated cyber and physical attacks, GMD, extreme weather)	Database of equipment and double-blind communication protocol	34	LPTs greater than 100 MVA (transmission) and 75 MVA (generator step-up)	178

Note: Information collected from a variety of sources. For individual references, see the sections on each program.

The programs also differ in the mechanisms they employ. SED is a voluntary program NERC developed to address high-impact, low-frequency (HILF) events by creating a database of utility-owned spare equipment that could be a resource for industry should an event occur.[72] In contrast, STEP imposes certain contractual obligations on participants and SpareConnect is a protocol for communication.

In addition to the diverse qualifying events and primary mechanisms, these programs also have varying types and levels of participation as well as available spares. Each program is unique, and in some ways they complement each other. Because utilities seek a variety of risk mitigation options and can and often do commit to more than one, there are certain overlaps in the membership and available or committed number of equipment among these programs. The extent of the overlap is unclear, however, because strict confidentiality agreements exist for the participants of these programs. Such confidentiality agreements also mean that the specific data on the spare equipment or participating members is generally not made publicly available. For STEP, however, the names of participating members can be found in EEI's regulatory filings at FERC.[73]

As shown in Table 4-1, a total of 34 members together committed a total of 178 LPTs to NERC's SED program as of February 2016. As of March 2016, STEP had 56 participating members. While the exact number of LPTs available through STEP is not available, EEI estimated in its original 2006 application to FERC a range of 71 to 105, for a total capacity of approximately 50,000 MVA.[74] STEP's membership and sharing capabilities have grown since the original FERC application.[75] SpareConnect had a total of 126 participants as of March 2016; the types and numbers of equipment are not available.

4.1.1. NERC SED Program

While NERC has had an informal transformer spares database since the early 1980s, NERC relaunched the SED program in 2010 to enhance the bulk electric system's resilience and recovery in the face of wide-ranging high impact, low frequency (HILF) events that could result in the damage or failure of a large number of transformers. HILF events—which include coordinated cyber, physical, and blended attacks, the high-altitude detonation of a nuclear weapon, and major natural disasters like earthquakes, tsunamis, large hurricanes, pandemics, and geomagnetic disturbances caused by solar weather—were examined in a 2009 NERC and DOE co-sponsored workshop and a subsequent 2010 report entitled *High-Impact, Low-Frequency Event Risk to the North American Bulk Power System.*[76] In an effort to meet one of the recommendations in that report, NERC created a task force to update its existing spare equipment database.

The objective of SED is to provide an automated system with enhanced information security and usability for the industry to locate spare equipment in the event of an emergency or other non-routine failure. The SED is populated and managed by participating organizations bound by a mutual confidentiality agreement; requests for equipment are double-blind. Participation is voluntary and requires no commitment or mandatory sharing of spares.[77]

Unlike EEI's STEP program, however, the SED program has not been granted preapproval from FERC or state regulators for equipment transfers. Thus, in certain circumstances, the ability to transfer the ownership of transformers from one company to another may require additional approvals, even during an emergency. As of February 2016, 34 entities were participating in the SED Program, and together they offered 178 transformers.[78]

4.1.2. EEI STEP Program

In 2006, EEI, a trade association for U.S. investor-owned electric utilities, initiated STEP to strengthen the electricity sector's ability to restore the transmission system in the event of deliberate destruction of power transformers in connection with a terrorist event.[79] The STEP program requires participating utilities to maintain (and sometimes acquire) a specific number of transformers up to 500 kV to be made available to other utilities in case of a critical substation failure. Sharing of transformers is mandatory based on a binding contract subject to a "triggering event"—a coordinated act of deliberate, documented terrorism resulting in the destruction or disabling of a transmission substation and the declaration of a state of emergency by the President.[80]

Participants of STEP sign a binding contract called the "Spare Transformer Sharing Agreement" that conveys the governance of the program and provides strict confidentiality provisions to ensure that participating utilities' information is protected.[81] Under this Agreement, each participating utility is obligated to commit a certain MVA capacity of spare transformers for each voltage class in which it is a member. The quantity committed is based upon the size of the utility and the utility's self-assessment of its ability to restore the system to normal operating conditions in the event of losing its five most critical substations per voltage class.[82] Thus, STEP enables participating utilities the ability, at a minimum, to recover from the simultaneous loss of up to five of their substations. In some cases, utilities have committed additional spares beyond their requirement, thus giving the program the ability to support the recovery of more than 5 substations per voltage class.[83]

STEP's commitment requirements are reviewed and updated annually to ensure that all voltage classes have an adequate number of spares.[84] The transfer of spare equipment pursuant to STEP has been approved by the Federal Energy Regulatory Commission and, to the extent necessary, STEP participants secure pre-approval from their state utility regulators when they first join STEP.[85] As a result, no additional regulatory approvals are necessary to access STEP's spare capacity during a declared state of emergency by the President.

As of March 2016, 56 electric utilities were members of STEP. Reportedly, these companies served over 98 million residential, industrial, and commercial customers, which comprise approximately 67% of U.S. electricity customers.[86] To participate in STEP, each participating utility pays an enrollment fee of $10,000 and annual dues of $7,500.[87] FERC and state commissions have issued orders approving participation and cost recovery.[88]

In September 2006, FERC granted blanket authorization for the transfer of transmission equipment under the STEP program and, addressing future cost-recovery issues, found that participation in the program was prudent.[89] State regulators with jurisdiction over participating utilities have also granted pre-approval for STEP transfers.

The program is designed to deal with terrorist events, but it also provides a mechanism for voluntary sharing of transformers in other emergencies, although these may require additional regulatory approvals. EEI requires annual recertification and conducts a STEP program drill every summer to ensure the program and its members will be fully prepared to respond in the event of an actual triggering event.

Table 4-2. Transformers Required Under STEP Agreement at STEP Establishment in 2006

Voltage class (kV)	# of participating utilities with transformers in each voltage class	Transformers needed in class	Transformers that must be purchased
500-230	17	10-15	3-5
345-230	4	6-10	1
345-161	5	3-5	1
345-138	12	15-20	3-5
345-115	7	5-10	1
230-138	10	8-10	1-2
230-115	14	8-10	1
230-069	5	10-15	7-9
138-069	8	5-10	3-6
TOTAL	82	72-105	21-31

STEP provides a ready mechanism for participating utilities to share assets in the event that existing equipment is deliberately destroyed in a terrorist attack. Each participating utility enters into a binding contract that provides legally enforceable rights to access hard-to-replace transformers that have been committed to STEP. STEP members commit to share specific assets in voltage classes within which they operate (see Table 4-3).[90] The sale price of a transformer through STEP is the seller's choice of either the net book value or the replacement cost, plus loadout and transportation costs and related tax liability.

Based on the expectation that equipment in each voltage class is generally interchangeable, committing these assets to STEP would provide participating utilities with ready access to a large pool of recovery assets that they otherwise would not be entitled to use. STEP also underscores the importance of partnerships within the industry as it fosters meaningful relationships among its members. Members of STEP meet regularly to administer the program, perform drill exercises, and share technical expertise.

4.1.3. SpareConnect

SpareConnect, developed by EEI and supported by the American Public Power Association, the Canadian Electricity Association, the Electric Power Supply Association, the Large Public Power Council, and the National Rural Electric Cooperative Association, allows owners and operators of bulk power system facilities to network and share spare transformers and related equipment.[91] As of August, 2015, there were more than 120 entities participating in SpareConnect.[92]

Both STEP and SpareConnect require participants to already own physical assets,[93] and have established criteria for deploying spare transformers.[94] However, SpareConnect is less formal than STEP, building on existing communication channels between utilities and allowing them to connect regarding equipment and other technical needs during an emergency or other non-routine failure.[95] In addition, SpareConnect is designed for emergency events unrelated to terrorist activity. Through SpareConnect's confidential online platform, the entire electric industry can reach out to other members, complementing utilities' own spare programs,[96] as well as existing programs such as STEP and voluntary mutual assistance programs.[97]

Because the program relies on shared industry resources, SpareConnect does not manage its own central database of spares.[98] Instead, it serves as a conduit for points of contact at various utilities so that in case of an emergency, members can quickly connect with other participants in the same voltage class who can provide backup equipment.[99] Utilities that have been matched will then discuss specific arrangements such as terms and conditions or transportation.[100] Lastly, SpareConnect remains a voluntary, mutually cooperative program, and does not obligate any participants to provide information or equipment.[101]

4.2. Business Models for Proposed Transformer Sharing and Rental

4.2.1. Grid Assurance

Grid Assurance is a company formed by utilities and energy companies with the goal of developing a more cost-effective method to procure incremental spare equipment collaboratively in comparison to each utility acquiring spares on its own.[102] The founding partners include some of the largest energy companies in the United States, including American Electric Power, BHE U.S. Transmission (Berkshire Hathaway Energy), Duke Energy, Edison Transmission (Edison International), Eversource Energy, and

Great Plains Energy. Grid Assurance will maintain a large-scale inventory of spare transmission equipment that is ready for rapid deployment to any of its subscribers in case of an emergency. The service is similar to STEP, but aims to be more comprehensive, providing spares for related equipment as well as transformers and covering a wider range of situations than just terrorist attacks.[103]

Grid Assurance, currently in development, is expected to be fully functional by January 2018. The program expects to maintain an inventory of at least 100 transformers that each cost between $2 million and $10 million.[104] In March 2016, FERC found that subscribing to the Grid Assurance sparing service and purchasing equipment from Grid Assurance in an emergency are prudent. FERC also ruled that subscribers would not have to pursue full rate cases to recover related costs, but instead could use single-issue ratemaking.[105]

4.2.2. Wattstock

An independent private company, Wattstock, offers the Transformer Recovery Inventory Program (TRIP), the "only available viable broad National Grid Resiliency solution for all transformers," citing low participation and limited applicability as the reasons for other programs' inadequate coverage.[106] Compared to other existing programs, Wattstock claims TRIP offers more transparent pricing and terms with better coverage, service, and performance. The STEP program, as well as the Pooled Inventory Management program, an emergency equipment sharing arrangement for the nuclear industry,[107] have set regulatory precedent for recouping investment in the TRIP program.

The goal of the TRIP program is to build a national inventory of LPT spares, comprised of sixty to 100 modular Wattstock Recovery Flex Transformers (RFT) located at regional distribution centers. Participants pay an enrollment fee and annual membership, as well as a rental fee for usage of spares, with an option for purchasing the spare.[108] Wattstock says a spare unit can be shipped and installed within two to three weeks of an emergency event.[109] TRIP currently offers nine generator step-up transformer models, which "represent 97% of the traditional MVA's in the market."[110] For transmission transformers, TRIP offers five models, which represent 2000 transmission transformers, or 60 percent of grid critical MVA. The program presents itself as a low-cost alternative to purchasing spares and an efficient way to enhance grid resiliency—the cost of membership is $0.000067/KWh. For a TRIP member, if a transformer fails, Wattstock can quickly install a temporary unit until normal operations resume, thus bypassing longer and more costly processes such as repairs, evaluation of damage, purchasing units with long shipping times, and searching within the transformer market for a suitable unit.

Wattstock uses a formula, which it calls the "Wattstock Score," to quantitatively determine optimal transformer-to-spare matches for recovery. Factors that are assessed are electrical fit (voltage), proximity fit (location and delivery time), and physical size fit. The best available match will produce the highest score. If necessary, scores can also be categorized by criticality, region, or other variables. Additionally, a decay curve, indicating the level of stability, is formed by repeatedly removing the spare transformer with the highest score and recalculating the overall score. The scores can be applied in different ways with the aim of helping gauge transformer recovery plans and determining the number and placement of recovery transformers.

4.3. Individual Utilities' Emergency Spare Strategies[111]

Utilities have implemented various combinations of spare transformer strategies, including the stocking of interchangeable spare transformers, the ordering of conventional spares in advance, and the early retirement of conventional transformers for use as spares.

Utilities stock conventional spares that are equivalent and interchangeable to their critical transformers.[112] While they are typically used for planned replacements or individual unit failures, these transformers can also be used as emergency spares as needed. Under this approach, the spares are identical to those transformers to be replaced and often stored at the substation, next to existing transformers. This allows for quick energization without the transformer being moved; however, due to the close proximity of such spares to the existing transformers, these spares are also exposed to potential HILF physical attacks or weather events.

Another approach is ordering conventional spares earlier than needed for critical substations nearing the end of their service lives. This way, utilities can secure in advance a spare that they will certainly need eventually. In this approach, utilities assess the health and the probability of failure of each transformer to project the remaining life of the transformer. Such assessment enables a cost analysis as well as the estimation of return on investment.[113] It should be noted, however, that spare transformers require maintenance.

In this last approach, some utilities retain retired transformers to repurpose them as emergency spares. These are transformers that have retired but not failed, which would allow them to be used as temporary spares until a new transformer is manufactured and transported.

4.4. IEEE Substation Security Standard

A source of guidance to industry regarding the physical security of transmission facilities is IEEE (the Institute of Electrical and Electronics Engineers) Standard 1402-2000, Guide for Electric Power Substation Physical and Electronic Security. The standard, which dates back to 2000, addresses human intrusion into power substations by calling for security assessments and presenting a variety of potential security measures, such as motion detectors, cameras, guards, and barriers. The practices described in the standard are meant to "mitigate the risks associated with the fact that substations are typically unmanned, and thus susceptible to unauthorized access, theft and vandalism."[114] They were not designed to defend against attacks intended to destroy a substation's capability to operate, such as those made with explosives, projectiles, and vehicles.

Voluntary IEEE 1402 has in a sense been overtaken by the mandatory NERC reliability standard CIP-014-2, which also addresses physical security. However, as IEEE 1402 describes particular security strategies, presents a variety of specific measures, and sets expectations for different levels of security, it can still provide a useful point of reference for industry developing required security plans.

4.5. Research and Development Initiatives

In addition to the efforts by electric utilities and organizations, transformer manufacturers have been continuously working to enhance their products and transformer designs for utmost reliability. As such, a number of manufacturers are exploring the research and development (R&D) of mitigation and hardening options, including the consideration of parts that are more resilient to potential threats, as well as protective devices. Discussions with power transformer manufacturers indicate that they are working to ensure that their products meet the needs of their customers today and in the anticipated future, and that transformers can operate under expected or normal operating conditions as well as in emergency situations. Some of the R&D areas include: alternate materials and designs to improve resilience, physical hardening of transformers; on-line or remote monitoring devices for LPTs; explosion-proof transformers; transportable or mobile transformers; transformers with armored panels to prevent ballistic damage; improving thermal performance; and using non-magnetic materials. At least one manufacturer has launched a transformer and grid resilience program, offering assessment, hardening, monitoring, and rapid response/replacement services.[115]

In addition to the R&D in design specifications, some manufacturers are also engaged in the development of flexible spare transformers of various types, such as the Recovery Transformers (RecX). The U.S. Department of Homeland Security Science & Technology Directorate (DHS S&T), the Electric Power Research Institute, ABB, and CenterPoint Energy (CNP), developed RecX, a prototype EHV transformer that would drastically reduce the recovery time associated with the loss of EHV transformers. The RecX, though single-phase, is, at 125,000 pounds, still smaller, lighter, and easier to transport in triples than a traditional 400,000 pound three-phase EHV transformer.[116] Three can be installed simultaneously more quickly than a single three-phase unit. The RecX began operating in CNP's grid in March 2012, after a successful exercise that included the transportation, installation, assembly, commissioning and energization of the transformer in less than one week. The RecX is a 345:138kV, 200 MVA per phase transformer (equivalent to 600 MVA) and was designed to be an applicable replacement for more than 90 percent of transformers in this voltage class, which is the largest single voltage class of EHV transformers.[117]

Some utilities are working with manufacturers to establish agreements in advance to expedite the manufacturing of transformers if needed. Such an agreement may involve manufacturers preordering and stocking parts with long lead times, having a master agreement or transformer design in advance, or negotiating reduced lead times in case of an emergency. However, it should be noted that an agreement that provides one utility higher priority delivery might increase the lead-time for another utility, due to finite production capability; therefore, this may not improve the overall response time to meeting all utilities' transformer orders.[118]

The Department of Energy's Office of Electricity Delivery and Energy Reliability is also seeking to promote standardized and flexible LPTs. In June 2016, DOE/OE announced the availability of $1.5 million in funding for further research and development on the subject.[119]

4.6. Transformer Transportation Working Group

Whether for an LPT procured through normal means, acquired from a program of spares, or being relocated from one company site to another, transportation of this equipment presents some extraordinary challenges, including requirements for special railcars, road permits, and exceptional handling procedures. Recognizing the limited availability and difficult transport logistics of LPTs as potential challenges for electric grid resilience, in 2014, the electricity industry convened the Transformer Transportation Working Group (TTWG) in coordination with the Electricity Subsector Coordinating Council and its Senior Executive Working Group to develop an industry action plan on the movement of LPTs.[f] The TTWG has been tasked with identifying essential government and private sector partners and their specific capabilities to help enhance and expedite the efficient and secure movement of LPTs.

In 2015, the TTWG analyzed transportation stages by breaking down typical rail, road, and barge movements into specific sub-components and activities to highlight potential transportation bottlenecks and support missions. The TTWG identified the following high priority recommendation areas: streamlining permitting and clearance processes, prioritizing access to transportation assets and infrastructure, conducting joint industry government exercises and drills, and ensuring security needs are met.

This utility industry group is further engaged in extensive outreach with the transportation industry, in particular, Class I railroads, to address transformer transportation challenges. The utility industry is expanding information sharing between utilities and transportation entities, developing emergency playbooks and support guides, and performing exercises and drills. To date, the industry has received significant support and cooperation from the railroad industry in this effort, including evaluating the inventory and availability of, and priority access to, specialized rail equipment needed to transport transformers. Under emergency conditions, the utility and transportation industries would make every effort possible to expedite the movement of critical transformers.

5. Assessing the Effectiveness of the Existing Security Regime

The electricity industry has a long history of a resilience practice, which includes redundancy of protection system elements and mutual assistance agreements in case of an emergency. The policies and programs described in this report are a diverse group with a wide range of applications to the mitigation of risks applicable to large power transformers. There are federally mandated grid reliability standards, presidential authorities for emergency response, public-private research and development efforts, ISO interconnection codes, and spare equipment sharing arrangements. The formalized industry-led transformer sharing programs provide institutional mechanisms to facilitate and sometimes enforce mutual assistance and transfer of equipment in an event that incapacitates LPTs.

It is not physically feasible to protect the entire network of electric power infrastructure despite the multiple layers of protective measures and security strategies that exist in the government and in the industry. It is for this reason that national risk management strategies for critical infrastructure embrace the importance of resilience—"the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies."[120] Thus, the key question is what the government should do to mitigate the risks associated with multiple transformer loss, beyond what is already covered by industry programs. This extends beyond knowing the available number of spares or whether spare transformers are interchangeable with the affected transformers.

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[f] The working group consists of a functional cross-section of transmission engineering and operations, mutual assistance, spare equipment, logistics, and security executives along with subject matter experts from the major sectors and trade associations of the electric utility industry.

5.1. Considerations for a Risk Assessment Framework as Applied to LPTs

Despite the information available on the industry spare transformer sharing programs, it is very difficult to quantify or measure the effectiveness of the programs or the extent to which risks are being mitigated, and such an assessment is beyond the scope of this project and report. Various methodologies are available to facilitate risk assessment. In order to ensure that a common risk assessment approach is used to set priorities across sectors, the National infrastructure Protection Plan articulated a risk assessment framework as part of its strategy for managing risks.[121] The NIPP framework assesses risk as a function of consequence, vulnerability, and threat (R = f(C,V,T)).

In the context of LPTs, ***threats*** are those events that have the potential to cause loss of LPTs; ***vulnerabilities*** are areas in which the transmission system presents a weakness to the loss of LPTs, considering protective measures, resilience, and redundancies already in place; and ***consequences*** are the potential impacts resulting from a loss of LPTs.

Not all risks are equal. Some are more likely to happen than others. That is, threats may differ in probability as well as nature. The cost of a risk—or in other words, the consequence—can also vary greatly.

LPT spare and communication programs do not reduce the threat or vulnerability elements of risk. Instead, these programs will primarily work to reduce the consequences in the event of a loss of one or more LPTs by facilitating recovery via a replacement LPT in less time than the alternative without the programs (e.g., from a manufacturer). Other policies discussed primarily would work to reduce the vulnerabilities of the system. Each of these elements of risk assessment is discussed below focusing on to what degree assessments have been performed or could be performed, and what gaps in knowledge exist. There is significant additional work to be performed in this area; the goal here is to begin to lay out some of the considerations.

5.1.1. Threats

Threats to LPTs include natural disasters and extreme weather conditions; cyber and physical security threats, including terrorism; and equipment failure and aging infrastructure. The impact of these sharing programs will depend on the conditions under which they may be used. The triggering events for the programs reviewed in the report vary. The one most established, STEP, is limited to situations resulting from a terrorist attack, with a presidential state-of-emergency declaration. All of the programs in fact (including those under development) would seem to include terrorist attacks (see Table 5-1). All of the programs except STEP (which addresses only terrorist attacks) would seem to cover extreme weather events. Only the two programs under development seem to include any event, although given their stage, terms of participation could be subject to change. SpareConnect covers “emergency and non-routine” events, although in the information available, non-routine is not defined.

Table 5-1. Qualifying Events for LPT Programs

Program	Qualifying Events	Type of Program
STEP	Terrorist attacks	Obligatory sharing of individually held reserves (Voluntary for other threats)
Spare Connect	Any emergency or non-routine failures	Communication channel that identifies participants with resources matching need
SED	HILF events (coordinated cyber and physical attacks, GMD, extreme weather)	Database of equipment and double-blind communication protocol
Wattstock*	No restrictions Membership Required	Private Inventory for rental or purchase
Grid Assurance	No restrictions Subscription required	Centralized/shared inventory
* Program under development. Detailed terms of participation not available.		

Note: Information collected from a variety of sources. For individual references, see the sections on each program.

The nature of the threat—whether temporally and geographically dispersed, or single-attack or coordinated multiple attacks, for example—will influence the level of risk and the ability of the programs to mitigate that risk. It is also important to understand the probability of occurrence of these events. For some events such as hurricanes and other weather-related events, it is possible to develop estimates of likelihood of occurrence by geographic location based on historical data. Extensive data exists on extreme weather events. The National Oceanic and Atmospheric Administration (NOAA)'s National Centers for Environmental Information (NCEI) maintains several databases of severe weather events including storm events, severe weather inventory and lightning events. These data extend back as far as the 1950s.[122] For some other events, where no or very sparse historical data exists, such as physical or terrorist attacks, it is difficult to estimate the probability of an attack, or possibility for simultaneous attacks over multiple substations.

5.1.2. Vulnerabilities

Vulnerability assessment is an important subset of the risk equation. Vulnerability is a measure of the extent to which a particular threat causes failure or some other outcome of concern. How vulnerable the system is will depend on the impact of the event—given a particular threat, what is the likelihood the transformer will fail, and what are the associated impacts on the grid. Utilities and others routinely use power system load flow models to analyze the impacts of such failures on their systems to ensure that overloads do not occur either in real-time or under any likely contingency. These same methods could be applied to assess the impacts of the loss of one or more LPTs over a specific geographic area. [g] If a threat affects more than one LPT or affects the grid overall, the analysis would have to consider those impacts. While methods to assess the impacts of the loss of one or more transformers on the grid are established, assessing the potential for failure of an LPT due to a specific threat is more difficult. While data exists on the fire risks at transformers (from routine failures)[h], more research is needed on the incidences of LPT failures associated with other event types (e.g., storms, attacks, etc.).

5.1.3. Consequences

In assessing the potential of these LPT sharing and communication programs in limiting consequences, it is necessary to understand whether there are adequate transformer spares in place to respond to a threat and whether there is adequate coverage of key LPTs. This report assessed the existing spares available through these programs—estimated at 34 members with 178 LPTs in NERC's SED program; 56 members with 71 to 105 LPTs in STEP and 126 participants in SpareConnect. EEI's STEP program participants serve about 67 percent of U.S. electricity customers.[123] STEP participants commit a specific number of spares based upon the size of the utility and the utility's self-assessment of its ability to recover from the loss of its five most critical substations per voltage class. In other words, STEP's capability to respond to an event might be limited to those where no more than five critical substations are destroyed or impaired. No other programs set such parameters. Two programs, SED and SpareConnect, are communication channels for entities to discuss sharing resources without obligation.

The five programs surveyed here are all voluntary, and additional research is needed to assess whether the majority of LPT owners are participants in one program or another. According to the information available, there are perhaps as many as 200 entities participating, with perhaps as many as 300 transformers. In addition, there is apparent overlap of LPTs and members among these programs, and thus, it is unclear how many LPT spares are truly available.

Another key factor will be how diverse transformer classes are across areas being protected. For example, the EEI STEP recommended maintaining between 72-105 transformers of different voltage classes upon commencement of the program in 2006, to provide coverage against physical attacks across 56 participating utilities. If the equipment classes are very different across different geographic areas, then the risks of having insufficient inventory may be higher. Two programs, Grid Assurance and Wattstock, are still in development or startup stages, so their potential contribution to the overall inventory is unknown. Understanding the ability of these programs to respond to an individual threat would require a much greater level of information on the number, size, location, and transportation logistics of each of the programs.

A comprehensive assessment would also consider associated equipment, transportation, labor, and other resource needs evaluating whether there are adequate supporting materials and workforce, as well as institutional, logistical, and regulatory arrangements to be able to facilitate the simultaneous

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[g] Contingency analysis evaluates the impacts on an electric power system from the loss or failure of part of system (e.g. a transmission line, a generator or a transformer). The industry frequently uses an "N-1" standard (referring to the ability to operate without loss of service even after the failure of one key component in the grid) in planning for system reliability.

[h] See for example: H.-P. Berg, N. Fritze, Reliability Of Main Transformers, Bundesamt für Strahlenschutz, Salzgitter, Germany which identifies several databases on events resulting in fires at transformer. Accessed on May 12, 2016.
http://gnedenko-forum.org/Journal/2011/012011/RTA_1_2011-07.pdf

transportation and installation of multiple LPTs, among others. Transportation of LPTs is a significant challenge.[124] In the case of STEP, participating members have secured all required FERC and state regulatory approvals for the transfer of equipment so that no additional regulatory procedures are required to access such capacity, though STEP members need to obtain FERC approval if they seek to recover costs associated with any transformers they acquire under the program.

The extent to which these programs mitigate risks ultimately could be measured by the reduction in impacts. In the context of the NIPP, these impacts, or consequences**,** are measured as the losses or damages that result. Based on the criteria set forth in HSPD-7,[125] these are divided into four main categories:

- **Human Impact** including effects on life and physical well-being (e.g., fatalities, injuries). In the context of loss of LPTs this might include loss of life due to extended power outages, or direct impacts from the threat itself (e.g., fire, explosion).
- **Economic Impact** includes the direct and indirect effects on the economy. In the context of loss of LPTs this would include the losses to the utility from disruption of service (i.e., lost revenues) or to the customer (e.g., lost business, food spoilage), costs to respond to and recover from the disruption, costs to rebuild the asset, and long-term costs due to any environmental damages.
- **Impact on Public Confidence** including effect on public confidence in the utility, damage to goodwill, and any impacts on national economic or political institutions.
- **Impact on Government Capability** including ability to maintain order, deliver essential public services, ensure public health and safety, and carry out national security-related missions.

There are relatively well-established analytic methods to evaluate most of these types of impacts (the most significant) and some have been applied to problems of long-term, widespread grid outages,[i] as well as impacts from the increased price of power from a wide range of events. These analyses are likely not needed to assess the value of these LPT risk mitigation programs, and benefits could be established in terms of other metrics (e.g., lost load, changes in wholesale power prices). In any case, an overall study methodology would need to address many of the uncertainties identified above, including: the probabilities of HILF events, including the nature and geographic extent of the event; the impact of the threat event on LPTs, preferably based on historic data correlating similar events and failures; the functioning of the spare programs under a specific threat condition (e.g., how many spares would be called upon; when would they be in place; what gaps would remain); and what the impact would be on the system with the spares in place and under the alternative outcome absent these programs.

5.2. Summary

While various types of LPT risk mitigation mechanisms currently exist in the United States, they—individually and together—have limitations. NERC reliability standards require owners and operators to implement plans for protecting their transmission facilities against physical attacks and geomagnetic disturbances. However, these standards leave the particular methods and criteria up to those entities. While policies and regulations (e.g., the Stafford Act and the DPA) are in place to assist in emergency

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[i] See for example a summary of recent studies to quantify the August 2003 Blackout, The Economic Impacts of the August 2003 Blackout, Prepared by the Electricity Consumers Resource Council (ELCON) - February 9, 2004. Accessed May 12, 2016. http://www.elcon.org/Documents/Profiles%20and%20Publications/Economic%20Impacts%20of%20August%202003%20Blackout.pdf

response and recovery, there is no uniform guidance on how to interpret the language or apply them in a meaningful way to respond to LPT losses. Further, the transportation of LPTs generally require crossing state and sometimes international borders, which means that state regulations must also be taken into consideration, especially to expedite the movement of LPTs during an emergency. Physical challenges can also prove a hurdle to transportation.

EEI's STEP is the most mature LPT spare sharing program to date. However, STEP activation is required only when there is a Presidential declaration of a state of emergency as a result of terrorist attacks, in which case the sharing of transformers by members would be mandatory. No other events (for example extreme weather events) are covered as "triggering events;" however, STEP does facilitate voluntary sharing of equipment for other types of incidents. STEP terms are designed so that participants are prepared to recover from the simultaneous loss of up to five of their substations. In other words, it is unclear if the STEP program would be sufficient to recover from an event that incapacitates more than five critical substations simultaneously. It is also the only active program with prior authorization from both FERC and from states for the transfer of transmission equipment.

Although NERC's SED and SpareConnect cover a wide range of threats, they are voluntary programs that do not enforce any mandatory action or sharing of equipment from participants. SpareConnect and SED have been put to use a number of times; however, there has not been a large-scale event since these programs were established. SpareConnect facilitates communication without obligating the users to commit or share equipment. The RecX program, was successfully executed and installed in 2012, did not result in additional production of RecX units. Grid Assurance and Wattstock are still in development or startup stages.

Additional research is required to estimate the extent to which the programs mitigate different types of risks. Some of this research is ongoing in the area of the types of LPTs required in the event of the loss of one or more LPTs and how the programs match up to these needs in terms of their inventory, but also their participation. Additional information is needed on how different threats would affect LPTs and the likelihood of occurrence.

Appendix A. List of STEP Participants

- Allegheny Energy, Inc.
- Ameren Services Corporation
- American Electric Power Service Co.
- American Transmission Co. LLC
- Arizona Public Services Company
- Avista Corporation
- Bonneville Power Administration
- CenterPoint Energy
- Commonwealth Edison Company
- Consolidated Edison Company of NY
- Constellation Energy
- Dayton Power and Light Company
- Duke Energy Business Services LLC
- Duke Energy Carolinas, LLC
- Entergy, Inc.
- Idaho Power
- Indianapolis Power & Light
- ITC Transmission
- Kansas City Power & Light
- LG&E and KU Energy Services Co. LLC
- Michigan Electric Transmission Co.
- MidAmerican Energy
- New England Electric
- NextEra Energy (FPL)
- Niagara Mohawk
- Northeast Utilities Service Company
- Northern Indiana Public Service Company

- NSTAR Electric Company
- NV Energy
- Oklahoma Gas & Electric Services
- Oncor Electric Delivery Company
- Pacific Gas & Electric Company
- PECO Energy Company
- Pepco Holdings, Inc.
- PPL Electric Utilities Corporation
- Progress Energy Carolinas, Inc.
- Progress Energy Florida, Inc.
- Public Service Company of New Mexico
- Public Service Electric and Gas Company
- Puget Sound Energy, Inc.
- San Diego Gas & Electric Company
- Southern California Edison Company
- Southern Company Services, Inc.
- Tampa Electric Company
- Texas-New Mexico Power Company
- The United Illuminating Company
- Virginia Electric and Power Company
- Westar Energy
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