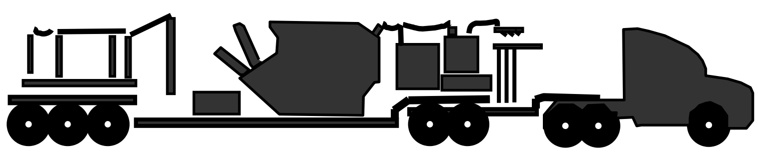
BENEFITS OF USING MOBILE TRANSFORMERS AND MOBILE SUBSTATIONS FOR RAPIDLY RESTORING ELECTRICAL SERVICE

A REPORT TO THE UNITED STATES CONGRESS PURSUANT TO SECTION 1816 OF THE ENERGY POLICY ACT OF 2005



August 2006

U.S. Department of Energy

The Secretary [of Energy] shall conduct a study of the benefits of using mobile transformers and mobile substations to rapidly restore electrical service to areas subjected to blackouts as a result of —

(A) equipment failure;
(B) natural disasters;
(C) acts of terrorism; or
(D) war.

Not later than 1 year after the date of enactment of this Act, the Secretary shall submit to the President and Congress a report on the study….

— Sec. 1816, the Energy Policy Act of 2005 (enacted August 8, 2005)

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Executive Summary

Section 1816 of the U.S. Energy Policy Act of 2005 (EPACT)[1] calls for a study on the benefits of using mobile transformers and mobile substations (MTS) to rapidly restore electrical service to areas subjected to blackouts as a result of equipment failure, natural disasters, acts of terrorism, or war. The law requires submittal of a report on the study to the President and Congress, not later than 1 year after EPACT's enactment.[2]

Background

MTS systems are used within a utility for a variety of reasons. Although MTS systems generally have larger losses and higher costs than conventional systems, their deployment capability (roughly 12 to 24 hours) is a major advantage to utilities. This flexibility allows them to be switched from one task to another relatively easily and is in fact a major justification for the utility to own and operate a MTS. Potential purposes for a MTS include planned maintenance, temporary increases in substation capacity, forced outage repairs, weather and other natural outages, and sabotage and attacks.

A MTS includes the trailer, switchgear, breakers, emergency or station power supply, a compact high-power-density transformer, and enhanced cooling capability. When needed, the MTS enables temporary restoration of grid service while circumventing damaged substation equipment, allowing time to procure certain long lead-time grid components.

Feasibility of Using MTS for "Rapid" Restoration of Electric Service

Weather and natural disasters are the main cause of electrical outages, most often by impacting the power lines leading to and from the substations, rather than disrupting the substations themselves. Yet, in those cases where a substation is affected, a MTS can be used by utilities to temporarily replace substation transformers in the low- and medium-power range (10-100 MVA). In general, MTS systems are too small to replace grid-critical high-power transformers (> 100 MVA), which represent approximately 5% of substation transformer applications in the United States.

Critical infrastructures and other facilities that require guaranteed electric service to function, such as the communications industry or first responders, generally need such service either instantaneously or within less than 5 minutes. MTS is capable of restoring substation operations in some cases within a 12-24 hour period. Thus, it is a delayed line of defense, falling behind uninterruptible power supplies, redundant rapid transfer to alternate power feed, and on-site generation. However, where disruption is prolonged due to equipment failure or total destruction from a war or act of terrorism, and especially where the problems are isolated to the substation, the MTS can play a critical role in reestablishing grid connection.

[1] Public Law 109-58, August 8, 2005.
[2] This report was prepared by the Secretary of Energy under the direction of the Office of Electricity Delivery and Energy Reliability. Technical support for the study was coordinated by B. McConnell, S. Hadley, and T. King, Oak Ridge National Laboratory.

Feasibility of using MTS for the Federal Government and Critical Infrastructures

The most obvious users of MTS systems within the Federal Government are the Federal electric utilities, such as the Tennessee Valley Authority, Bonneville Power Authority, and Western Area Power Administration. They currently use MTS systems for their own systems or those of their distribution utility customers. Similar to other utilities, power administrations use MTS systems for planned maintenance, temporary capacity increases, forced outage repairs, and weather and other natural outages.

Other possible government users are large military bases. However, most vital emergency power needs are usually already provided through on-site generators or redundant grid connections. Yet, the MTS systems can provide a tertiary line of defense to these critical facilities. Joint ownership of MTS systems may benefit both large Federal users of power and local utilities.

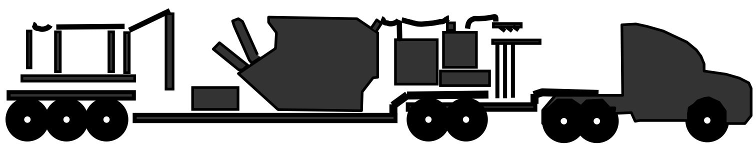
Although MTS systems can serve a vital role in restoration, the potential value of MTS systems for restoring electrical service to many critical loads is limited since it is very unusual to find a single critical infrastructure load greater than 3 MVA (lower limit for MTS viability) where standards, regulations, and emergency back-up procedures do not dictate either on-site back-up generation or alternate electrical feeds.

Feasibility of Reducing Dependence on Foreign Suppliers of Electrical Grid Components

Foreign producers dominate large-power transformer markets in North America, while medium-power transformers are essentially all produced in North America, with > 60% produced in the United States. Mobile systems currently fill the market need for temporary, medium-voltage transformers and substations (10-100 MVA). Large-power transformers (> 100 MVA) or higher-voltage transformers (>230 kV) are not currently replaceable using MTS, while transformers of 1-10 MVA size are generally available from multiple sources in a relatively short time period (2-3 days).

Since MTS are classed as low- and medium-power transformers, increasing or stockpiling MTS has no effect on the U. S. dependence on foreign production for large-power transformers. It also has little impact on the low- and medium-power transformer market, which is already supported by a domestic manufacturing capability.

BENEFITS OF USING MOBILE TRANSFORMERS AND MOBILE SUBSTATIONS FOR RAPIDLY RESTORING ELECTRICAL SERVICE



1. Introduction

Section 1816 of EPACT calls for a report on the benefits of using mobile transformers and mobile substations (MTS) to rapidly restore electrical service to areas subjected to blackouts as a result of equipment failure, natural disasters, acts of terrorism, or war. (See Appendix A for the entire text of the section.)

This document is the report to Congress. DOE views the report requirements as consisting of two parts: the first, "an analysis of the feasibility of using mobile transformers and mobile substations to rapidly restore electrical power to military bases; the Federal Government; communications industries; first responders; and other critical infrastructures, as determined by the Secretary", is addressed in Section 2 of this report; the second, "an analysis of the feasibility of using mobile transformers and mobile substations to reduce dependence on foreign entities for key elements of the electrical grid system of the United States", is discussed in Section 3 of this report.

The report is further organized as follows:

- Section 2, in addressing the rapid restoration of electrical service, provides a broad overview of how transformers are used within the electric grid and the difference between stationary and mobile transformers. It also describes the applications for MTS systems and the rationale for their use.

- Section 3, in analyzing dependence on foreign suppliers, reviews the transformer market, including its overall size, domestic and foreign sources, the manufacturers involved, and other material and labor issues.

- Section 4 presents specific recommendations for the development of MTS systems that can serve a vital role in protecting the Nation's electrical infrastructure.

2. Rapid Restoration of Electrical Service

2.1 Technology Overview

2.1.1 Description of Grid

The U.S. transmission grid is made up of power lines that operate at a wide range of voltages and power-carrying capacities. Figure 1 shows a simplified arrangement of the grid system in the United States. At the electric-generating plant**,** the three-phase power leaves the generator and enters a generator step-up (GSU) transformer located in the transmission substation, which is typically adjacent to the generator building. This substation uses large GSU transformers to convert the generator's voltage (which is at a nominal 25-kV level) up to high-level voltages (115 to 765 kV) for economical, low-loss, long-distance transmission on the grid.

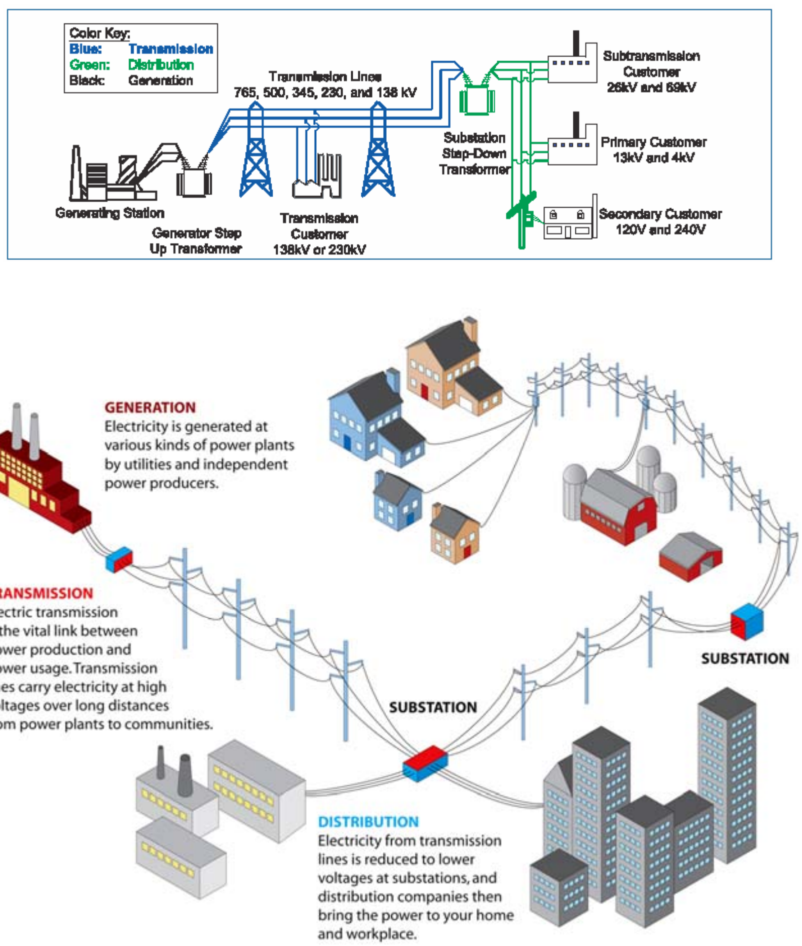


Fig. 1. Electric grid representation.

Following transmission, the voltage is stepped down at least once in order to distribute the power. Heavy industry may take power at transmission-level voltages, but most commercial and all residential service will have voltages stepped down at substations to the distribution voltages (2.5 to 35 kV). Finally, there are transformers mounted on poles or within the buildings to lower the levels even further for use by the end-users, typically 120/240 V, 280/440 V in residential and commercial end use.

At every point where there is a change in voltage, a transformer is needed that steps the voltage either up or down. There are essentially five levels of voltages used for transmitting and distributing AC power (Table 1): Ultra-High Voltage (UHV, 1100 kV), Extra-High Voltage (EHV, 345 to 765 kV), High Voltage (HV, 115 to 230 kV), medium (or sub-transmission) voltage (MV, 34.5 to 115 kV), and distribution voltage (2.5 to 35 kV). The UHV, EHV, HV, and MV equipment is mainly located at power plants or at electric power substations in the electric grid, while distribution-level transformers are located in the distribution network on poles, in buildings, in service vaults, or on outdoor pads.

Table 1. AC voltage classes

Transmission Voltages		Distribution Voltages	
Class	kV	Class	kV
Medium Voltage (MV)	34.5	2.5	2.4
	46	5	4.16
	69	8.66	7.2
	115	15	12.47
High Voltage (HV)	115	25	22.9
	138	35	32.5
	161		
	230		
Extra-High Voltage (EHV)	345		
	500		
	765		
Ultra-High Voltage (UHV)	1100*		

*1100 kV is not presently used in North America.

2.1.2 Description of Substation

A substation is a high-voltage electric system facility. It is used to switch generators, equipment, and circuits or lines in and out of the system. It is also used to change AC voltages from one level to another. Some substations are small with little more than a transformer and associated switches. Others are large with several transformers and dozens of switches and other equipment. The electricity flow through a substation is illustrated in Figure 2.

Source: OSHA

Fig. 2. Substation overview.

A typical substation is illustrated in Figure 3. Three transformers, each with a nominal 25-MVA rating, reduce voltage from 69 to 13.8 kV. Note the cooling radiators and bushings on the tops of the transformers; both are subject to damage during severe weather such as tornados or hurricanes. Such damage is often repairable in the field, and spare equipment is kept in inventory. In addition, the redundancy in this substation and sister substations a few miles away constitute modern utility practice in urban environments. This substation serves several shopping centers, an office park, and several residential subdivisions. The substation is relatively compact but has room for perhaps one additional transformer.

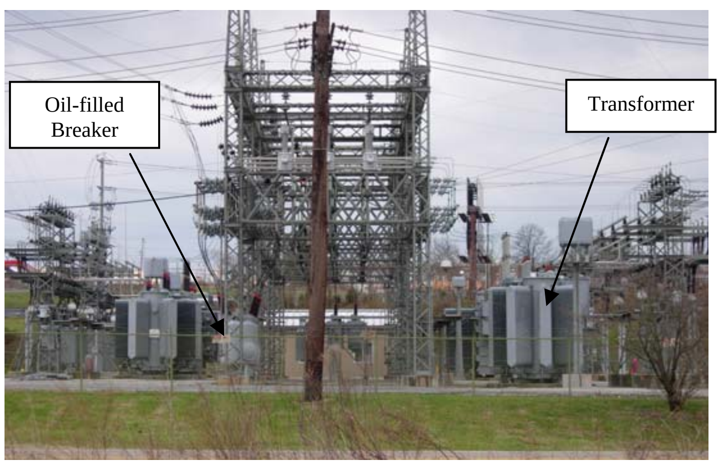


Fig. 3. A utility substation using modern oil-filled transformers.

In Figure 4, the two medium-sized, 3-phase, 161-kV power transformers each have an estimated oil natural-air-forced flow (ONAF) capacity of 50 MVA. The extensive cooling fans on the radiators indicate that this station expects a relatively high load during peak conditions (usually summer). This substation is one of the sister substations to the substation shown in Figure 3.

Should the need arise, there is adequate room for expansion and the placement of a MTS for maintenance or parallel service.

Fig. 4. A utility substation with both modern transformers and bus structure.

2.1.3 Types of Transformers

For transformers, the key parameter is more often the amount of power that can be transferred rather than the voltage. This parameter is measured in volt-amperes (VA) and incorporates both the real power (measured in watts) and reactive power (measured in volt-amperes reactive or VAR) because of the nature of the three-phase alternating current. Figure 5 identifies some typical customer power requirements. However, not all load within a facility is considered critical. While a hospital (especially trauma center) has peak load of 0.5-2 MVA and has full back-up generation, a semiconductor manufacturing plant may have only 1-2 MVA critical in a 30 MVA peak. A refinery or large chemical plant can easily have a load larger than 100 MVA, but would often generate its own electricity.

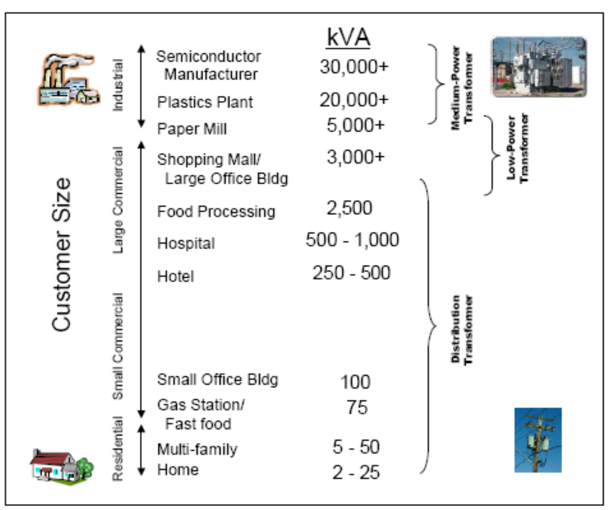


Fig. 5. Customer power requirements.

High-power transformers are defined as those with a rating over 100 MVA (megavolt-amperes), while medium-power transformers are between 10 and 100 MVA. Low- or small-power transformers are 1 to 10 MVA. The range of low-power transformers overlaps the large-distribution transformers (1 to 5 MVA), but low-power transformers have high-side voltages that are sub-transmission level or higher. Because of this overlap, estimates of small-power and large-distribution transformers may be "double counted" in inventories; hence, no reliable estimate of the number of these sized transformers is available.

Transformers with distribution voltage levels are also called distribution transformers and are commodity items. Distribution transformers are relatively small, ranging in size from "bucket size" to a few cubic meters (5 kVA to 5 MVA); they are easily replaced and are stocked for emergency purposes by both utilities and electrical supply wholesalers. Both liquid and dry types are used by industrial/commercial facilities. Because of higher efficiency, longer life, lower weight/volume, and predominant outdoor use, utilities employ essentially all liquid/oil transformers. Distribution transformers are not considered further in this report.

All power transformers are large, heavy, expensive, and generally use a paper/oil–based or hybrid paper/oil/solid insulation system. High-side voltage levels range from 35 to 765 kV. Prices for even the smallest units approach $100K, and several 100–200 MVA units easily sell for $1M. The large (up to 1100 MVA) GSU and HV transmission units are now approaching $3–5M or higher. Medium-power transformers for use in conventional substations have a nominal price of about $600K for a 50-MVA unit, but prices vary according to specifications, such as desired loss level and associated value of losses (A and B factors), impedance requirements, tap changers, cooling requirements, and accessories.

In high-load-density applications, transformers in most generating, transmission, and sub-transmission substations are installed or configured within the network in a manner that provides redundancy (so called N-1 and N-2 contingency). Within a substation, multiple units provide either parallel operation or allow for fast load transfer. In addition, there is often a spare in the substation or a system spare stored in a convenient central location. The latter method, however, requires the ability to transport (large units often weigh more than 50 tons and require rail transport and heavy lifting capability) and to install the spare at the required location, a process that can take several weeks. In lightly loaded suburban and rural areas, a substation may have only one transformer and essentially no contingency, which means that the load served is at risk of long-term outage if the substation or switchgear is damaged beyond repair. An example of this situation is provided later in this report.

Other distinguishing parameters of transformers are their insulation type (dry paper/oil based, also called liquid based, and hybrid liquid/non-paper systems), number of phases (one or three phase), adjustability (mechanisms for varying voltage and phase output), portability, core/coil configuration (shell or core form), and winding configurations (dual or auto). Transformation of power between voltages also requires extensive equipment such as disconnect switchgear, cooling systems, monitoring equipment, breakers, voltage adjustment equipment (tap-changing devices), and lightning arresters. Until recently, all medium- and large-power transformers were paper/oil or mixed insulation systems. A recent development by ABB allows the use of dry insulation for medium-power transformers (to 42 MVA) operating at 69 kV. This report only considers power transformers, specifically addressing mobile substations or portable transformers that nominally are rated at 5 to 100 MVA with HV ratings of 230 kV or lower.

2.1.4 Description of Mobile Transformers and Substations

In the usual stationary or fixed applications, the transformers, switchgear, protective systems, and station back-up power can be spread over a large area for insulating, safety, and maintenance purposes. In contrast, the mobile system is generally self-contained and mounted on a large trailer. Figures 6 and 7 show a typical mobile substation with some of the ancillary equipment. The units are generally mounted on mobile trailers (or possibly, in some special cases, on flatbed railcars). In most cases, special permits are still required to move the units because of the large weight. Differing state transportation load limits on non-Federal local roads further complicate the issue.

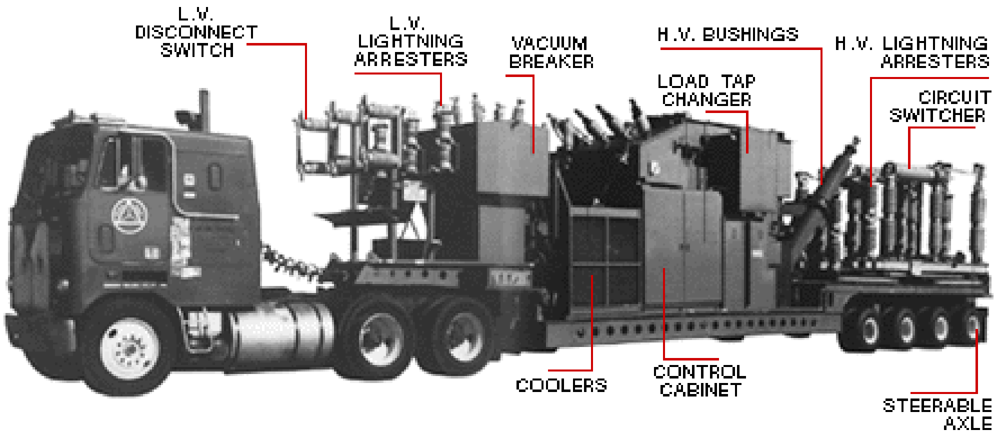


Figure 6. Components of mobile transformer.

Figure 7. Mobile substation in transit.

Mobile transformers are used by utilities to temporarily replace transformers that are out of service either for maintenance or because of forced outage. Mobile transformers are most widely available in the medium-power range (10 to 100 MVA) with HV ratings to 245 kV. Large-power transformers or higher-voltage transformers are too large to be mobile either because of physical dimensions or weight.

As described in the *Standard Handbook for Electrical Engineers* (Fink and Carroll, 1969), the mobile unit is designed to be a multi-purpose package delivering maximum kVA for allowable weight. Performance and design criteria vary considerably from those of a conventional transformer. The margin between the operating voltage level of the insulation structure (BIL) and the operating voltage is generally smaller, the average winding temperature rise over ambient is generally higher, the overload capability is less (*If only oil/paper is used. It should be noted that for modern Nomex® or hybrid systems, this is not true.*), and losses and impedance tend to be higher. The circuitry of the mobile unit is generally more complicated, in order to meet a variety of operating situations in a particular utility system.

Typical mobile transformer characteristics are shown in Tables 2 and 3. High-side voltages range from 35 to 245 kV with sizes ranging from 5 MVA to 100 MVA. Estimates by transformer manufacturers indicate that there are roughly 500 to 600 mobile transformers in service (slightly greater than 1% of the medium-power transformer inventory). Some of these transformers are quite old but are still serviceable because the number of hours that the mobile transformers are used is much lower than that of fixed installations. Because the mobile units operate at a higher power density than stationary units, losses are higher and, consequently, utilities use them only until a suitable stationary unit is obtained. According to manufacturers of mobile substations, the cost is about three times the cost of the fixed transformer alone. However, this includes the trailer, switchgear, breakers, emergency or station power supply, a compact high-power-density transformer, and enhanced cooling capability.

Table 2. Comparison of mobile and fixed transformers

	Mobile	Fixed
Insulation	Nomex®/Oil	Paper/Oil-Nomex®
Trise (°C)	Up to 115	65
Flux Density	1.78	1.5–1.75
Current Density	4 kA/cm^2	0.25–0.5 kA/cm^2
Loss Evaluation	No	Yes
Full Load Losses	1.5%	<0.5%
%Z	12–15%	<10%
Breakers	Yes	Substation
Switches	Yes	Substation
Auxiliary Power	Yes	Substation

Table 3. Mobile transformer characteristics

	Low	Nominal	High
MVA Rating	5	25	100
HV (kV)	35	115	245
LV (kV)	5	15	115
Total Weight (1000#)	50	95	150

2.2 Mobile Applications

2.2.1 Rationale for Use of Mobiles

Many of the critical infrastructures in this country rely heavily on electric power for their continued operation. Certain infrastructures, including the communications industry, public health, and government services such as first responders in emergencies, have a crucial role to play in a rapid response to outages. However, the critical infrastructure that would deal most directly with MTS systems is the electric power industry, which owns and operates the substations in which MTS systems would be used to replace lost equipment.

The electrical grid is a tightly integrated network that requires precise operation of all components to safely and efficiently provide power to end users. While the vast majority of outages are due to power line failures, the grid is also highly vulnerable to disruption at substations, where multiple lines intersect. Because substations are nodal points, a single failure can impact a large number of end users. There are thousands of substations across the country, and in any year, transformers at some of these will fail or be pulled from service. Unexpected failures can seriously disrupt the grid in the surrounding territory. As indicated earlier, there is usually sufficient redundancy in the system to withstand most single-transformer failures; however, substations serving low-load-density areas may not have sufficient contingency to overcome the loss.

MTS systems are used for a variety of reasons within a utility. However, the losses and costs associated with these systems are generally too high for them to be used as long-term replacements. In addition, MTS systems have lower impedance, which results in higher fault currents, leading to greater stress on grid components such as breakers. Rather, utilities utilize MTS systems for their main advantage—their rapid deployment capability (roughly 12 to 24 hours). Their flexibility allows them to be switched from one task to another relatively easily and is in fact a main rationale for a utility to own and operate a MTS. The potential purposes of an MTS include the following:

Planned maintenance
Temporary substation capacity increases
Forced outage repairs
Weather and other natural outages
Sabotage and attacks

Planned Maintenance

MTS systems are used on a day-to-day basis within the utility to provide alternate capacity during planned maintenance of substations. Because it is desirable to have MTS systems available for emergency duty during peak loading or extreme weather conditions, utilities schedule their planned maintenance around the time when MTS systems are less likely to be needed for emergency use. Since the utility will have only a limited number of MTS systems, substation repairs must then be staggered or delayed due to unplanned substation transformer outages.

Temporary Substation Capacity Increases

MTS systems may be called upon when an area may be faced with a temporary load increase that is not expected to last more than several months or perhaps a couple of years. Examples are construction projects or major plant modifications that require high electrical loads that will drop following completion. Special events can boost the capacity needs for a short time period. An MTS can be used to avoid the cost of a permanent upgrade that would rarely be used. Another example is to rapidly provide increased substation capacity during peak load conditions prior to substation upgrades, in the case where equipment deliveries were delayed or other problems arose that slowed the capacity expansion.

Forced Outage Repairs

One of the main areas in utility systems where MTS systems could reduce vulnerabilities is in medium-voltage rural areas without redundancy. Often the grid in these areas is topologically in a radial arrangement that does not allow for the redundancy of parallel circuits. Loss of a substation or even a key transformer within the substation can cause significant supply problems downstream. The Dyersburg example described in Sect. 2.2.3 shows the social and economic impact of the loss of a substation in regions that do not have multiple feeds.

Unplanned repairs can be called for due to existing equipment failure, weather phenomenon, or intentional disruptions. Equipment failure is the most common rationale for deployment. Lightning can cause a delayed failure or accelerate the aging of critical elements of the transformer. As transformers age, an increasing percentage of them can face sudden failure. Utilities attempt to monitor transformer conditions such as oil chemistry or load profiles to predict impending failure, but for many reasons, unexpected failures can still occur.

Subsequent to forced outages there are startup issues that should be addressed. The IEEE *Recommended Practices for Emergency and Standby Power Systems for Industrial and Commercial Applications* (IEEE, 1987) contains words of caution in the section on startup power. Paragraph 3.3.6 applies to all mobile equipment of all types in emergency situations: “Mobile equipment may suffice if it can be reasonably assumed to be available when needed. (Who has the highest priority when all have the need?)” Section 4.5.6 of the same standard suggests rental equipment as a viable alternative if mobile power is found to be too expensive (IEEE, 1987).

Weather and Other Natural Outages

Weather and natural disasters are the main cause of electrical outages, although most often these have a larger impact on the power lines leading to and from the substations than on the substations and transformers themselves. Some natural disasters can harm substation operations and create a need for MTS systems. The most likely are intense thunderstorms and tornados. Tornados are powerful enough that if they strike a substation, the equipment will generally be destroyed and require replacement. Floods also can cause massive damage either from the force of the water or shorting out and thus damaging equipment. It is generally flooding or flying debris that causes damage during hurricanes since substations can be designed to withstand hurricane-level winds.

Sabotage and Attacks

Intentional disruptions such as sabotage could severely harm our Nation's electrical grid, and most substations are very vulnerable to attack. Substations are usually unmanned, remote, exposed, and have few physical barriers. Utilities rely more on redundancy of the grid for mitigation rather than on hardening of individual sites. The larger sites frequently have personnel and improved protections, but the consequences of loss of these large sites are comparatively greater as well. There are few options available for the replacement of a destroyed high-power transformer. While MTS systems as large as 100 MVA exist, MTS systems are typically below 50 MVA in size, with high-side voltages not exceeding 230 kV. High-power transformers, as described above, are greater than 100 MVA and can have high-side voltages of 345 kV or higher and at present can not be backed up by MTS.

MTS systems can play a crucial role in several scenarios involving deliberate attacks. The ultimate target may be a critical infrastructure with limited access to electric power through just one or two medium-power substations. If the facility is vital to area health or other social needs and its substation links are destroyed, MTS systems may be useful in returning the facility to normal operations more quickly. This may be especially true if the attack strikes several substations, perhaps in order to bring down portions of a large urban area. The choice the utility must make is generally between mobile substations and either fixed or mobile emergency generation. Even with the use of emergency generation, small mobile transformers may be called upon to adjust voltages in the area, or to mitigate prolonged disruption.

2.2.2 Industry Experts' Interviews

A number of utility personnel and consultants were interviewed to determine the appropriate role that MTS systems play within their company. They identified the categories above as potential uses for MTS systems, with the main use being substation repair and maintenance. Construction and maintenance schedules are based on the availability of their MTS, and any delays can cause a domino-like rescheduling of other work.

The utilities may share their equipment within their own distribution utilities, but there did not appear to be much sharing of the equipment with other utilities. In some cases, they lease equipment to preferred customers at reasonable rates. One utility representative mentioned that a transformer serving a coal mine within his utility's territory had failed and that a MTS was used to provide continued operation.

One consultant familiar with the industry noted that MTS systems had been used for rebuilding and construction in substations, as temporary substations during construction of a new substation, for handling temporary loads that are transient in location like highway construction, and in military applications. Temporary substations had also been needed for new developments where line construction and new substations are behind the budget curve (sometimes for several years). Other utility representatives indicated that mobile systems were used for transformer failure replacements (up to 6 months), feeding isolated areas where service may be curtailed at a later date. A consultant noted that in areas hit by disasters like Hurricane Katrina, these units "are a Godsend." Since large-utility-class transformers require a 6-month to 1-year lead time in a normal economic environment, mobiles are very helpful in these situations.

2.2.3 Examples of Uses of MTS

Dyersburg, Tennessee

Rural areas typically have electric load density that is both lower and less critical than urban areas. Often substations will have only a single transformer or at best a set of four single-phase units that provide back-up for a single-phase failure. In addition, these rural areas are a radial configuration, which often means that substations have no redundant substation. In April 2006, a set of tornados swept through the area surrounding Dyersburg, TN resulting in major damage to one substation in the area near New Bern, TN. As shown in Fig. 8, the substation, a 161/13.2 kV, 10/13/16 MVA unit, was completely destroyed leaving the town of New Bern and a nearby industry without power, idling some 900 employees. Service was restored using a mobile transformer from the TVA while a new substation is constructed. (Smith-King of *Jackson Sun*, Photo and data from Patterson (TVA), Nashville Electric Systems)

Fig. 8. Biffle Road substation tornado damage, near Dyersburg, Tennessee.

Coleman National Fish Hatchery, California

On July 9, 2003, with temperatures in the Central Valley of California topping 100°F, a transformer failed at the Coleman National Fish Hatchery south of Redding. As planned, the emergency back-up generators kicked in to supply power, and Western Area Power Administration crews immediately began efforts to repair the transformer but were unsuccessful. Western maintains the power facilities that serve the hatchery under a contract with the Bureau of Reclamation; the U.S. Fish and Wildlife Service operates the hatchery. The hatchery releases about 12 million fall-run chinook salmon smelts, 1 million late-fall-run chinook, and 600,000 steelhead trout each year. The steelhead trout is on the threatened and endangered species list, and the chinook are possible candidates for the list. The two diesel back-up generators that were used burned 766 gallons of diesel a day, an additional expense and source of air emissions. On July 14, Western decided to install a mobile substation housed at the nearby Olinda Substation.

On July 15, the mobile substation was delivered to the hatchery. Maintenance crews started connecting the Pacific Gas and Electric (PG&E) power lines to the mobile substation and the lower-voltage lines from the mobile substation to the hatchery equipment. By July 16, the mobile substation had been connected, but crews encountered problems when it was energized. Fortunately, those problems were resolved, and the mobile substation was carrying the hatchery load by the afternoon of July 17. The mobile substation, mounted on a 60-foot flatbed, included a transformer that could be set for the 60- to 12-kV voltage change needed at the hatchery.

Fig. 9. Coleman National Fish Hatchery *(Source: FWS)*.

Chicago Loop

On April 13, 1999, subbasements in the Downtown Loop of Chicago, Illinois, were flooded due to construction in tunnels under the Chicago River. Power was shut off at the substations to avoid shorting out the systems. In response, businesses rented numerous diesel-generating sets to provide power to individual buildings. Patten Power Systems alone provided 35 generating sets representing 15 MW of power. Some locations also brought in mobile transformers to allow the transformation of power from emergency generators to lower voltages needed within the buildings. However, these transformers were of distribution-level size, in the 500-kVA range, rather than the larger MTS systems.

Sturgis, South Dakota

Black Hills Corporation in Rapid City, South Dakota, provides power for the western South Dakota region. Included in their territory is Sturgis, South Dakota, where for 1 week each summer the Sturgis Motorcycle Rally is held. This enormous gathering of motorcycle riders from around the country can expand the population of the town from 6,400 to over 500,000. A representative of the Black Hills Corporation has said that they use an MTS to increase the power capacity during this time.

Vermont Electric Power Company

Vermont Electric Power Company, which provides transmission service to several area distribution utilities, maintains an MTS system for use in its region. In designing the mobile system, locations and road approach limitations to substations had to be taken into consideration so that the vehicle carrying the mobile system would have adequate clearance. Figure 10 shows a typical arrangement for an MTS system at one of the substations (Wright, 2003). This 115- to 39-kV substation has a single transformer and would need an MTS system to be back online quickly. The utility had purchased a transportable 50-MVA transformer in 1974. In 2001, they redesigned the truck and support equipment to make it more mobile and easier to set up in the event of a power emergency.

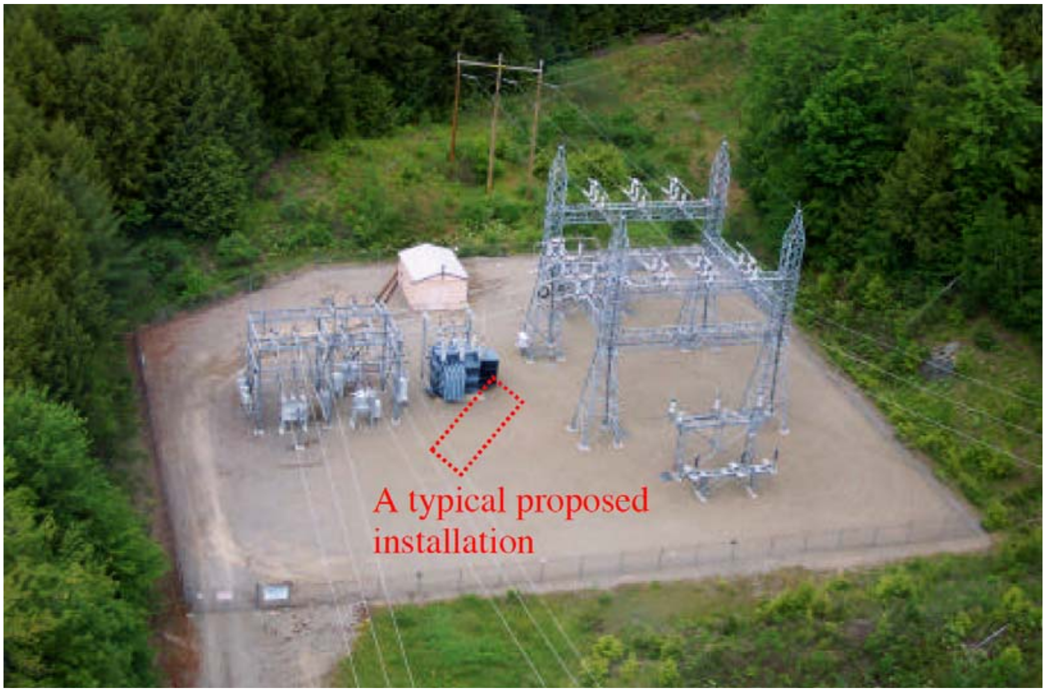


Fig. 10. MTS proposed position within Vermont Electric substation.

2.3 Potential Applications in Government

The most obvious users of MTS systems within the Federal Government are the Federal electric utilities, such as the Tennessee Valley Authority (TVA), Bonneville Power Authority (BPA), and Western Area Power Administration (WAPA). These utilities currently use MTS systems for their own systems or those of their distribution utility customers. They may either directly own the systems or have agreements with their distribution utility customers that allow them to use the systems as needed. The Dyersburg and Coleman National Fish Hatchery case studies, discussed in section 2.2.3, are examples of MTS use by TVA and WAPA.

MTS systems are a small fraction of the overall transformation capacity. They cannot be expected to supplant a large fraction of total government transformation requirements. The highest priority government functions already have in place on-site generation and/or redundancy in connections to the grid. The MTS systems can provide a tertiary line of defense to the critical facilities.

2.3.1 Military Bases

Military bases can have power systems that are about as large as a town. The systems are often old and yet in some cases could be critical to our Nation's national security. In the 1990s, Congress established a policy for privatization of the utilities at military bases. As a consequence, many of the systems have been sold to contractors or the local utilities.

The Department of Defense Energy Security Policy since 1992 has stated the following:

> Policy: It is a basic responsibility of Defense managers and commanders to know the vulnerability of their missions and facilities to energy disruptions, whether the energy source is internal or external to the command. Lastly, it is essential to take action to eliminate critical energy support vulnerabilities. (Morales, 1992)

According to the Department of the Army's Installation Management Agency (Wilberger, 2004), military facilities are required to develop energy security plans for their facilities, which should be integrated into the installation security plans.

> In general, these energy security plans should address utility system vulnerability, emergency preparedness requirements, and remedial actions needed to protect against potential problems. Energy security plans should be consistent with the Army's strategy to privatize utilities and reduce the cost of operating and maintaining the utility infrastructure. Installations should clearly define their utility requirements and partner with their local utility suppliers to meet them. Any remedial actions that run counter to utilities privatization, in terms of ownership and operation, must be approved by ASCIM [the Assistant Chief of Staff for Installation Management]. (Wilberger, 2004)

Based on these directives, military facilities are to work with their local utilities in ensuring that adequate infrastructures are in place. Rather than own and maintain its own utility equipment, the strategy is to encourage the privatization of infrastructure. Because the substation and downstream infrastructure on the bases would be owned by the local utility and if MTS were deemed necessary in specific cases to ensure energy security, it could be advantageous for both the military and the utility to jointly invest in an MTS system. The military base may be of such criticality that a spare substation/transformer would be useful, while having such a system mobile could also be advantageous to the utility since it would then be available in the event of other substation outages.

2.3.2 Other Federal Government

On Dec. 17, 2003, President Bush signed Homeland Security Presidential Directive (HSPD) - 7 that sets the policies of the Government with regard to critical infrastructure. The policy states the following:

> (7) It is the policy of the United States to enhance the protection of our Nation's critical infrastructure and key resources against terrorist acts that could:
>
> (a) cause catastrophic health effects or mass casualties comparable to those from the use of a weapon of mass destruction;
> (b) impair Federal departments and agencies' abilities to perform essential missions, or to ensure the public's health and safety;
> (c) undermine State and local government capacities to maintain order and to deliver minimum essential public services;
> (d damage the private sector's capability to ensure the orderly functioning of the economy and delivery of essential services;
> (e) have a negative effect on the economy through the cascading disruption of other critical infrastructure and key resources; or
> (f) undermine the public's morale and confidence in our national economic and political institutions.
>
> (8) Federal departments and agencies will identify, prioritize, and coordinate the protection of critical infrastructure and key resources in order to prevent, deter, and mitigate the effects of deliberate efforts to destroy, incapacitate, or exploit them. Federal departments and agencies will work with State and local governments and the private sector to accomplish this objective. (White, 2003)

Furthermore, HSPD-7 directs all agencies to address the vulnerabilities within their own domain.

> (24) All Federal department and agency heads are responsible for the identification, prioritization, assessment, remediation, and protection of their respective internal critical infrastructure and key resources. Consistent with the Federal Information Security Management Act of 2002, agencies will identify and provide information security protections commensurate with the risk and magnitude of the harm resulting from the unauthorized access, use, disclosure, disruption, modification, or destruction of information. (White, 2003)

Similar to the military bases, most other components of the Federal Government are end-use customers for electric power, and are not involved at the level that would put them in control of substations where MTS systems would be applicable. Essential functions are supported by back-up generation. However, if there is a federal facility that is large enough to require a significant fraction of a substation’s output, has a critical need for power, is isolated on the grid, does not have uninterruptible power supplies, redundant transfer to alternate power feeds or on-site back up generation, and that a spare transformer would significantly increase their energy security, then a joint ownership agreement of an MTS with the local utility could be considered. As with the military base example, the MTS would be useful to the facility for redundancy and of potentially more value to the utility than a spare transformer because of its mobility.

2.3.3 Communications Industry

In June 2006, the Federal Communication Commission released a report on the impact of Hurricane Katrina on telecommunications and media infrastructure. While the panel's report emphasizes the severe damage the storm and its aftermath caused to communications systems, it also found that the utility communication systems did not have a significant rate of failure because: 1) the systems were designed to remain intact to aid restoration of electric service following a significant storm event; 2) they were built with significant on-site back-up power supplies (batteries and generators); 3) last mile connections to tower sites and the backbone transport are typically owned by the utility and have redundant paths; and 4) the staff responsible for the communications network have a focus on continuing maintenance of network elements (for example, exercising standby generators on a routine basis). (Section 1(A)(9))

Telephone systems (and now most cell sites) do not depend on the grid to function. While MTS systems may play a role in defending against prolonged outages, they fall behind uninterruptible power supplies, redundant transfer to alternate power feeds, and on-site generation as the tools of choice for guaranteed electric service immediately after a disruption.

2.3.4 State and Local Government / First Responders

State and local governments are responsible for initial recovery following a disaster. First responders include the local police, fire, emergency medical services (EMS), and state highway patrols. Typically, the facilities of the first responders have internal redundant power systems (if critical enough) or back-up generation to enable them to function as long as fuel is available. These organizations would not directly deploy MTS systems, but rather would assist the local utility in its restoration efforts. MTS systems would be most helpful in restoring power to broader, less critical facilities. However, there may be occasions in rural areas where multiple critical first-responder facilities are on a non-redundant distribution system, so the substation feeding the line may have a priority need for an MTS.

3. Reducing Dependence on Foreign Suppliers

3.1 Market Characteristics

In determining the feasibility of utilizing MTS systems to reduce dependence on foreign suppliers, it is important to understand current market conditions and characteristics of the transformer industry. Several key questions will be addressed, including the following:

- What is the overall size of the transformer market?
- How many units are installed and who manufactures them?
- How many transformers need to be manufactured each year?
- What is the relationship between the U.S. market and the worldwide market?
- How much of the market is domestically produced?
- What is the market for MTS systems as one component of the overall transformer industry?
- What are the material and other supply limitations?

3.1.1 Size of Transformer Market

Peak electricity demand in the United States in 2004 was 700 GW (NERC, 2005). Assuming that an average of 2.5 medium- or large-power transformations are required from power plant to distribution system and an average size of 35 MVA per transformer, this suggests that there are roughly 50,000 high- and medium-voltage transformers in the United States. The total size of the installed transformer base is shown in Table 4. Looking at historical power demands and applying the formula above on the estimated number of transformers needed, the total number of transformers required in the future is expected to increase. In the past several years, power transformer sales have lagged behind electric growth as the industry adjusted to deregulation. Combining new demand and replacement of failures, one could expect a growth in transformer sales of 4% in future years, and sales figures for the recent past support this conclusion.

Table 4. National transformer statistics (best engineering estimates)

	Voltage range (kV)	Power range (MVA)	Number	Average age
Large Power	115–765	200–1200	2500	40+
Medium Power	65–345	10–100	45000	35+
Low Power	35–69	1–10	5000	25+
Mobile Power	35–245	1–100	600	20+

Given a total installed market of 50,000 transformers, a 2% growth rate in electricity demand would require an additional 1000 transformers each year even without a replacement market. (Ref. Manufacturer Communications)

In addition to normal load growth, transformers are also needed to replace failures in the existing inventory. Power transformers are generally considered to be long lived. Utilities routinely depreciate them over 20 years for accounting purposes and use 30-year periods in planning analysis. However, Bartley and James estimate that units may be failing earlier in life than conventional wisdom indicates, with average life at failure being about 14 years for all applications and 18 years for utilities (Bartley 2003a). However, the average age of the presently installed units is over 40 years, and there are some in use that are over 70 years old. The age issue and predicted increase in failures (Bartley 2003a) suggest a possible need for mobile transformers for emergency and maintenance support. These MTS would temporarily supply load following failures or assist heavily loaded substations during peak conditions, thereby lowering the stress placed on older units.

Figure 11 shows the annual installation of transformer capacity through 1996 (Bartley 2003b), and Fig. 12 shows an analysis of the failure rate of transformers as a function of age (Bartley 2003a). This data would indicate that failures may be occurring earlier than anticipated, and hence production beyond the nominal growth rate may be needed.

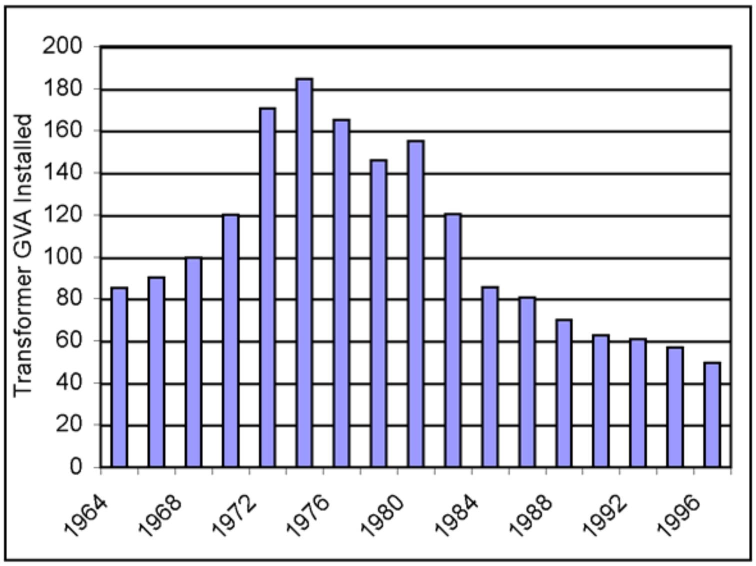


Fig. 11. Gigavolt-ampere (GVA) of transformer installations by year.

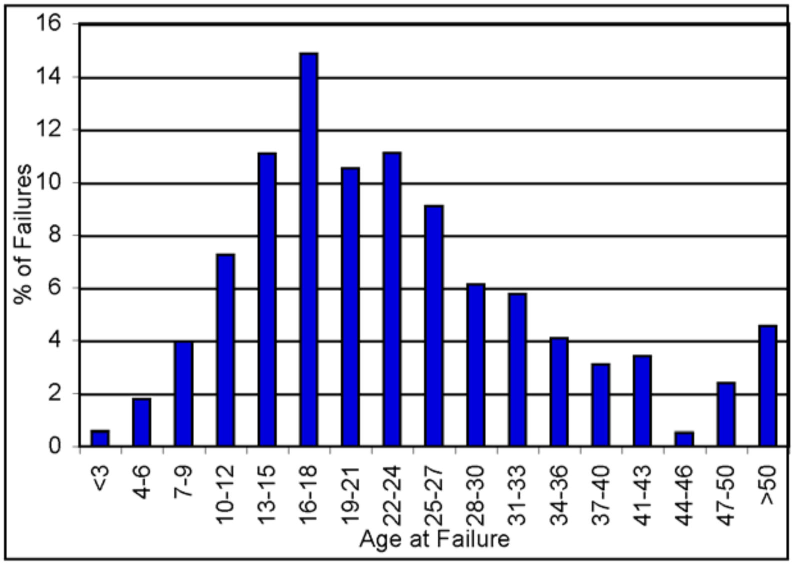


Fig. 12. Age of transformer at failure.

Combining the failure projections from Bartley's paper with continued installations of only 25 GVA/year between 1996 and 2006 (consistent with the 1996 installation amount) and failures based on Fig. 12, the resulting level of failures in GVA is shown in Fig. 13. At 4.9 GVA of transformer failures in 2006, the country would need 140 additional 35-MVA transformers in addition to the 1000+ needed for new growth, and, as seen in Fig. 13, these amounts will continue to grow.

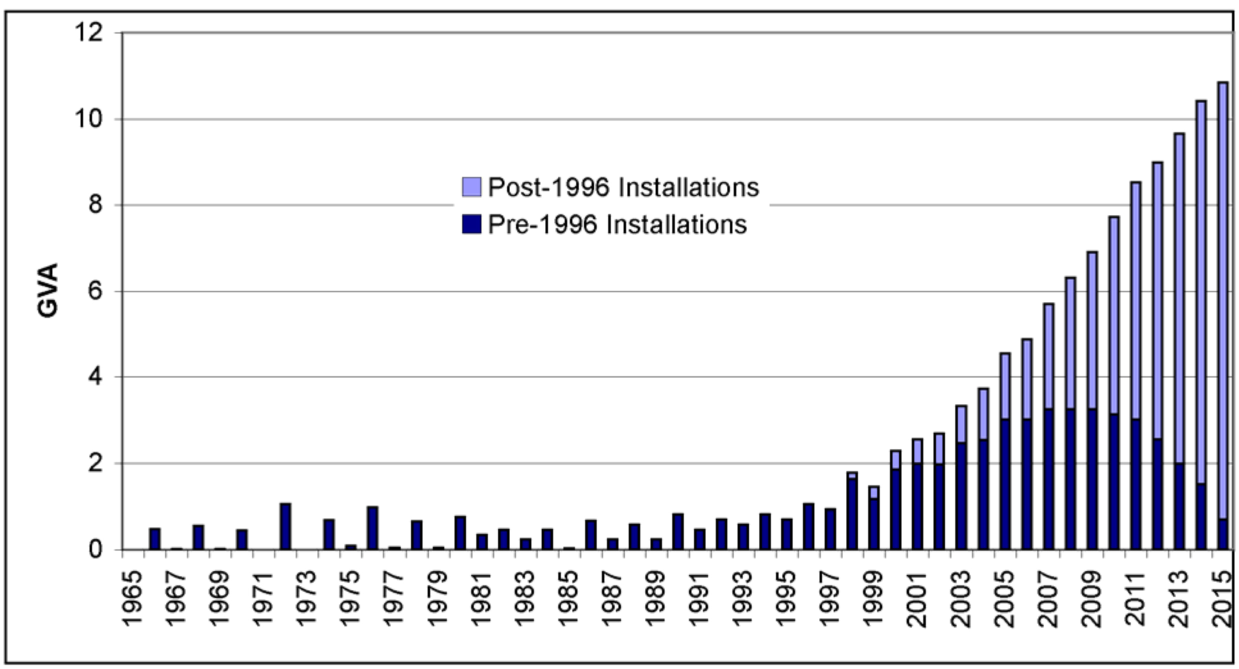


Fig. 13. Failure projections.

Although the U.S. annual market for transformer sales is 1100 to 1200 per year, MTS systems will only be a fraction of that total. Current MTS markets are limited due to the cost and inefficiencies of the systems compared with non-mobile equipment. While MTS systems are extremely valuable when rapid restoration or other short-term service is required, they are not viable replacements for stationary substations. Currently, there are an estimated 600 MTS systems in an overall U.S. market of around 50,000 transformers, or 1.2%. As increasing numbers of transformers age and fail, and as electric reliability becomes more critical to the Nation's economy, the use of mobile transformers in proportion to total transformers could increase.

3.1.2 Breakdown of Market by Manufacturer

The main manufacturers of medium-power transformers are Waukesha Electric Systems, Kuhlman Electric, ABB, GE Prolec, and Delta Star, while ABB, VA Tech, GE Prolec, Hyundai, Seimens, HICO, and Pauwels supply large-power transformers. Mobile substations are generally a subset of the low- and medium-power transformer market. Among mobile transformers, the major manufacturers are Delta Star, Pauwels, Kuhlman, and ABB, with Delta Star being the largest. Mobile transformers can either be built directly as mobile or, in some cases, older transformers can be refurbished and made portable.

Tables 5 through 8 quantify the North American transformer market. Over 80% of the medium–power transformer North American market is manufactured in the United States.

Table 5. Large-power transformer manufacturers

Company	% of North American market	Manufacturing location	
		United States	Offshore
ABB	27–29	Y	Y (Worldwide)
Seimens/VA Tech	22–24	N	Y(Worldwide)
GE-Prolec	11–13	N	Y(Mexico)
Hyundai	10–12	N	Y(Korea)
HICO (Hyosung)	<5	N	Y(Korea)
Pauwels	<5	N	Y(Belgium)
Waukesha	<5	Y	N
VTC	<4	N	Y(Mexico, India)
Kuhlman	<3	N	Y(Mexico)
Mitsubishi	<2	N	Y(Japan)
PA Transformer	<2	Y	N
Areva T&D	<1	N	Y (France)
Compton Greaves	See Pauwels	N	Y(India)

Table 6. Medium-power transformer manufacturers

Company	% North American market	MTS	Dry (D)	Manufacturing location	
			Liquid (L)	United States	Offshore
Waukesha	34–36	N	L	Y	N
Kuhlman	17–19	Y	L	Y	Y(Mexico)
ABB	15–17	Y	L, D	Y	Y (Worldwide)
GE-Prolec	11–13	N	L, D	Y	Y(Mexico)
Delta Star	9–10	Y	L	Y	N
VTC	<3	N	L, D	Y	Y(Mexico, India)
HICO (Hyosung)	<2	Y	L, D	N	Y(Korea)
PA Transformer	<2	N	L	Y	N
Pauwels	<2	Y	L, D	Y	Y(Belgium)
Schneider (Sq.D)	<2	N	L, D	Y	Y(France)
Seimens/VA Tech	<2	Y	L, D	N	Y(Europe)
Compton Greaves	<1	N	L, D	N	Y(India)
Howard	<1	N	L	Y	N
Niagara Trans.	<1	N	L, D	Y	N
Hyundai	Y	Y	L, D	N	Y(Korea)

Table 7. Major low-power transformer manufacturers

Company	MTS	Dry (D)	Manufacturing location	
		Liquid (L)	United States	Offshore
ABB	Y	L, D	Y	Y (Worldwide)
Delta Star	Y	L	Y	N
HICO (Hyosung)	Y	L, D	N	Y(Korea)
Hyundai	Y	L, D	N	Y(Korea)
Kuhlman	Y	L	Y	Y(Mexico)
Pauwels	Y	L, D	Y	Y(Canada)
Seimens/VA Tech	Y	L, D	N	Y(Worldwide)
Compton Greaves	N	L, D	N	Y(India)
Federal Pacific	N	D	Y	N
GE-Prolec	N	L, D	Y	Y(Mexico)
Howard	N	L	Y	N
Niagara Trans.	N	L, D	Y	N
PA Transformer	N	L	Y	N
Schneider(Sq.D)	N	L, D	Y	Y(France)
VTC	N	L, D	Y	Y(Mexico, India)

Table 8. Mobile transformer manufacturers

Company	Estimated % of MTS market	Plant location	
		United States	Offshore
Delta Star	50	Y	N
Pauwels	25	N	Y(Canada)
Kuhlman	10	N	Y(Mexico)
ABB	5	N	Y(Europe)
Howard	<1	Y	N
HICO (Hyosung)	<1	N	Y(Korea)
Hyundai	<1	N	Y(Korea)
Seimens/VA Tech	<1	N	Y(Europe)

Mergers of several major manufacturers continue. The VA Tech and Seimens merger has received the European Union's approval, and Compton Greaves has acquired Pauwels. In the medium-power area, Waukesha has expanded its plants in Waukesha, Wisconsin, and is now an active player in the large-power market with the capacity to build up to 420 MVA and 345 kV. The recent opening of Howard Industries' new medium-power transformer plant in Mississippi suggests an anticipated increase in product demand for the sector.

While the size range (10–100 MVA) suggests that the manufacturer of portable transformers and MTS is a subset of the general medium-power transformer sector, the MTS system is a very specialized application that requires careful engineering and fabrication techniques that are significantly different from those for a fixed substation. While all MTS manufacturers are also players in the fixed market, the reverse is not true. The major manufacturers in the worldwide MTS market, such as ABB and VA Tech/Siemens, are not active in the North American market, but an increase in MTS demand could encourage them to enter.

Mobile transformers can be either single or three phase, and the unit may be the transformer alone (a portable transformer) or the complete substation package with breakers, tap changers, protective equipment, station power (battery and generator), and trailer.

In addition to the new transformer market, there are a few suppliers of used or rental transformers. Included are both low- and medium-power transformers and MTS. Guaranteed delivery times and lists of available inventory enable utilities and industry to preplan for forced outage replacement with guaranteed availability for these suppliers. Some of the players in this market are Aggreko/Sunbelt, Power Asset Recovery, GE, and Midwest.

3.1.3 Domestic as Compared to World Market

The world market for electrical equipment ($30.8B) is dominated by ABB, with a 23% share of world power products (Ref. ABB). For transformers, a $14.8B world market, the key manufacturers are ABB with 21%, Siemens with 11%, Areva with 6%, and Schneider with 6%. The power transformer share of the world transformer market is about 30%. This suggests that the present North American market is about 20% of the world's total power transformer market.

The ABB global market summary identifies the major issues for the electric grid. For North America and South America, there is an aged infrastructure that needs to be refurbished. In the United States, reliability concerns and passage of EPACT may trigger T&D investments. In Northern Europe, Central Europe, and the Mediterranean, there is a need for interconnections and power-grid upgrades that will require replacement and refurbishment. The power systems of the world are experiencing the highest growth in North Asia and China where continued strong government commitment to power infrastructure is creating the prospect of the world's most modern power grid. Also in South Asia and India, rural electrification is increasing demand for power distribution products and systems with a trend for quality and branding. In the Middle East and Africa, the oil and gas sector is the main driver for power T&D.

The largest and fastest growing part of the power transformer market is in China, India, and Asia. In fact the world's largest power transformer plant is located in Chongqing in central China and is being built by a consortium of ABB, Siemens, and the Chinese government. (Hein) This plant is one of the People's Republic of China's flagship factories, and not only will it be the world's largest transformer plant, it will also have the world's largest transformers, which are also being built by ABB. These units are supplied to the power plant at the Three Gorges Dam. ABB has stated that while the plant is not dependent on the production volume for the Three Gorges, it is supplying the 12 gigantic transformers for the right wing of the power plant at the dam. The average output of each transformer is 840 MVA, which is enough to supply a large modern city. Siemens and a Chinese vendor provide the 14 transformers on the other side of the project.

Mobile systems currently fill the market need for temporary, medium-voltage transformers and substations. Because they do not directly compete against foreign (or domestic) manufacturing of stationary transformers, mobile transformers, to some extent, complement foreign manufacture of stationary transformers because they provide a short-term solution until the foreign or domestic stationary transformer is delivered. The difference in travel time for domestic versus foreign-made transformers may only be a small factor in the overall time to receive the product. Price and proven performance are the two major issues for purchasers of power transformers.

3.1.4 Material and Labor Supply Issues

The main materials required in the manufacture of a transformer are the low-loss, high-silicon steel used for the core, the copper used for the windings, and the insulating materials.

Electrical steel, or silicon electrical steel, contains relatively high amounts (3 to 4.5%) of silicon. This addition enhances certain magnetic properties, leading to lower losses and high permeability. It is usually in the form of cold-rolled strips, called laminations, that are less than 2 mm thick.

There are two main types of electrical steel, grain oriented and non-oriented. Grain-oriented electrical steel usually has a silicon level of 3% and is processed in such a way that the optimum properties are developed in the coil rolling direction. Power transformers use grain-oriented steel to reduce losses. Electrical steel is usually coated to increase electrical resistance between laminations to lower eddy currents and to provide corrosion resistance. Main domestic suppliers of electric steel are AK Steel and Allegheny Ludlum. Electrical steel is also available from Japan, India, China, and the European Union. Variation in electrical steel prices can cause large fluctuations in transformer prices.

While aluminum windings are found in distribution transformers, the lower losses and physical properties of copper make it the only real choice for power transformer coils. Copper is a commodity that is traded on world markets, and as with electrical steel, the price of copper strongly influences the cost of power transformers. According to the Copper Development Association, Chile is the world’s largest producer, followed by the United States. The major producers of the wire used in transformers (magnet wire) are Phelps-Dodge and Algonquin Industries Division of Rea.

Several major corporations supply insulating materials. The key players are Weidmann Electrical Technology and Dupont. Dupont is the only supplier of the high-temperature insulation system Nomex® that is used alone and with paper/oil hybrid insulation systems for high-power-density, high-temperature operations.

Various analyses by manufacturers and independent market analysts have determined that there is a current and increasing shortage of basic transformer materials, namely, transformer steel and copper. Manufacturers indicate that over a two-year period, prices for copper have risen to $4/lb, a 450% increase, while high-grade H1 core steel has increased 50% over the last year to a nominal $2.87/kg. Since copper and steel are the major portions of the cost, power transformer prices have risen very sharply. The major explanation for this is the increased demand for all transformer materials in the Asian market. Following the law of supply and demand, the two domestic transformer steel manufacturers are currently supplying a large portion of their spot market product to the Asian and Chinese markets.

The production of power transformers is a labor-intensive process, and labor costs constitute 8 to 12% of a power transformer’s final cost. Power transformer manufacturers have moved many plants offshore to countries with low labor costs (Mexico, India, China, and Korea) that are also closer to the higher demand. While the technical skills needed are not commonplace, the workforces can be trained relatively quickly.

4. Conclusions and Recommendations

Rapid Restoration of Electrical Service

MTS systems can serve a vital role in protecting the Nation's electrical infrastructure. Their flexibility allows them to switch from one purpose to another relatively easily. When needed, the MTS enables temporary restoration of grid service while circumventing damaged substation equipment, allowing time to procure certain long lead-time grid components.

However, for seamless continuity of operation, it is critical that there is virtually a continuous supply of electricity. This can only occur through uninterruptible power supplies (e.g. batteries), redundant power feeds, and on-site generation. Yet, where disruption is prolonged due to equipment failure or total destruction from a war or act of terrorism, and especially where the problems are isolated to the substation, the MTS can play a critical role in reestablishing grid connections.

Supply for Prioritized Government Functions

Government facilities and local utilities know their systems' redundancy and needs. Local utility involvement is crucial since most components of the federal government are end-use customers for electric power and are not involved at the level that would put them in control of the substations where MTS systems could be applicable. For cases that have been identified through existing processes to have a need for additional redundancy and for which MTS systems make good economic and security sense, there may be some justification for the government to consider through single or joint ownership. However, because of the variety of ways emergency power can be provided, each case should be considered independently.

Regulatory

A fixed substation is considered part of the transmission and distribution (T&D) grid. Although mobile substations and mobile transformers are not a permanent part of the grid structure; they play a vital role in maintaining the reliability and security of a utility's grid system. The availability of mobile transformers and mobile substations enables system operators to rapidly restore electrical service where there is equipment failure, forced outage repairs, natural disasters, and acts of terrorism. When mobile transformers and mobile substations are used to restore electrical service in such situations, they function as part of the permanent grid system. In effect, they are an integral and critical part of the utility's electrical system. Accordingly, an investment in technologies like this to address reliability and security concerns may be prudent in today's operating environment and should not be discouraged simply because the technologies are unconventional.

Reducing Dependence on Foreign Suppliers

Foreign producers dominate large-power transformer markets in North America, while medium-power transformers are essentially all produced in North America, with > 60% produced in the United States. Mobile systems currently fill the market need for temporary, medium-voltage transformers and substations (10-100 MVA). Large-power transformers (> 100 MVA) or higher-voltage transformers (>230 kV) are not currently replaceable using MTS, while transformers of 1-10 MVA size are generally available from multiple sources in a relatively short time period (2-3 days).

MTS are classed as low- and medium-power transformers and has no effect on the U. S. dependence on foreign production for large-power transformers. The low- and medium-power transformer market is already supported by a domestic manufacturing capability. In addition, because they do not directly compete against foreign (or domestic) manufacturing of stationary transformers, mobile transformers, to some extent, complement the manufacture of stationary transformers because they provide a short-term solution until the foreign or domestic stationary transformer is delivered.

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Appendix A

Energy Policy Act of 2005, Section 1816

SEC. 1816. STUDY OF RAPID ELECTRICAL GRID RESTORATION

(a) STUDY—

(1) IN GENERAL—The Secretary shall conduct a study of the benefits of using mobile transformers and mobile substations to rapidly restore electrical service to areas subjected to blackouts as a result of—

(A) equipment failure;

(B) natural disasters;

(C) acts of terrorism; or

(D) war.

(2) CONTENTS—The study under paragraph (1) shall contain an analysis of—

(A) the feasibility of using mobile transformers and mobile substations to reduce dependence on foreign entities for key elements of the electrical grid system of the United States;

(B) the feasibility of using mobile transformers and mobile substations to rapidly restore electrical power to—

(i) military bases;

(ii) the Federal Government;

(iii) communications industries;

(iv) first responders; and

(v) other critical infrastructures, as determined by the Secretary;

(C) the quantity of mobile transformers and mobile substations necessary—

(i) to eliminate dependence on foreign sources for key electrical grid components in the United States;

(ii) to rapidly deploy technology to fully restore full electrical service to prioritized Governmental functions; and

(iii) to identify manufacturing sources in existence on the date of enactment of this Act that have previously manufactured specialized mobile transformer or mobile substation products for Federal agencies.

(b) REPORT—

(1) IN GENERAL—Not later than 1 year after the date of enactment of this Act, the Secretary shall submit to the President and Congress a report on the study under subsection (a).

(2) INCLUSION—The report shall include a description of the results of the analysis under subsection (a)(2).

Appendix B

List of Acronyms

AC	Alternating Current
BIL	Basic Impulse Insulation Level
BPA	Bonneville Power Authority
DC	Direct Current
DoD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DVP	Dominion Virginia Power
EHV	Extra-High Voltage
EMS	Emergency Medical Services
EPACT	U.S. Energy Policy Act of 2005
GSU	Generator Step-Up
GVA	Gigavolt-Ampere
HEC	Humphreys Engineer Center
HSPD	Homeland Security Presidential Directive
HV	High Voltage
kV	Kilovolts
KVA	Kilovolt-Ampere
MTS	Mobile Transformers and Substations
MV	Medium Voltage
MVA	Megavolt-Ampere
O&M	Operations and Maintenance
ONAF	Oil Natural-Air-Forced Flow
PG&E	Pacific Gas and Electric
R&D	Research and Development
RD&D	Research, Development, and Demonstration
T&D	Transmission and Distribution
TVA	Tennessee Valley Authority
UHV	Ultra-High Voltage
VA	Volt-Ampere
VAR	Volt-Ampere Reactive
WAPA	Western Area Power Administration

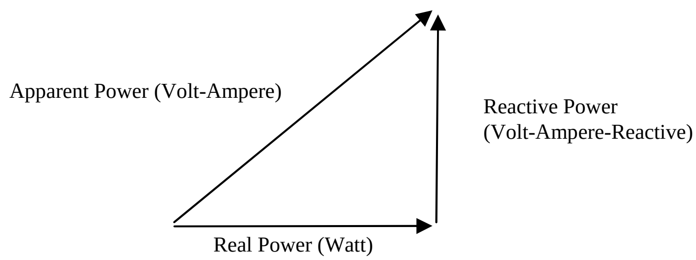
Appendix C

Electricity Glossary

Active Power: Also known as “real power”. The rate at which work is performed or that energy is transferred, commonly measured in watts or kilowatts.

Alternating Current (AC): Current that changes periodically (sinusoidally) with time.

Apparent Power: The product of voltage and current phasors, usually expressed in kilovolt-amperes (kVA) or megavolt-amperes (MVA).



Blackout: Emergency loss of electricity due to failure of generation, transmission, or distribution.

Bulk Power System: All electric generating plants, transmission lines, and equipment.

Bus: Shortened from the word busbar, a node in an electrical network where one or more elements are connected together.

Capacity: The rated continuous load-carrying ability, expressed in megawatts (MW) or megavolt-amperes (MVA) of generation, transmission, or other electrical equipment.

Circuit: A conductor or a system of conductors through which electric current flows.

Circuit Breaker: A switching device connected to the end of a transmission line capable of opening or closing the circuit.

Contingency: The unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch, or other electrical equipment.

Current: The flow of electrons in an electrical conductor measures in Amperes.

Demand: Amount of power consumers require at a particular time.

Direct Current (DC): Current that is steady and does not change with time.

Distribution Network: The portion of an electric system that is dedicated to delivering electric energy to an end user, at or below 69 kV.

Electrical Energy: The generation or use of electric power by a device over a period of time, usually expressed in kilowatthours (kWh).

Fault: Refers to some abnormal system condition, usually means a short circuit.

Generation (Electricity): The process of producing electrical energy from other forms of energy.

Generator: Generally, an electromechanical device used to convert mechanical power to electrical power.

Grid: An electrical transmission and/or distribution network.

High Voltage Lines: Used to transmit power between utilities. The definition of “high” varies, but it is opposed to “low” voltage lines that deliver power to homes and most businesses.

Load (Electric): The amount of electric power delivered or required at any specific point or points on a system.

Outage: The period during which a generating unit, transmission line, or other facility is out of service.

Power/Phase Angle: The angular relationship between an ac (sinusoidal) voltage across a circuit element and the ac (sinusoidal) current through it.

Protective Relay: A device designed to detect abnormal system conditions and initiate the operation of circuit breakers or other control equipment.

Reactive Power: The portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. It is usually expressed in kilovars (kVAR) or megavars (MVAR). Reactive power must be supplied to most types of equipment with windings, such as motors and transformers.

Real Power: See “Active Power”.

Relay: A device that controls the opening and subsequent reclosing of circuit breakers.

Reliability: The degree of performance of the elements of the bulk power system that results in electricity being delivered to customers within accepted standards and in the amount desired.

Security: The ability of the electric system to withstand sudden disturbances.

Stability: The ability of an electric system to maintain a state of equilibrium during normal and abnormal system conditions or disturbances.

Substation: Facility equipment that switches, changes, or regulates electric voltage.

Switching Station: Facility equipment used to tie together two or more electric circuits through switches.

Transformer: A device that operates on magnetic principles to increase (step up) or decrease (step down) voltage.

Transmission: An interconnected group of lines and associate equipment for the movement of electric energy between points of supply and points at which it is transferred for delivery to customers or is delivered to other electric systems.

Voltage: The electrical force, or “pressure”, that causes current to flow in a circuit, measured in volts.

Voltage-Ampere-Reactive (VAR): A measure of reactive power.