IEEE Guide for Safety in the Installation of Mobile Substation Equipment

IEEE Power Engineering Society

Sponsored by the
Substations Committee

1268™

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

4 November 2005

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Sponsor

Substations Committee
of the
IEEE Power Engineering Society

Approved 9 June 2005

IEEE-SA Standards Board

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Abstract: Information pertaining to the installation of mobile substation equipment up to 245 kV is provided in this guide.
Keywords: grounding, installation, 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 1268-2005, IEEE Guide for Safety in the 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 and resulted in the original 1997 edition of this guide.

This revision is the result of several comments received in a previous reaffirmation ballot. This revision addresses those comments, most of which requested clarifications or more direct guidance on the installation of mobile substation equipment.

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 Safety in the 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 245 kV.

1.2 Purpose

The purpose of this guide is to establish general transport, setup, 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. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Accredited Standards Committee C2-2002, National Electrical Safety Code® (NESC®).[1]

ANSI C37.32™-2002, American National Standard for Switchgear—High Voltage Air Switches, Bus Supports, and Switch Accessories—Schedules of Preferred Ratings, Manufacturing Specifications, and Application Guide.[2]

ANSI Z535.2, Environmental and Facility Safety Signs.

IEEE Std 80™, IEEE Guide for Safety in AC Substation Grounding.[3]

[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 (http://standards.ieee.org/).
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IEEE Std 525™, IEEE Guide for the Design and Installation of Cable Systems in Substations.

IEEE Std 998™ , IEEE Guide for Direct Lightning Stroke Shielding of Substations.

IEEE Std C37.91™, IEEE Guide for Protective Relay Applications to Power Transformers.

IEEE Std C62.22™, IEEE Guide for Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

NFPA 70, 2005 Edition, National Electrical Code® (NEC®).[4]

3. Definitions

For the purposes of this guide, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B3][5] should be referenced for terms not defined in this clause.

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: The maximum electrical potential that a substation grounding grid might 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 might 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.

3.9 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.

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[3] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).
[4] The NEC® is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA (http://www.nfpa.org/). Copies are also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).
[5] The numbers in brackets correspond to those of the bibliography in Annex A.

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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 are given in Rule 124 of the 2002 National Electrical Safety Code (NESC). Clearances to energized parts for safety of personnel are given in Table 124-1 "Clearances from Live Parts" of the 2002 NESC unless adequate insulation or suitable barriers are provided. Rule 124A.3 of the 2002 NESC states a minimum of 2.6 m between any ungrounded part or parts of indeterminate potential and any permanent supporting surface where workers might stand. Temporary structures might be required to maintain proper clearances.

The following 4.2 and 4.3 refer to the clearances for those temporary connections required to install the mobile. These clearances will not be tested and therefore need to follow the requirements of the NEC, ANSI C37.32-2002, etc. Tested devices such as the mobile substation (if tested) with its permanently installed equipment may have clearances that are less than those of the temporary connections required to place the mobile in service.

4.2 Phase-to-ground clearances

ANSI C37.32-2002 lists recommended and minimum clearances of energized parts to grounded parts in Table 3, Column 4, and Column 5, respectively. Where applicable, refer to Table 710-33 of the 2005 NEC.

4.3 Phase-to-phase clearances

Minimum metal-to-metal clearances between all disconnecting switches, bus supports, and rigid conductors are given in Table 5, Column 3, of ANSI C37.32-2002. Distances between nonrigid parts can be adjusted to provide such minimum clearances. Recommended centerline-to-centerline phase spacing for switches is given in Table 5, Column 6, Column 7, and Column 8 of ANSI C37.32-2002. Where applicable, refer to Table 710-33 of the 2005 NEC.

5. Grounding

5.1 General

IEEE Std 80 provides general and specific guidelines for grounding substations and can be applied to mobile substation equipment. This clause is intended to discuss specific items that need special emphasis or special treatment.

Mobile substations or transformer trailers might be installed in many locations. The trailers might be installed on utility property or non-utility property. On utility property, the mobile substation might be installed inside or outside the permanent substation fence. The mobile substation located outside the permanent substation fence might 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 needs to be given to the touch and step voltages at the mobile substation fence because it is the most likely point of contact by non-utility personnel. Transferred potential rise between the mobile (and its fencing, if applicable) and the substation needs to be managed

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5.2 Safety criteria

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

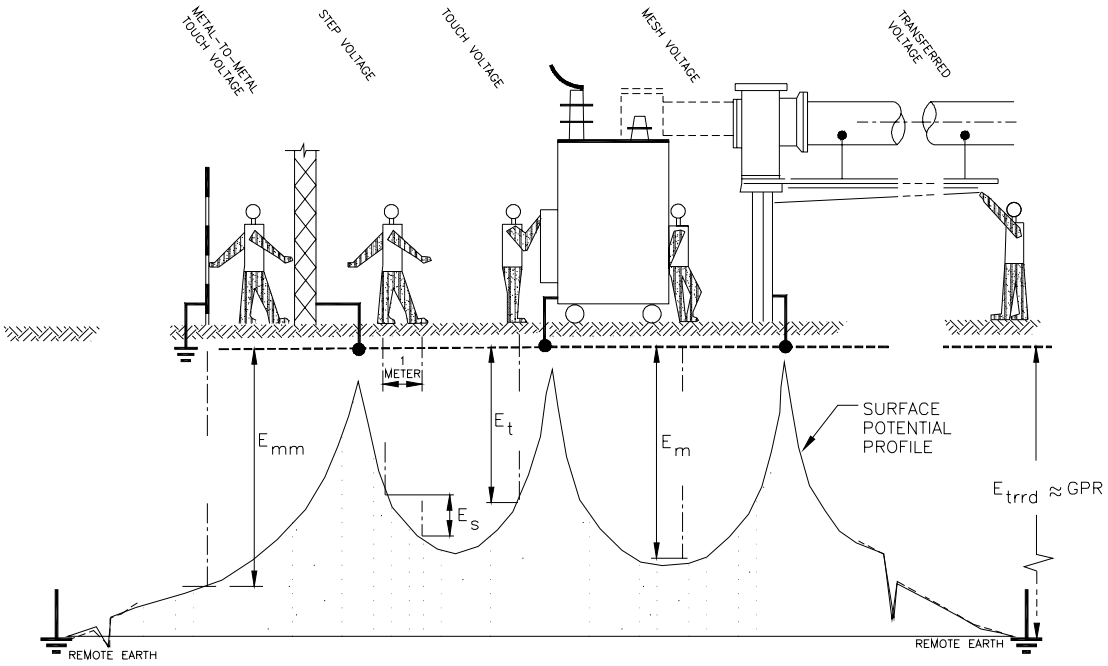


Figure 1—Basic shock situations

The purpose of the grounding system is as follows:

a) To 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) To ensure that a person in the vicinity of grounded facilities is not exposed to the danger of electrical shock greater than allowable by IEEE Std 80

Transferred voltage needs to be considered when a mobile substation is located outside a permanent substation ground grid. If a minimal grounding system is installed around the mobile substation, this transferred voltage might make it very difficult to satisfy tolerable touch and step voltage limits without additional measures. Persons within the mobile substation fence can be protected with appropriate personal protective equipment.

CAUTION

The user is cautioned to protect the public outside the fence from high transferred touch and step voltages.

The grounding system is intended to limit the touch, step, and metal-to-metal touch voltages to acceptable levels for personnel safety and safe equipment operation. If acceptable shock voltages are not achieved, insulating gloves and/or boots can be worn by personnel working around the mobile substation.

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Appropriate signs or barriers can be placed around the mobile substation. For a mobile substation located outside the permanent substation fence, the touch voltage around the mobile substation fence might still be a problem (see 5.4).

5.3 Items to ground

5.3.1 Fence

WARNING

The fence might be either connected to or isolated from the mobile substation grid.
Dangerous voltages can exist during a fault for either case and are described in the following list.

a) A dangerous voltage might 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.

b) If an ungrounded conductive temporary fence is installed adjacent to a grounded substation fence, an isolation section might be necessary to prevent a transfer voltage on the temporary fence.

c) If an isolated conductive temporary fence is installed, it will still attain a fraction of the mobile substation ground potential rise (GPR) due to conduction through the earth, and might pose a danger to persons touching the fence.

5.3.2 Gate

A conductive gate can be bonded to a conductive fence and a bonding conductor can be installed across the gate opening. If the gate swings outward, a loop conductor can be installed to control the touch voltages when opening the gate. If the gate opens inward, no special grounding might be needed unless the fence is isolated from the mobile substation's ground grid. A jumper can be installed across the gate opening to provide continuity to the perimeter conductor.

5.3.3 Trailer frame

The trailer frame and/or trailer ground bus can be connected to the mobile substation 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 can be connected to the mobile substation ground grid using separate, properly sized conductors for each piece of equipment. Multiple trailers (e.g., a switch and fuse trailer used with a mobile transformer trailer) can be connected via the mobile substation grid or a direct cable tie to prevent voltages between them.

CAUTION

Take caution 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) or removable conducting parts (e.g., steps, dollies) can be connected to the trailer ground bus or the ground grid, or both, to minimize voltages between them.

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5.3.4 Cable shield grounding

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

5.3.5 Operator platforms, plates, or insulating mats

In the absence of a properly designed ground grid, or to supplement a properly designed ground grid, operator platforms, plates, and/or special mats can be installed and connected to the grid at all switches and handles that are accessible from the ground. The special mats can be conductive, insulating, or a combination conductive mesh covered by insulating material.

5.3.6 Neutral grounding

Neutral conductors of adequate fault-current capacity can be installed from the mobile transformer to the grid. Feeder neutrals can be connected to the provided attachment point (neutral bushing) or directly to the grid. Transmission line shield wires can be connected to the grid to lower the complete grounding system resistance. Due to the higher resistance of a separate mobile substation grid not connected to the permanent 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 might be exceeded by return currents.

When the mobile substation is located outside the permanent substation fence, the permanent and mobile substation grids can be connected together to lower the GPR. 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. Feeder neutrals and transmission line shield wires are most often left attached to their terminations at the substation buses, with power cables connecting the mobile substation to these buses. The connection of the mobile substation neutral to the permanent substation neutral bus or ground grid will provide another ground connection between the two grids.

5.3.7 Temporary equipment

Any temporary equipment connected to the trailer or equipment on the trailer can 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 might 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 might require different considerations. If the GPR from the permanent substation grid transfers to the often minimal mobile substation grid, it might be difficult to provide adequate safety for persons inside and outside the mobile substation fence. In such cases, persons inside the fence can be protected using appropriate personal protective equipment. For protection of persons outside the fence, see 5.4.2. A low impedance ground path is required to allow operation of protective devices. This might be accomplished by connection of the mobile substation to the permanent substation grounding, connection to the system neutral, or by a separate mobile substation grounding system.

The length of service and the location of the mobile substation are factors in determining the design of the mobile substation ground grid, including what grounding to install and what deviations from standard practices are acceptable. The grid conductor might 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

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the soil surface might be a solution to the touch voltage hazard when a minimal grounding system is installed. This mat might be installed over all or part of the mobile substation area. A layer of high-resistivity material might be installed to help increase the acceptable levels of touch and step voltages. The safe practice of wearing insulating gloves and/or boots might be considered for all personnel inside the mobile substation fence when it is located away from the permanent 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. The protection of persons outside the fence from both touch and step voltages requires different considerations that are dependent on the available short circuit current. For conductive fences, a buried perimeter conductor, either attached to or isolated from the mobile substation grid, might be used. A non-conductive fence can be used as one alternative although other alternatives can be designed. For conducting (metallic) fences, a buried perimeter conductor outside the fence can be installed and connected to the fence to lower the touch voltage. A layer of rock or other high-resistivity material might 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 might be connected to the grid according to local code requirements and accepted utility practices. See 5.3.2 for gate grounding methods.

CAUTION

When the mobile substation is located outside the permanent substation and a common side is shared with the utility or a customer, isolation sections or insulated fencing might be necessary to prevent a dangerous transferred voltage from being conducted on the adjacent fence.

If the mobile substation is located outside and/or away from the permanent substation, take special care to ensure that the touch and step voltages at the fence are acceptable. In the absence of a normally designed and installed grounding system, it might be preferable to isolate the mobile substation fence from the grid. In some cases, especially when the mobile substation is some distance away from the permanent substation, a solution might be the use of non-conductive fence.

5.5 Connection to the existing grid

Above-grade connections might be installed between the permanent substation grid and the mobile grid. When this method is used, consider the following:

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 these 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 might be incurred when the mobile substation is removed from service.

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6. Installation procedures

6.1 Planning

Successful utilization of a mobile substation is dependent on detailed planning of the installation. Mobile substation sites can be selected for suitability prior to emergency situations to facilitate proper installation in a timely manner.

A site within an existing substation can be selected based on a review of the existing substation drawings and a field inspection of the location. Sites outside an existing permanent substation can 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 the mobile substation physical size, electrical clearances, and access requirements need to be considered. This includes related equipment, such as oil tankers and service or test equipment.

The proposed mobile substation travel route can 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 can be determined and they can be obtained from the appropriate departments or agencies.

Oil spill containment can also be considered in the selection of the site, wherever feasible. It might be possible to utilize the oil spill containment measures in the permanent substation, even when the mobile substation is placed outside the permanent substation fence. In other cases, temporary oil spill containment measures might be utilized, where required by national or local codes.

In addition to the details of planning for installation at specific sites, studies can be done to determine the impact of the mobile substation on the performance and protection of the electric distribution system. Standard protective relay settings might be applicable and can be determined prior to required use.

Safety analysis and grounding system design for specific sites can be predetermined prior to required use in order to make appropriate plans and have required materials available for quick installation.

6.2 Surface/site preparation

6.2.1 Existing substation sites

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

6.2.2 New temporary locations

The site can be graded for drainage and equipment installation. Installation of the ground grid is based on the guidance found in Clause 5. Install proper fencing 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.

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6.3 Preparing the mobile substation for transport

Prepare the mobile substation for transportation to the site in accordance with the relevant jurisdictional transportation authority and manufacturer's instructions. This includes the transformer, switches, breakers, control/relay systems, and all connections. Verify shipping dimensions, and inspect the trailers, tires, etc.

Include the following items in a general inspection of the mobile substation prior to transportation:

a) Check the oil level in all tanks, compartments, and bushings and perform dissolved gas in oil tests.

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 Positioning the mobile substation

Position the mobile substation so the route of the temporary high-voltage primary and secondary conductors will not interfere with maintenance of existing substation equipment.

CAUTION

Barricade power and ground cables placed on the ground between the permanent and mobile substations to guard against personnel injury from the whipping action of those cables in the event of a fault.

If feasible, constrain these cables to minimize movement in the event of a fault. Verify electrical and working clearances. Some mobile substations, due to low profile, might require barriers even if placed inside the fenced substation.

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) Allow no more than 5° deviation from level in any direction (side to side, front to rear).

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6.4.3 Grounding the mobile substation

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

Refer to manufacturer's instructions for recommended tests prior to energization. The following tests are suggested:

a) Transformer
   1) Transformer turns ratio
   2) Insulation, oil dielectric, and dissolved gas in oil tests

b) Circuit-interrupting devices
   1) High-potential dielectric tests on interrupting devices
   2) Insulation and dielectric tests

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

d) Relays

e) Operational test—primary and secondary current injection test

6.4.6 Equipment setup

Install the mobile substation in accordance with the manufacturer's instructions. Install lightning protection systems and verify all connections to the arresters and the ground grid.

6.4.7 Pre-energization check items

Prior to energization, verify the following:

a) Power cable connections

b) Control and data acquisition

c) Station service

d) System neutral

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e) Cooling system, including fan and pump operation (proper rotation) and valve position

f) Transformer tap position

g) Operation of load tap changer

h) Transformer primary protective device

i) Coordination of relays/trip circuit checks/alarms

j) Battery and charging systems

k) System phasing

l) Mobile substation grounding, including fence, and all grounding connections

m) Electrical clearances

n) Barriers and warning signs

o) Electrical operation of protective devices

p) Operation and alignment of disconnect switches

q) Stress cone orientation

r) Oil containment considerations

s) Connections to local remote terminal unit (RTU)

t) Check pressure on gas-interrupting devices

u) Record any control wiring changes

6.4.8 Energizing the mobile substation

Energize and load the mobile substation in accordance with established operational practices. Periodically record load, oil temperature, and winding temperatures. Also, consider obtaining periodic gas-in-oil samples and analysis while the unit is in service.

6.5 Removing the mobile substation from service

De-energize the mobile substation in accordance with established operational practices and manufacturer's instructions. Obtain an oil sample for a dissolved gas-in-oil test.

Keep the mobile substation cooling system in operation until top oil temperature has dropped to an acceptable level.

6.5.1 Preparing the mobile substation for transport to storage

Prepare the mobile substation for transportation to storage in accordance with 6.3.

6.5.2 Preparing the mobile substation for storage

Store the mobile substation in accordance with the manufacturer's instructions. This includes checking the power for battery and cabinet heaters, the battery charger float voltage, and the grounding. General inspection and testing, such as oil circulation, nitrogen pressure, oil testing, tire integrity, and other general maintenance, are suggested to allow for any needed repairs prior to the next deployment.

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7. Enclosure practices

7.1 General

Section 110 of the 2002 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. Jurisdictional codes or standards might allow waiver of certain rules for emergency or temporary installations. It is the responsibility of the entity installing the mobile substation to determine if the installation qualifies for such a waiver.

CAUTION

In general, avoid such noncompliance to the extent possible, and correct any condition that might endanger persons or property as soon as practical.

7.2 Fence safety clearances

Rule 110.A of the 2002 NESC provides guidance on locating fence with respect to live parts. In accordance with the NESC, locate exposed live parts outside the safety clearance zone.

7.3 Warning signs

Display appropriate signs. Consideration might be given to locating signs on all sides of the mobile substation enclosure. Refer to ANSI Z535.2 for further guidance in designing and locating the signs.

8. Protection of transformer

8.1 General

Protect the transformer for the following reasons:

a) To electrically isolate 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, might be required.

The choice of interrupting device can 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 they incorporate a visual open break. They do not protect well against some types of faults. Also, fuses are not generally used to energize or de-energize the transformer and therefore might require a separate device for this purpose. Circuit breakers or other types of interrupting devices, such as vacuum switches or circuit

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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.

8.2 Types of transformer failures

When considering transformer protection, the ability of the scheme to detect and clear the following types of failures might be considered:

a) Winding failures
b) Tap changer failures
c) Bushing failures
d) Terminal board failures
e) Core failures
f) Cooling system failures
g) 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 (base rating) 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. 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 might be detrimental to the connected polyphase and single-phase motors and other loads. If required, add special protection for single-phasing conditions.

Base the selection of the fuse and proper ampere rating 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

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Ampere rating selection is facilitated by data published by fuse manufacturers. Such data include time-current characteristic curves, preloading adjustment curves, ambient temperature data 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. Consider this also when selecting the fuse rating.

8.3.2 Differential protection

Current differential relaying is a common type of protection for transformers of approximately 10 MVA (base 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 might 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 can 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) can be used to clear the transformer from the faulted bus or line before the transformer is damaged. On some small transformers, overcurrent relays can also protect in the case of internal transformer faults, and on larger transformers, overcurrent relays can 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.

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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. If an internal fault develops, the rapid rise in oil pressure or pressure pulse is transmitted by the transformer oil and operates a relay. Small rises in oil pressure (e.g., due to changes in loading or ambient temperature) are 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 can 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, consider 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 involve the following considerations:

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 is 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 might 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).

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8.5.4 Circuit switcher

A circuit switcher is a mechanical switching device with an integral interrupter, suitable for making, carrying, and interrupting currents under normal circuit conditions. It is also suitable for interrupting specified short-circuit current that is less than its close-and-latch, momentary, and short-time current ratings. Note: This device might be suitable for transformer protection where the majority of faults are limited by the transformer and system impedance. If possible, 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 can be detected by remote line relays and cleared by the remote breakers before the circuit switcher opens. The circuit switcher might be blocked from tripping using an instantaneous overcurrent relay, or it might be allowed to attempt interruption depending on user preference.

9. Work practices

The references listed in Clause 2, the Handbook of Occupational Safety and Health (HOSH) [B2], or the Regulations and Procedures of the Occupational Safety and Health Administration (OSHA) [B4] have sections that cover general work practices for electrical equipment. Follow the applicable sections to ensure safe work practices for installation of the mobile substation. Annex B lists relevant sections for these references. Users of this guide outside the U.S. and Canada might refer to equivalent documents in their countries. If no such documents exist, it is suggested 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 allocating space for the mobile substation within the permanent substation fenced area, consider permanent or temporary lighting-fixture locations and aiming of floodlight-type fixtures to accommodate the mobile substation.

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

In addition to fixed lighting units (either permanent or temporary), a wide variety of portable lights exist. 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, consider the particular type of plug-in lighting units used by substation repair crews.

10.2 Operational external light

Lights can be mounted on the mobile substation trailer to indicate when the mobile substation is energized. Position the lights to be clearly visible from the front, sides, and rear.

10.3 Alarm external light

A blinking alarm light can 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 selected alarm conditions.

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11. Direct lightning stroke protection

The risk of direct lightning strokes to mobile substations is typically 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.

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 are low in profile to comply with maximum height restrictions for highway travel. As a result, they are less susceptible to attracting direct strokes and might be partially shielded by adjacent structures or transmission lines.

Nevertheless, for installations in areas of high lightning 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 for guidance.

Before installing special shielding, the engineer can 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 is necessary.

12. Surge protection

The shielding from direct strokes as discussed in Clause 11 does not, of course, provide any protection from surges coming in on the line conductors or from nearby direct strokes. The mobile transformer can be fitted with surge arresters located near its terminals to provide this protection. Connect the arresters to the protected equipment and ground grid or equipment frame with leads as short and straight as possible.

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 for guidance in the application of metal-oxide surge arresters.

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Annex A

(informative)

Bibliography

[B1] Canadian Electrical Code, Part I, 17th Edition (C22.1), Safety Standard for Electrical Installations.[6]

[B2] Handbook of Occupational Safety and Health, Fourth Edition, Canadian Government Publication, Minister of Supply and Services, 1989.

[B3] IEEE 100™, *The Authoritataive Dictionary of IEEE Standards Terms,* Seventh Edition.[7]

[B4] Occupational Safety and Health Administration's Regulations and Procedures, Volume I—General Industry Safety Standards, Part 1910, and General Construction Standard, Part 1926.

[6] The Canadian Electrical Code is available from the Canadian Standards Association, 178 Rexdale Boulevard, Etobicoke, Ontario, Canada M9W 1R3.
[7] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

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Annex B

(informative)

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

B.1 Relevant codes and practices

Jurisdictional authorities might have their own approved codes and practices, and can be referenced in lieu of the publications listed in this annex.

B.1.1 HOSH—Canada

The HOSH [B2] addresses the minimum working conditions that are required for employees in their workplace, including electrical safety.

B.1.2 OSHA's Regulations and Procedures—U.S.

OSHA Regulations and Procedures [B4] contains two subparts (R and S) in Volume I of the General Industry Standards and Interpretations 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. 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 Subpart R and Subpart S of this document, contains two flowcharts 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 NEC—U.S.

Although the NEC 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 NESC—U.S.

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

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B.1.5 Canadian Electrical Code, Part I—Canada

Although Part I of the Canadian Electrical Code (CEC) [B1] 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) Rule 10-408 and Rule 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) Section 400-30 through Section 400-36, Portable Cables—NEC

c) Section 710-45, Power Cables—NEC

d) Rule 4-038 and Rule 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

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B.3 General work practices that might 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 might 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) Section 8.4 through Section 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, and N), General Safety Rules—NESC
j) Rule 440 and Rule 441 (A and B), Additional Rules for Supply Employees—NESC
k) Rule 230 through Rule 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, and 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) Section 8.10 and Section 8.11, Poles and Elevated Structures—HOSH
h) Section 8.12 through Section 8.18, Isolation of Electrical Equipment—HOSH
i) Section 8.23, Switches and Control Devices—HOSH
j) Rule 174, Disconnection of Fuses—NESC
k) Rule 190 through Rule 193, Surge Arresters—NESC
l) Rule 422 (A, B, and C), Overhead Line Operating Procedures—NESC
m) Rule 121 (B and C), Equipment Inspections—NESC
n) Rule 380 and Rule 383 through Rule 385, Equipment Installation—NESC

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o) Section 450-26, Indoor Oil Insulated Transformer Installation—NEC

p) Section 450-27, Outdoor Oil Insulated Transformer Installation—NEC

q) Rule 2-300, Rule 2-308, Rule 2-314, and Rule 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) Section 12.1, Section 12.2, and Section 12.3, Safety Material, Equipment, Devices, and Clothing—HOSH

h) Section 12.4 and Section 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) Section 8.19 through Section 8.22, Safety Grounding—HOSH

c) Rule 92 (B, D, and E) and Rule 93 through Rule 97, Grounding—NESC

d) Rule 123, Protective Grounding—NESC

e) Rule 36-300, Rule 36-302, Rule 36-304, Rule 36-306, and Rule 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, from accidental injury during any electrical work:

a) Subsection 1910.303 (h), Basic Protection Requirements—OSHA (Subpart S)

b) Section 1910.335, Safeguards for Personnel Protection —OSHA (Subpart S)

c) Rule 110 (A, C, and D) and Rule 111 (A and 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

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h) Section 110-32, Work Space about Electrical Equipment—NEC

i) Section 110-34, Work Space—NEC

j) Rule 2-200 and Rule 2-202, Protection of Persons and Property—CEC

k) Rule 26-006, Fences for High Voltage Installations—CEC

l) Rule 26-302, Rule 26-304, Rule 26-308, Rule 26-312, Rule 26-316, and Rule 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) Rule 160 through Rule 164, Conductor—NESC

c) Rule 370 through Rule 374, Supply Cable Termination—NESC

d) Section 310-5, Minimum Size of Conductor—NEC

e) Section 310-15, Ampacity—NEC

f) Rule 4-14—CEC

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

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