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IEEE Guide for the Safe Installation of Mobile Substation Equipment

Sponsor

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IEEE Power Engineering Society

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IEEE Standards Board

Abstract: Information pertaining to the installation of mobile substation equipment up to 230 kV is provided.
Keywords: grounding, installation, lighting, lightning stroke protection, mobile substation equipment, shielding, step voltage, surge protection, touch voltage, transferred voltage

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Introduction

(This introduction is not part of IEEE Std 1268-1997, IEEE Guide for the Safe Installation of Mobile Substation Equipment.)

Prior to the development of this guide, information regarding safe installation and operation of mobile substations was not available from a single source. To provide a single source of information for general transport, set-up, installation, and safe operation of mobile substation equipment, members of Working Group D4 (Substation Safety) unanimously voted to develop a comprehensive guide. The West Coast Subcommittee volunteered to assist in the development of the guide. Accordingly, a project authorization was requested and was approved by the IEEE Standards Board in September 1991.

This guide was developed with the intent to identify specific areas of concern and offer design assistance in those areas. Recognizing that mobile substations and their installation practices vary widely, the intent of this guide is not to provide a step-by-step set of instructions for individual units. Instead, an attempt was made by the working group to provide generic information on topics and items pertaining to safe installation and operation of mobile substation equipment.

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IEEE Guide for the Safe Installation of Mobile Substation Equipment

1. Overview

1.1 Scope

This guide contains information on general topics and items pertaining to the installation of mobile substation equipment. The guide recognizes that mobile substations vary widely regarding the particular devices and equipment used. It is beyond the scope of this guide to provide a specific step-by-step set of instructions for individual units. This guide covers installation of mobile substation equipment up to 230 kV.

1.2 Purpose

The purpose of this guide is to establish general transport, set-up, and installation guidelines for the safe use of mobile substation equipment. This guide has been developed with the intent to identify specific areas of concern and offer design assistance in those areas.

2. References

This guide shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply.

Accredited Standards Committee C2-1997, National Electrical Safety Code® (NESC®).[1]

ANSI C37.32-1990 Schedules of Preferred Ratings, Manufacturing Specifications, and Application Guide for High-Voltage Air Switches, Bus Supports, and Switch Accessories.[2]

ANSI Z535.2-1991 Environmental and Facility Safety Signs.

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[1]The NESC® is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[2]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

Canadian Electrical Code, Part I, 17th Edition (C22.1-1994), Safety Standard for Electrical Installations.[3]

IEEE Std 80-1986 (Reaff 1991) IEEE Guide for Safety in AC Substation Grounding (ANSI).[4]

IEEE Std 100-1996 IEEE Standard Dictionary of Electrical and Electronics Terms.

IEEE Std 525-1992 IEEE Guide for Design and Installation of Cable Systems in Substations (ANSI).

IEEE Std 998-1996 IEEE Guide for Direct Lightning Stroke Shielding of Substations (ANSI).

IEEE Std 1119-1988 (Reaff 1993) IEEE Guide for Fence Safety Clearances in Electric-Supply Stations (ANSI).[5]

IEEE Std C37.91-1985 (Reaff 1990) IEEE Guide for Protective Relay Applications to Power Transformers (ANSI).

IEEE Std C62.22-1991 IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems (ANSI).

NFPA 70-1996, National Electrical Code® (NEC®).[6]

3. Definitions

Definitions of terms pertinent to the subject matter are listed here. Definitions as given herein apply specifically to the application of this guide. For additional definitions, see IEEE Std 100-1996 .

3.1 clearances: The separation between two conductors, between conductors and supports or other objects, or between conductors and ground.

3.2 electric-supply equipment: Equipment that produces, modifies, regulates, controls, or safeguards a supply of electric energy.

3.3 electric-supply station: Any building, room, or separate space within which electric-supply equipment is located and the interior of which is accessible, as a rule, only to properly qualified persons. This includes generating stations and substations, including their associated generator, storage battery, transformer, and switchgear rooms.

3.4 exposed: Not isolated or guarded.

3.5 ground potential rise (GPR): The maximum electrical potential that a substation grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth.

3.6 live parts: Those parts that are designed to operate at voltage different from that of the earth.

3.7 metal-to-metal touch voltage: The voltage between metallic objects or structures within the substation site that may be bridged by direct hand-to-hand or hand-to-feet contact.

3.8 mobile substation equipment: Substation equipment mounted and readily movable as a system of transportable devices.

[3]The Canadian Electrical Code is available from the Canadian Standards Association, 178 Rexdale Boulevard, Etobicoke, Ontario, Canada M9W 1R3.
[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.
[5]IEEE Std 1119-1988 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.
[6]The NEC® is available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA. It is also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3.9 step voltage: The difference in surface potential experienced by a person not in contact with any grounded object and whose feet are spaced 1 m apart.

3.10 touch voltage: The potential difference between the ground potential rise and the surface potential at the point where a person is standing while at the same time having one hand in contact with a grounded structure.

3.11 transferred voltage: A special case of the touch voltage where a voltage is transferred into or out of the substation from or to a remote point external to the substation site.

4. Electrical clearances

4.1 General

Guarding and clearances to energized parts should comply with Rule 124 of the National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-1997). Clearances to energized parts for safety of personnel should be as given in Table 124-1 of the NESC unless adequate insulation or suitable barriers are provided. Any ungrounded part or parts of indeterminate potential should be located a minimum of 102 in (2.6 m) above any permanent supporting surface for workers in accordance with NESC Rule 124A.3.

4.2 Phase-to-ground clearances

Recommended and minimum clearances of energized parts to grounded parts should be in accordance with “Ground Clearances” as given in Columns 4 and 5, respectively, of Table 3 of ANSI C37.32-1990 . Alternatively, minimum clearance to grounded parts should be in accordance with Table 710-33 of the National Electrical Code® (NEC®) (NFPA 70-1996) for indoor and industrial environments.

4.3 Phase-to-phase clearances

Minimum metal-to-metal clearances between all disconnecting switch bus supports and rigid conductors should be in accordance with Column 3 of Table 3 of ANSI C37.32-1990 . Distances between nonrigid parts should be adjusted to provide such minimum clearances. Recommended centerline-to-centerline phase spacing for switches are given in Columns 6, 7, and 8 of that same table. Alternatively, minimum phase-to-phase clearances of live parts should be in accordance with Table 710-33 of the NEC for indoor and industrial environments.

5. Grounding

5.1 General

Mobile substations or transformer trailers may be installed in many locations. The trailers may be installed on utility property or non-utility property. On utility property, the mobile substation may be installed inside or outside the substation fence. The mobile substation located outside the permanent substation fence may be located next to the substation, a distance away from the substation, on the transmission line right-of-way, or on non-utility property. When the mobile substation is located outside the substation fence or on non-utility property, special attention should be given to the touch voltages at the mobile substation fence because it is the most likely point of contact by non-utility personnel.

5.2 Safety criteria

The basic shock situations for mobile substations are the same as for permanent substations, as indicated in IEEE Std 80-1986 and as shown in Figure 1 below.

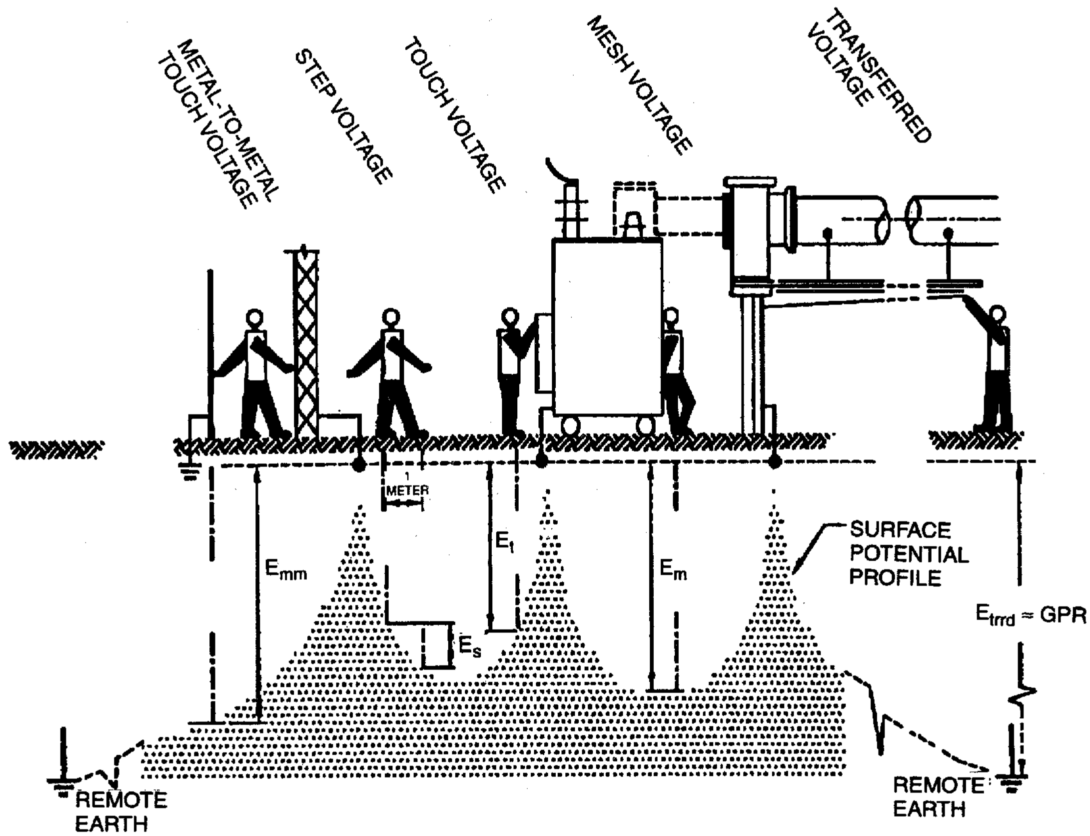

Figure 1— Basic shock situations

The purpose of the grounding system is to

a) Provide a means to conduct electric current into the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service.
b) Ensure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electrical shock.

Transferred voltage needs to be considered when a mobile substation is located outside a substation and a ground connection is installed between the mobile substation and the substation ground grid.

The grounding system should limit the touch, step, and metal-to-metal touch voltage levels to acceptable levels for personnel safety and safe equipment operation. If acceptable shock voltages are not possible or practical, insulating gloves and/or boots should be worn by personnel working around the mobile substation. Appropriate signs or barriers should be placed around the mobile substation. For a mobile substation located outside the permanent substation, however, the touch voltage around the mobile substation fence should still be addressed (see 5.4).

5.3 Items to ground

5.3.1 Fence

The fences may be either connected to the mobile substation grid or isolated. A dangerous voltage may exist if an isolated conducting (metallic) fence and the trailer can be bridged by a person standing between them. Connecting the fence and trailer together will lower the voltage between them, even if they may not be touched at the same time. If an ungrounded conducting temporary fence is installed adjacent to a grounded substation fence, an isolation section may be necessary to prevent a transfer voltage on the temporary fence.

5.3.2 Gate

A conducting gate should be bonded to a conducting fence. If the gate swings outward, a loop conductor should be installed to control the touch voltages when opening the gate. If the gate opens inward, no special grounding may be needed unless the fence is isolated from the mobile substation's ground grid.

5.3.3 Trailer frame

The trailer frame and/or trailer ground bus should be connected to the grid with a conductor of a size adequate to carry the available fault current. If the trailer has no ground bus for the equipment connections, all equipment and the trailer should be connected to the mobile substation ground grid using separate conductors of proper size for each piece of equipment. Multiple trailers (e.g., a switch and fuse trailer used with a mobile transformer trailer) should be connected via the grid or a direct cable tie to prevent voltages between them. Caution should be taken while any maintenance is performed on the trailer (e.g., changing or removing tires and adjusting jacks) while the unit is in service. Movable (e.g., slide-out switch bases, etc.) or removable conducting parts (e.g., steps, dollies, etc.) should be connected to the trailer ground bus or the ground grid, or both, to eliminate voltages between them.

5.3.4 Cable shield grounding

Cable shields should be grounded. If the cable shield is to be grounded at both ends, the shield must be sized to conduct fault current or have a separate parallel conductor to prevent excessive current in the shield. Refer to IEEE Std 525-1992 for further guidance.

5.3.5 Operator platforms or plates

In the absence of a properly designed ground grid, operator platforms or plates should be installed and connected to the grid at all switch handles that are accessible from the ground. In the case of a properly designed ground grid, operator platforms and plates may be installed as a supplement to the ground grid and connected to the grid. If the trailer jacks are to be adjusted while the mobile substation is in service, a platform or plates connected to the grid should be installed at the jack handle.

5.3.6 Neutral grounding

Neutral conductors of adequate fault-current capacity should be installed from the mobile transformer to the grid. Feeder neutrals should be connected to the provided attachment point (neutral bushing) or directly to the grid. If possible, transmission line shield wires should be connected to the grid. Due to the higher resistance of a separate mobile grid not connected to the main substation grid, a high percentage of the fault current will flow on the neutral and transmission line shield wires. In some cases, the current limits of these wires may be exceeded by return currents. When the mobile substation is located outside the substation fence, the grids should be connected together, if practical, to lower the ground potential rise. Installation of two or more ground cables is desirable to reduce the inductive reactance between the two ground mats and to lower the transient overvoltages.

5.3.7 Temporary equipment

Any temporary equipment connected to the trailer or equipment on the trailer should be grounded to the grid or trailer ground bus.

5.4 Methods of grounding

5.4.1 Mobile substation grounding

A mobile substation installed inside a substation fence should have the trailer or trailers connected to the substation grid in a minimum of two locations. A mobile substation located outside and away from the substation may require different considerations. The length of service and the location of the mobile substation are factors in determining what grounding should be installed and what deviations from standard practices are acceptable. The grid conductor may be placed on the soil surface and connected to driven ground rods to help lower the touch voltage and hold the cable in place. A buried conductor and ground rods would result in lower touch voltages during a fault. A counterpoise or portable ground mat installed on the soil surface may be a solution to the touch voltage hazard when a minimal grounding system is installed. This mat may be installed over all or part of the mobile substation area. A layer of high-resistivity material may be installed to help increase the acceptable levels of touch and step voltages. The emergency installation of a mobile substation may cause the utility to deviate from standard practices on clearances and type of grid installation. The safe practice of wearing insulating gloves and/or boots should be considered for all personnel inside the fence of the mobile substation when it is located away from the substation fence.

5.4.2 Mobile substation fence grounding

The fence around the mobile substation is the most likely point of contact by non-utility personnel. The fence is often constructed to a lower standard than a permanent fence because it is a temporary installation. For conducting (metallic) fences, a buried perimeter conductor outside the fence should be installed and each fence post should be connected to this conductor to lower the touch voltage. A layer of rock or other high-resistivity material may be installed inside the fence, 1 m outside the fence, or both. A rock layer will increase the contact resistance of a person’s foot and will lower the body current. The fence fabric and barbed wire may be connected to the grid according to the normal practice of the utility. A jumper should be installed across the gate opening to provide continuity of the perimeter conductor. A conducting gate should be bonded to conducting gate posts. When the mobile substation is located outside the substation and a common side is shared with the utility or a customer, isolation sections or insulated fencing may be necessary to prevent a dangerous transferred voltage from being conducted on the adjacent fence.

5.5 Connection to the existing grid

Above-grade connections may be installed between the existing substation grid and the mobile grid. When this method is used, the following should be considered:

a) Tripping hazard
b) Exposure to high current during fault conditions
c) Exposure to cable movements under electromechanical forces during fault conditions

An above-grade connection is accessible not only to utility personnel but also to non-utility personnel and animals. A fence or other barriers can avoid this accessibility.

A below-grade connection eliminates the above-grade hazards, but involves additional time and cost to install. If the connection is from utility property to non-utility property, a removal cost of the connecting conductor may be incurred when the mobile substation is removed from service.

6. Installation procedures

6.1 Planning

Successful utilization of a mobile substation is dependent on detailed planning of the installation. Mobile substation sites throughout the system should be selected prior to emergency situations to allow proper installation in a timely manner.

A site within an existing substation should be selected based on a review of the existing substation drawings and a field inspection of the location. Sites outside an existing substation should be selected to keep the need for grading to a minimum. The proximity to required facilities such as transmission and distribution lines and an adequate space to satisfy physical size, electrical clearances, and access requirements need to be considered.

The proposed route to be traveled should be reviewed to ensure that all physical clearance requirements and weight restrictions including any specific local codes are satisfied. The need for any special insurance or permits should be determined and they should be obtained from the appropriate departments or agencies.

6.2 Surface/site preparation

6.2.1 Existing substation sites

The site selected should allow connection to the various power and control systems in a safe and efficient manner. Working clearances should be maintained for the mobile substation and existing substation equipment. Additional support material should be installed (matting, cribbing, etc.) as necessary in poor soil conditions resulting from seasonal variations (rainy season, spring thaw conditions). Review substation drawings for routing/location of temporary equipment (e.g., control cables, power cables, barrier materials, etc.).

6.2.2 New temporary locations

The site should be graded for the proper drainage and equipment installation. Installation of the ground grid should be based on the design requirements. Proper fencing should be installed to secure the site.

6.2.3 All locations

Obtain operational clearance as required, and install any temporary structures required for primary or secondary connections. Install any temporary bus and temporary high-voltage jumper connections as required for the mobile substation.

6.3 Preparing the mobile substation for transport

The mobile substation should be prepared for transportation to the site in accordance with system standards and manufacturer’s instructions. This includes the transformer, switches, breakers, control/relay systems, and all connections.

6.3.1 General inspection

The following items should be included in a general inspection of the mobile substation prior to transportation:

a) Check the oil level in all tanks, compartments, and bushings.
b) For units with a nitrogen blanket, verify that the gas supply is adequate and that the cylinder is in the transport position.

c) Verify that arresters are secured in the transport position.
d) Check high-voltage power fuses, if equipped.
e) Close the bottom valves of the cooling system to decrease the possibility of oil leaks during transit.
f) Inspect high- and low-side disconnect switches and verify that blades are clamped in the closed position.
g) Verify that a set of instruction manuals and control drawings are with the unit.
h) Lock and secure all cabinet doors for transit.
i) Verify that all shipping braces, rock guards, and protective covers are secured for transit.
j) Verify that bushing shorting jumpers are in place.

6.4 Placing the mobile substation in service

6.4.1 Locating the mobile substation

Locate the mobile substation so the route of the temporary high-voltage primary and secondary conductors will not interfere with maintenance of existing substation equipment. Verify that there is adequate electrical clearance to adjacent structures, equipment, and fence.

6.4.2 Leveling the mobile substation

When leveling the mobile substation

a) Block and level all mobile substation trailers.
b) Support the weight of the mobile substation on temporary cribbing.
c) Remove the weight of the trailers from the tires.
d) Allow no more than 5 ° deviation from level in any direction (side to side, front to rear).

6.4.3 Grounding the mobile substation

Connect the mobile substation to the ground grid utilizing the recommendations in Clause 5. Avoid routing of temporary ground risers in vehicle traffic areas. Verify continuity of the mobile substation’s ground bus and connections to equipment.

Connect the neutral bushing(s) of the transformer to system neutral with an appropriately rated conductor.

6.4.4 Inspection of equipment after transport

Check equipment (transformer, bushings, arresters, breaker, insulators, switches, relays, etc.) for damage and oil leaks after transport. Check the following for proper levels and functions:

a) Oil levels in transformer tank, compartments, and bushings
b) Transformer tank pressure
c) Pressure relief device

6.4.5 Testing

The following tests are recommended prior to energization:

a) Transformer
    1) Transformer turns ratio
    2) Insulation and dielectric tests
b) Circuit-interrupting devices
    1) Hi-pot the vacuum bottles
    2) Insulation and dielectric tests
    3) Check pressure on gas interrupting devices

c) Current transformer
    1) Transformer turns ratio
    2) Insulation tests

6.4.6 Equipment set-up

Install the mobile substation in accordance with the manufacturer and system standards. All connections including power cable, control and data acquisition, station service, neutral, and grounding should be verified prior to energization. Lightning protection systems should be installed, and all connections to the arresters and the ground grid should be verified.

Power cables should be properly supported to relieve strain on terminations. Power, control, and communication cables should be grounded in accordance with the established standards of the utility company.

6.4.7 Pre-energization check items

a) Cooling system: fan and pump operation (proper rotation) and valve position
b) Transformer tap position
c) Transformer primary protective device
d) Coordination of relays/trip circuit checks
e) Battery and charging systems
f) System phasing
g) Mobile substation grounding, including fence
h) Electrical clearances
i) Barriers and warning signs
j) Electrical operation of protective devices
k) Operation and alignment of disconnect switches
l) Connections to local remote terminal unit (RTU)

6.4.8 Energizing the mobile substation

Energizing and loading of the mobile substation should be conducted in accordance with established system operational practices. Periodic recording of load and oil and winding temperatures is recommended.

6.5 Removing the mobile substation from service

De-energizing the mobile substation should be performed in accordance with established system operational practices and manufacturer’s instructions. An oil sample for a dissolved gas-in-oil test should be obtained.

The mobile substation cooling system should remain in operation until top oil temperature has dropped to an acceptable level.

6.5.1 Preparing the mobile substation for transport to storage

The mobile substation should be prepared for transportation to storage in accordance with 6.3.

6.5.2 Preparing the mobile substation for storage

The mobile substation should be stored in accordance with the manufacturer’s instructions. This should include checking the power for battery and cabinet heaters, the battery charger float voltage, and the grounding. General inspection and testing are recommended to allow for any needed repairs prior to next deployment.

7. Enclosure practices

7.1 General

Section 110 of the NESC requires all electric supply stations to include fences, screens, partitions, or walls to form an enclosure to minimize the possibility of entrance of unauthorized persons or interference by them with equipment inside. Rule 014 of the NESC also permits waiver of rules for emergency or temporary installations under certain conditions. It is the responsibility of the designer to determine if the installation qualifies for such a waiver. In general, such noncompliance should be avoided to the extent possible, and any condition that might endanger persons or property should be corrected as soon as practical.

7.2 Fence safety clearances

Refer to IEEE Std 1119-1988 for guidance on locating fence with respect to live parts. In accordance with this guide, exposed live parts should be located outside the safety clearance zone.

7.3 Warning signs

Appropriate signs should be displayed. Consideration may be given to locating signs on all sides of the mobile substation enclosure. Refer to ANSI Z535.2-1991 for further guidance in designing and locating the signs.

7.4 Fence post installation

The following types of installations may be considered:

a) Direct embedded.
b) Swamp anchors.
c) Power installed foundations.
d) Concrete pier with a depth of 42 in (1.1 m) and a diameter of 9 in (230 mm). The depth may depend on local soil conditions. The post should be fully embedded.
e) Compacted stone pier with a depth of 42 in (1.1 m) and a diameter of 12 in (305 mm). The depth may depend on local soil conditions. The post should be fully embedded.

8. Protection of transformer

8.1 General

The transformer should be protected for the following reasons:

a) To separate the faulted unit from the system so that the system can continue to function
b) To limit damage to the faulted unit
c) To minimize the possibility of a fire
d) To minimize hazards to personnel

Faults internal to the transformer quite often involve a low magnitude of fault current relative to the available fault current at the terminals. For such conditions to be detected, a protection scheme with high sensitivity and high speed, as found in a transformer differential scheme or sudden pressure relay scheme, may be required.

Choice of interrupting device should be made considering the required interrupting capability, cost, weight, size, and isolating switch requirement. Fuses have the advantage of low cost, weight, and size; and incorporate a visual open break. They do not protect well against some types of faults. Also, fuses may not be used to energize or de-energize the transformer and therefore may require a separate device for this purpose. Circuit breakers or other types of interrupting devices, such as vacuum switches or circuit switchers, cost more than fuses and usually weigh more and are larger. However, they permit more sensitive relay protection and can be used to energize or de-energize the transformer. For detailed information on transformer protection, refer to IEEE Std C37.91-1985 .

8.2 Types of transformer failures

When considering transformer protection, the ability of the scheme to detect and clear the types of failures listed below should be considered.

a) Winding failures
b) Tap changer failures
c) Bushing failures
d) Terminal board failures
e) Core failures
f) Miscellaneous failures

8.3 Electrical detection of faults

8.3.1 Fuse protection

Fuses have the merits of being economical and requiring little maintenance. No dc battery supply or current transformers are needed. Fuses can reliably protect some power transformers against primary and secondary external faults. They will provide limited protection for internal faults. Generally, more sensitive means for protection from internal faults are provided for transformers of 10 MVA and higher. Fuses have been used at higher transformer ratings depending on the available fuse ampere ratings and the ability to coordinate with upstream protection devices. It should be recognized that the operation of one fuse on a three-phase system will not necessarily de-energize the fault. If the fault is not de-energized, the resulting single-phase service may be detrimental to the connected polyphase and single-phase motors and other loads. If required, special protection should be added for single-phasing conditions.

The selection of the fuse and proper ampere rating should be based on the following factors:

a) Fuse fault-interrupting capability and available system fault current
b) Maximum anticipated peak load current, daily peak loads, emergency peak loads, maximum permissible transformer load current, and the applicable transformer through-fault current protection curve
c) Hot-load pickup (inrush current upon instantaneous reclosing of source-side circuit breaker) and cold-load pickup (inrush current and undiversified load current after an extended outage)
d) Available primary system fault current and transformer impedance
e) Coordination with source-side protection equipment
f) Coordination with low-side protection equipment
g) Maximum allowable fault time on the low-side bus conductors
h) Transformer connections and grounding impedance as they affect the primary current for various types of secondary faults
i) Maximum degree of sensitivity for detection of high-impedance faults
j) Transformer magnetizing inrush

Ampere rating selection is facilitated by data published by fuse manufacturers. Such data includes time-current characteristic curves, ambient temperature and preloading adjustment curves, plus daily and emergency peak-loading tables.

Mobile and portable transformers are frequently designed and constructed with a higher-than-standard winding temperature rise to reduce their size and weight. Therefore, they have reduced overload capability. This should also be considered when selecting the fuse rating.

8.3.2 Differential protection

Current differential relaying is the most commonly used type of protection for transformers of approximately 10 MVA (self-cooled rating) and above. The term *differential relaying* refers to a current transformer connection scheme in which the net operating current to the relay is the difference between input and output currents to the zone of protection.

The following three general classes of relays are typically used with this current differential scheme:

a) Time overcurrent relay, which may include an instantaneous trip unit having a high-current setting;
b) Percentage differential relay, with restraint actuated by the input and output currents;
c) Percentage differential relay, with restraint actuated by one or more harmonics in addition to the restraint actuated by the input and output currents. Most modern transformer differential relays are this type.

Current transformer connections and ratios must be such that the net current in the relay operating coil for any type or location of external fault is effectively zero, unless relay current matching taps are available. Most modern relays have current matching taps.

8.3.3 Overcurrent relay protection

A fault external to a transformer can result in damage to the transformer. If the fault is not cleared promptly, the resulting overload on the transformer can cause severe overheating and failure. Overcurrent relays (or fuses, see 8.3.1) may be used to clear the transformer from the faulted bus or line before the transformer is damaged. On some small transformers, overcurrent relays may also protect in the case of internal transformer faults, and on larger transformers, overcurrent relays may be used to provide a backup for differential or sudden pressure relays.

8.4 Mechanical detection of faults

8.4.1 Sudden gas-pressure relay

The sudden gas-pressure relay is applicable to all gas-cushioned oil-immersed transformers and is mounted in the area of the gas space. It consists of a pressure-actuated switch, housed in a hermetically sealed case and isolated from the transformer gas space except for a pressure-equalizing orifice.

The relay operates on the difference between the pressure in the gas space of the transformer and the pressure inside the relay. An equalizing orifice tends to equalize these two pressures for slow changes in pressure due to loading and ambient temperature change. However, a more rapid rise in pressure in the gas space of the transformer due to a fault results in operation of the relay. High-energy arcs produce a large quantity of gas, which operates the relay in a short time. The operating time is longer for low-energy arcs.

8.4.2 Sudden oil-pressure relay

The sudden oil-pressure relay is applicable to all oil-immersed transformers and is mounted on the transformer tank wall below the minimum liquid level. Should an internal fault develop, the rapid rise in oil pressure or pressure pulse is transmitted by the transformer oil and operates a relay. In the event of small rises in oil pressure (e.g., due to changes in loading or ambient temperature), the increased pressure is also transmitted by the transformer oil. However, the pressure is relieved by equalizer holes, and the relay and the switch do not operate. Relay sensitivity and response to a fault are independent of transformer-operating pressure.

8.5 Fault clearing

A faulted transformer must be separated from its power source by fault clearing devices such as circuit breakers, remote tripping of circuit breakers via transfer trip, fault-initiating switches, circuit switchers, vacuum switches, or fuses. In addition to separating the transformer from its power source, consideration should be given to tripping oil pumps and fans to reduce their possible adverse effects in sustaining or spreading an oil fire.

Determination of the type of fault-clearing devices to be used should involve considerations such as

a) Installation and maintenance cost
b) Fault clearing time relative to fire hazard and repair or replacement costs of the transformer
c) System stability and reliability
d) System operating limitations
e) Device interrupting capability

8.5.1 Circuit breakers

Circuit breakers directly actuated by a protective relay system are usually provided where it is desirable to isolate a faulted transformer with minimum effect on other segments of the power system. They offer the fastest fault-clearing time and highest interrupting capability.

8.5.2 Remote tripping of circuit breakers

In some situations it may be difficult to justify the cost of local circuit breakers. Tripping of remote source circuit breakers by use of local relays and communication channels, or by use of fault-initiating switches (high-speed ground switches) are alternatives. When remote tripping is used, a power-operated disconnecting switch is usually connected on the source side of the transformer to isolate the transformer from the system. The switch is arranged to open automatically and cancels the remote transfer trip signal, or isolates the ground switch from the system. In both cases, this permits the remote breakers to reclose.

8.5.3 Fault-initiating switch

Remote tripping of circuit breakers can be accomplished by operating a high-speed ground switch. This applies a solid phase-to-ground fault on the source line so that remote line relays will detect it and trip the remote circuit breakers. A disadvantage of this scheme is the additional time required for the ground switch to close and the remote relays to detect the fault. Also, the ground switch phase and faulted phase(s) on the transformer may be different, thus imposing a multiphase fault on the system. Other disadvantages include the disturbance caused by placing a bolted fault on the system and an outage to other customers connected to the source line(s).

8.5.4 Circuit switcher

A circuit switcher is a mechanical switching device with a limited fault-interrupting rating. Internal faults or secondary faults limited by transformer impedance, where the magnitude of current is below the interrupting rating of the circuit switcher, can be cleared. It should be possible to coordinate remote line relays to avoid remote tripping for the lower magnitude faults. High-magnitude source-side faults on the transformer exceeding the interrupting rating of the circuit switcher must be detected by remote line relays and cleared by the remote breakers before the circuit switcher opens. The circuit switcher may be blocked from tripping using an instantaneous overcurrent relay, or it may be allowed to attempt interruption depending on user preference.

8.5.5 Vacuum switches

Many of the above comments made for circuit switchers are also applicable to vacuum switches.

9. Work practices

Although none of the references listed in Clause 2., HOSH [B1],[7] or OSHA [B2] have specific sections that cover work practices for electrical equipment such as mobile substations, the appropriate sections should be followed to ensure safe work practices. Furthermore, these only apply to Canada and the U.S., and therefore it is recommended that users of this guide outside these countries should attempt to locate equivalent documents in their countries. If no such documents exist, it is recommended that the listed documents be considered.

10. Lighting

10.1 Area lighting

General illumination for security of the mobile substation area can often be part of the initial substation design process. When allowing space for the mobile substation within the yard fenced area, consideration should be given to lighting fixture locations and aiming of floodlight-type fixtures to accommodate the mobile substation when needed.

If it is necessary to locate the mobile substation outside the station fence, then it may be practical to install temporary lighting fixtures. The permanent station fence posts, especially the corner posts, may provide a place for locating temporary lighting masts by attaching to these fence posts with U-bolts or other suitable hardware.

In addition to fixed lighting units (either permanent or temporary), there exists a wide variety of portable lights. These portable units can be as small as hand-held extension type lights or considerably larger devices on tripods. When determining the size and quantity of receptacles to be provided with the mobile substation, consideration should be given to the particular type of plug-in lighting units used by substation repair crews.

10.2 Red external light

Two red lights should be mounted on the mobile substation trailer. Lights should be clearly visible in the front, sides, and rear to indicate that the mobile substation is energized.

10.3 Amber external light

A blinking amber light should be mounted in a readily visible location on the mobile substation and connected such that it will be energized by an alarm relay that is activated by any and all alarm conditions.

11. Direct lightning stroke protection

11.1 General

The risk of direct lightning strokes to mobile substations is less than for permanent substations for the following reasons:

a) Mobile substations are usually installed for relatively short periods of time. The time of exposure, therefore, is low compared to permanent substations, and this leads to a lower probability that a direct stroke will occur.

[7]The numbers in brackets correspond to those of the bibliography in Annex A.

b) The area occupied by the installation is small compared to large switchyards or long transmission lines. For a given ground flash density, therefore, the probability of a stroke to the area will usually be quite low.
c) Mobile substations of necessity are low in profile since they must comply with maximum height restrictions for highway travel. As a result, they are less susceptible to attracting direct strokes and may be partially shielded by adjacent structures or transmission lines.

Nevertheless, for installations in areas of high keraunic activity, installations of long duration, or for installations on flat, open areas it is prudent to provide direct stroke shielding for the installation. Refer to IEEE Std 998-1996 for guidance.

11.2 Existing shielding

Before installing special shielding, the engineer should check the proposed site for existing shielding. If existing substation structures, overhead shield wires, or phase conductors provide adequate shielding for the mobile substation, no further shielding may be necessary.

11.3 Shielding with portable masts

In some cases it may be possible to fit a lightweight electrical-grade aluminum mast to brackets attached midway on the side of the mobile trailer. The mast can be removed for travel. When in place, the mast must be connected to the ground grid with a direct, low-impedance conductor.

In situations where a taller mast is required, a wooden or tubular metal structure can be set in the ground next to the mobile substation. A conductor extending 305 mm (12 in) above the pole can be used as the air terminal. In the case of a wooden pole, this conductor should run down the pole to connect to the ground grid.

11.4 Use of shield wires

A shield wire will provide a greater area of protection than a mast. A temporary shield wire can be strung between existing station structures, if available, or between two guyed poles if no existing structure is available. A single shield wire positioned at a suitable height will usually provide full shielding of the mobile substation.

12. Surge protection

The shielding from direct strokes discussed above does not, of course, provide any protection from surges coming in on the line conductors or from nearby direct strokes. The mobile transformer should be fitted with surge arresters located near its terminals to provide this protection. The arresters must be connected with a low-impedance conductor to the protected equipment and to the ground grid.

Low weight and the ability to be installed quickly are critical factors in mobile substation design. Selecting arresters with polymer housing can reduce arrester weight by about 70%. Mobile transformers often provide multiple voltage taps. Because of their wide protective margins, it is sometimes possible to select a metal-oxide arrester that will cover more than one voltage level. This arrangement speeds installation since arrester shunts do not have to be reconnected. It also reduces weight and height. See IEEE Std C62.22-1991 for guidance in the application of metal-oxide surge arresters.

Annex A Bibliography

(Informative)

[B1] Handbook of Occupational Safety and Health, 4th ed., Canadian Government Publication, Minister of Supply and Services, 1989.

[B2] Occupational Safety and Health Administration's Regulations and Procedures, Volume I—General Industry Safety Standards, 1910 and General Construction Standard, 1926.

Annex B Summary of relevant parts of the Canadian and U.S. work practice related documents

(Informative)

B.1 Relevant codes and practices

B.1.1 Handbook of Occupational Safety and Health (HOSH)—Canada [B1]

This document addresses the minimum working conditions that are required for employees in their workplace, including electrical safety.

B.1.2 Occupational Safety and Health Administration (OSHA) Regulations and Procedures—U.S. [B2]

This document contains two Subparts (R and S) in Volume I of the General Industry Standards and Interpretations of OSHA's Regulations and Procedures that are applicable to electrical work.

Subpart R covers special industries and is applicable to the operation and maintenance of electric power generation, control, and transformation, along with distribution and transmission lines and electrical equipment, and includes electrical utilities.

Subpart S addresses electrical safety requirements for the practical safeguarding of employees in their workplace. However, this subpart is not applicable to indoor or outdoor installations under the exclusive control of electrical utilities for the purpose of communications or metering, or the generation, control, transformation, transmission, and distribution of electrical energy, but because its purpose is the practical safeguarding of personnel from hazards arising from the use of electricity, parts of it have been included as reference material.

Appendix A, associated with the above two subparts of this document, contains two flow charts that are useful in helping the user decide which subpart of this document governs the electrical work being undertaken. Table 1, included in Appendix A, identifies the relevant sections of Subpart R that are in compliance with the requirements of Subpart S, and which other sections in Subpart R still apply regardless of compliance with Subpart S.

B.1.3 National Electric Code (NEC)—U.S

Although this document is purely advisory in nature and does not apply to electrical utilities, it has been included as a reference because its purpose is the practical safeguarding of persons and property from hazards arising from the use of electricity.

B.1.4 National Electrical Safety Code (NESC)—U.S

This standard covers the work practices that are necessary for the safeguarding of employees and the public from possible hazards arising from electrical lines and equipment.

B.1.5 Canadian Electrical Code, Part I (CEC)—Canada

Although this document does not apply to electrical utilities, it has been included as a reference because it contains practical information covering electrical work and electrical equipment.

B.2 Specific work practices applicable to mobile substations

B.2.1 General requirements

The following reference materials cover the general or basic work practice requirements for portable or mobile equipment:

a) Subsection 1910.308 (a), General Requirements—OSHA (Subpart S)
b) Rule 014, Temporary Installations—NESC

B.2.2 Grounding

The following reference materials cover the work practice requirements for grounding of portable or mobile equipment:

a) Subsection 1910.308 (a) (3), Special Systems—OSHA (Subpart S)
b) Subsection 1910.304 (f) (1), Grounding—OSHA (Subpart S)
c) Section 250-154, Grounding—NEC
d) Rules 10-408 and 10-514, Portable Equipment Bonding and Grounding—CEC

B.2.3 Portable cables

The following reference materials cover the work practice requirements for portable cables associated with portable or mobile equipment:

a) Subsection 1910.305 (h), Portable Cables—OSHA (Subpart S)
b) Sections 400-30 to 36, Portable Cables—NEC
c) Section 710-45, Power Cables—NEC
d) Rules 4-038 and 4-040, Portable Power Cables—CEC

B.2.4 Enclosures

The following reference materials cover the work practice requirements for permanent and temporary enclosures associated with portable or mobile equipment:

a) Section 3.7, Temporary Fences—HOSH
b) Section 710-43, Enclosures—NEC

B.3 General work practices that may be applicable to mobile substations

The following reference materials provide work practice requirements for any electrical work, on or near exposed energized parts or lines, that may be applicable to mobile substations (depending on circumstances).

B.3.1 Basic requirements

The following reference materials cover the basic work practice requirements for installation, operation, and maintenance work, on or near exposed energized parts or lines:

a) Subsection 1910.269 (c), Job Briefing—OSHA (Subpart R)
b) Subsection 1910.303 (h), General Requirements—OSHA (Subpart S)
c) Section 1910.332, Training—OSHA (Subpart S)
d) Section 1910.333, Selection and Use of Work Practices—OSHA (Subpart S)
e) Section 8.3, Safety Standards—HOSH

f) Sections 8.4 through 8.8, Safety Procedures—HOSH
g) Section 8.9, Coordination of Work—HOSH
h) Rule 410, General Requirements—NESC
i) Rule 420 (A, B, C, L & N), General Safety Rules—NESC
j) Rules 440 and 441 (A & B), Additional Rules for Supply Employees—NESC
k) Rules 230 through 235, Clearances—NESC

B.3.2 Lines and equipment

The following reference materials provide more specific work practice requirements for installation, operation, and maintenance work, on or near exposed energized parts or lines:

a) Subsection 1910.269 (l), Exposed Energized Parts—OSHA (Subpart R)
b) Subsection 1910.269 (q), Overhead Lines—OSHA (Subpart R)
c) Subsections 1910.269 (w) (1, 2, 4 & 7), Special Conditions—OSHA (Subpart R)
d) Subsection 1910.269 (m), De-Energizing for Protection—OSHA (Subpart R)
e) Subsection 1910.269 (u), Substation—OSHA (Subpart R)
f) Subsection 1910.308 (a), Special Systems—OSHA (Subpart S)
g) Sections 8.10 and 8.11, Poles and Elevated Structures—HOSH
h) Sections 8.12 through 8.18, Isolation of Electrical Equipment—HOSH
i) Section 8.23, Switches and Control Devices—HOSH
j) Rule 174, Disconnection of Fuses—NESC
k) Rules 190 through 193, Surge Arresters—NESC
l) Rule 422 (A, B & C), Overhead Line Operating Procedures—NESC
m) Rule 121 (B & C), Equipment Inspections—NESC
n) Rules 380 and 383 through 385, Equipment Installation—NESC
o) Section 450-26, Indoor Oil Insulated Transformer Installation—NEC
p) Section 450-27, Outdoor Oil Insulated Transformer Installation—NEC
q) Rules 2-300, 2-308, 2-314, and 2-322, Maintenance and Operation—CEC

B.3.3 Tools, equipment, and services

The following reference materials cover the tools, equipment, and services required to ensure the safety of a worker undertaking any electrical work:

a) Subsection 1910.269 (b), Medical Services and First Aid—OSHA (Subpart R)
b) Subsection 1910.269 (g), Personal Protection Equipment—OSHA (Subpart R)
c) Subsection 1910.269 (h), Ladders, Platforms, etc.—OSHA (Subpart R)
d) Subsection 1910.269 (i), Hand and Portable Power Tools—OSHA (Subpart R)
e) Subsection 1910.269 (j), Live Line Tools—OSHA (Subpart R)
f) Subsection 1910.269 (p), Mechanical Equipment—OSHA (Subpart R)
g) Sections 12.1 through 12.3, Safety Material, Equipment, Devices, and Clothing—HOSH
h) Sections 12.4 and 12.5, Protective Headgear and Footwear—HOSH
i) Rule 126, Equipment for Work on Energized Equipment—NESC

B.3.4 Grounding

The following reference materials cover the work practice requirements for grounding during any electrical work:

a) Subsection 1910.269 (n), Grounding—OSHA (Subpart R)
b) Sections 8.19 through 8.22, Safety Grounding—HOSH
c) Rules 92 (B, D & E) and 93 through 97, Grounding—NESC
d) Rule 123, Protective Grounding—NESC
e) Rules 36-300, 36-302, 36-304, 36-306, and 36-310, Grounding—CEC

B.3.5 Protective arrangements

The following reference materials cover the work practice requirements for protection of the worker, or a member of the public, during any electrical work from accidental injury:

a) Subsection 1910.303 (h), Basic Protection Requirements—OSHA (Subpart S)
b) Section 1910.335, Safeguards for Personnel Protection —OSHA (Subpart S)
c) Rules 110 (A, C & D) and 111 (A & B), Protective Arrangements—NESC
d) Rule 124, Guarding Live Parts (and Clearances)—NESC
e) Rule 125, Working Space About Electrical Equipment—NESC
f) Rule 411, Protective Methods and Devices—NESC
g) Section 110-31, Enclosures of Electrical Installations—NEC
h) Section 110-32, Work Space about Electrical Equipment—NEC
i) Section 110-34, Work Space—NEC
j) Rules 2-200 and 2-202, Protection of Persons and Property—CEC
k) Rule 26-006, Fences for High Voltage Installations—CEC
l) Rules 26-302, 26-304, 26-308, 26-312, 26-316, and 26-318, Fences—CEC

B.3.6 Cables, flexible cords, and conductors

The following reference materials cover the work practices associated with the use of cables, flexible cords, and conductors required during any electrical work:

a) Subsection 1910.303 (h), Flexible Cords and Cables—OSHA
b) Rules 160 through 164, Conductor—NESC
c) Rules 370 through 374, Supply Cable Termination—NESC
d) Section 310-5, Minimum Size of Conductor—NEC
e) Section 310-15, Ampacity—NEC

B.3.7 Illumination and emergency systems

The following reference materials cover the illumination and emergency systems required to ensure the safety of any worker undertaking any electrical work:

a) Subsection 1910.303 (h), Basic Lighting Requirements—OSHA (Subpart S)
b) Subsection 1910.308 (b), Emergency Lighting Systems—OSHA (Subpart S)
c) Section 6.6, Emergency Lighting Systems—HOSH
d) Section 6.7, Level of Lighting—HOSH

