6B.6—Substation Grounding

1. Scope

This standard covers the general requirements for the construction of company substation grounding systems. It outlines ground mat construction and required grounding connections. The methods outlined herein are nationally-recognized grounding procedures.

2. References

The latest revisions of the following documents apply to the extent specified herein:

IEEE 80, *Guide for Safety in AC Substation Grounding*

IEEE 81, *Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System*

IEEE 1036, *Guide for the Application of Shunt Power Capacitors*

AASHTO T 27, *Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates*

AASHTO T 335, *Standard Method of Test for Determining the Percentage of Fracture in Coarse Aggregate*

ASTM D5821, *Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate*

Should a conflict arise between the reference documents and parts of this document, the more stringent requirement as determined by the company will prevail.

3. General

3.1. Primary Functions

The primary function of the substation grounding system is to increase safety, both to persons and property. Secondarily, it aids in system operation. Adequate ground systems are essential to attain low ground resistance and safe ground voltage gradients within and adjacent to substations yards. The specifications set forth herein shall be followed as closely as possible to ensure the safety of company personnel and the general public.

3.2. Requirements and Philosophy

The company requires its substations, and substations of other ownership connected to its system to have grounding systems which limit “touch-” and “step-voltages” to safe levels during ground fault events.

Touch-voltages are voltages, developed during ground fault events across a person in contact with any piece of equipment connected to the substation ground mat and the earth on which they are standing. Step-voltages are voltages developed between the feet of a person walking in (or near) the substation, during ground fault events.

Permitted touch- and step-voltages are based on industry standards, specifically the recommendations in IEEE 80. This guide shall also be used as a basis for the calculations associated with company standards contained herein. Safe grounding designs in substations are used to meet the following objectives:

- to provide a means to carry electric currents to ground under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service
- to ensure that any person in the immediate area of the grounding facilities is not exposed to any danger of critical shock.

The general philosophy regarding resistance of substation grounding is, "the lower the better," with considerations for economics. The resistance from the ground mat to earth shall be one ohm, or less, for transmission substations and other large electrical facilities. In smaller distribution substations the acceptable range is usually from one to five ohms, depending on the local conditions. Resistance values of more than one ohm shall be brought to the immediate attention of substation engineering.

A ground mat resistance to earth of one ohm generally is adequate to:

1. protect personnel from injury and property from damage by high-voltage surges resulting from lightning, switching, or other causes
2. handle discharge currents from lightning arresters, spark gaps, and other similar devices
3. provide a ground return path for grounded-wye generators and transformers
4. provide stable ground conditions for protective relays
5. improve the reliability of electric process controls, computers, and communication circuits by making low-resistance ground connections accessible

4. Grounding Design

Substation grounding design shall provide a continuous grounding system consisting of a buried main ground grid with ground rods. All equipment, structures, fencing, gates, and buildings shall be connected to the main ground grid. All ground grid conductors which are below the surface shall be bonded at each joint, and at each ground rod, by Cadweld exothermic connections.

4.1. Wire Sizes and Requirements

All ground wires shall be bare and free of any insulation, except as otherwise specified herein.

4.1.1. Main Ground Grid

The main ground grid shall be constructed of 4/0 copper wire, soft-drawn, 19-strand copper wire for substations with a maximum available fault current of 30 kA or less (for one second) and 500 kcmil, soft-drawn, 37-strand copper wire for substations with a maximum available fault current above 30 kA. When expanding existing substations that were built with ground grid wire of 250 kcmil copper, the same ground wire shall be used. The main ground grid shall never be constructed with wire smaller than 4/0 copper.

4.1.2. Equipment

The minimum conductor size used for grounding major substation equipment such as power transformers, circuit breakers, regulators, and capacitor frames, shall be 4/0 soft-drawn copper wire.

Other substation equipment shall be grounded with copper wire as specified in Table 1.

Ground wire sizes shall be indicated on the grounding plan, grounding details, and other drawings as necessary to ensure the installation of ground conductors as specified in Table 1. Where wire is liable to be damaged, larger sizes shall be substituted or protection shall be provided.

Table 1—Wire Size for Grounding of Substation Equipment

Equipment	Copper Wire Size
Steel structures	4/0
Coupling capacitors, instrument transformers, and station service transformers	4/0
Surge arresters	4/0
Distribution-class surge arresters	#2 or larger
Grounding switches	4/0
Switch and fuse bases on wood poles	4/0
Switch-operating mechanism	4/0
Independent yard light supports, steel buildings, metal enclosures, and fencing	#4 or larger
Steel switchboard panels	#6
Meters, relays, and similar equipment on insulating panels	#10

4.2. Main Ground Grid

The main ground grid design shall provide a continuous ground system consisting of copper wire as specified in section 4.1.1, buried 18″ below subgrade and spaced in a grid pattern designed to meet the IEEE-80 requirement for safe “touch-” and “step-voltages.” The ground

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grid shall be designed for site-specific conditions using the CDEGS software program. When the frost level in the given area is deeper than 18″, a calculation to account for the frozen-soil effect should be performed using Soil Model Manager (a CDEGS module) to determine the worst case soil condition that the grounding grid should be designed for. All ground rods, grids, and structures within the substation shall be connected to the main ground grid.

When solid rock or other poor ground conditions are encountered, substation engineering shall be advised, so that a special grounding system can be designed and installed.

4.2.1. Peripheral Ground Conductors

Peripheral ground conductors shall be installed 4′ inside and outside the fence, parallel to the fence. The peripheral ground conductor shall be constructed of the same copper wire as the main ground grid, buried 18″ below subgrade and connected to the main ground grid at intervals equal to the pattern of the main ground grid. No building, metallic fence, or conductive structure of any kind shall be located between the fence and the property line.

4.2.2. Gate Grounding

A ground grid shall be installed at gates in such a way that a person in contact with the gate during opening and closing will always be standing over the grid. Gate grounding grids shall be connected directly to the peripheral ground conductors and to the main ground grid.

4.2.3. Ground Rods

Ground rod requirements shall be as specified in this subsection. Ground rods shall be ⅝″ diameter copperweld, and 8′ long. Ground rods shall be fully driven below the surface of the earth.

Ground rods shall be connected to the ground grid with approximately equal spacing within the yard, and along the fence. The normal maximum spacing shall be 50′.

One ground rod shall be installed for every grid connection at power transformers. One ground rod shall be located within 2′ of the point where major equipment neutrals connect with the main ground grid. If there are large areas within the substation fence that are not immediately used, rod spacing may be increased to approximately double the spacing in other areas.

4.3. Structure Grounding

All steel structures and all miscellaneous steel, including light framework, steel support structures, and metal buildings, shall be solidly connected to the main ground grid with 4/0 copper wire.

All line and bus support structures shall be connected to the ground grid at each column. Each switch structure, or other similar structures, shall be connected to the ground grid at two columns, preferably at two diagonally opposite columns. One grounded column will suffice on small structures supporting a single instrument transformer, surge arrester, or other similar equipment.

The substation ground system shall be bonded at one point to each water system present within the substation.

4.4. Equipment Grounding

All system neutrals, surge arresters, grounding devices, transformers, reactors, circuit breakers and similar equipment bases shall be connected to the main ground grid with 4/0 copper wire.

Surge arresters, spill gaps, grounding switches, metal housings, equipment guards, and all metallic non-current-carrying parts of current-carrying devices shall be solidly tied with grounding conductors to the main ground grid system except as follows:

1. In cases where system requirements dictate that transmission line overhead shield wires (located in substations) shall be isolated from the substation ground grid, the shield wires shall be terminated using insulated deadends.
2. In cases where it is desirable to ground overhead shield wires to substation ground grids, grounding steel support structures to the main grid shall be considered adequate for the overhead shield wires.
3. Switch and fuse bases attached to steel structures shall be considered adequately grounded through the steel and the main ground connection.

Grounding requirements for overhead transmission lines shall be dictated by overall system requirements and shall be addressed on a per-project basis.

Operating handles of group-operated switches shall be grounded directly to the main ground grid. A protective, galvanized, steel switch ground plate shall be provided for installations above 25 kV. The switch handle shall be connected directly to the main grid with a single run of 4/0 copper wire and a flexible copper strap. The switch handle shall be directly bonded to a switch ground plate. Two diagonally opposite corners of the switch ground plate shall be connected to the ground grid. The switch ground plate shall be located on top of the finish crushed rock layer and shall be of an adequate size and be positioned such that the switch operator's feet will never be outside the perimeter of the ground plate during switching operation.

4.5. Transformer Grounding

Transformer tanks shall be connected to the main grid at two points located at diagonally opposite corners of the tank.

Neutrals of grounded-wye-connected power transformers shall be connected to the main ground grid using two parallel 4/0 copper wires. These grounding copper wires shall be connected to the main ground grid through a PVC pipe attached to the transformer tank by the transformer manufacturer.

Lightning arresters shall be grounded to the main ground grid with 4/0 copper wire.

One ground rod shall be installed within 2′ of the point where the transformer neutral interconnects with the main ground grid. One ground rod shall be installed for each neutral and each lightning arrester ground connection to the main ground grid.

The neutrals, or grounded side, of wye-connected instrument and station service transformer primaries shall be solidly connected to the main ground system with 4/0 copper wire.

Neutrals of instrument transformer secondaries, whether that of a single transformer or a set of interconnected transformers, shall be grounded at one point only. This also applies to certain types of secondary circuit interconnections, such as differential relaying or current totalizing, and any auxiliary transformers that may be required in the circuit. The location for the connection to the main ground system shall be at the switchboard and be connected such that it will not be removed unintentionally during testing or other work on the circuit.

The neutrals of unrelated secondaries shall be connected to the ground individually with one connection under a single screw (and not, for example, through the use of a single conductor jumpered from point-to-point on the terminal boards).

Neutrals of station service transformer secondaries shall be grounded at the transformer and at the main switch under the lug provided in the switch enclosure, thence to the main ground system.

4.6. Conduit and Cable Grounding

4.6.1. General

All metallic conduit shall be effectively connected to the ground grid, either by direct connection or by attachment to metal enclosures which are adequately connected to the ground grid.

Neutral conductor placed outside metallic conduit that carries feeder cables shall be bonded to the metallic conduit at both ends.

4.6.2. Distribution Substations

Metallic sheaths of control cable in distribution substations shall be grounded at one end only, unless specified otherwise. Control cable sheaths shall be grounded at the control house end of the cable. The control cable sheath at the equipment end shall be covered with electrical tape.

4.6.3. Transmission Substations

4.6.3.1. Below 230 kV

The method for grounding control cable sheaths in transmission substations below 230 kV shall be the same as specified for distribution substations
(see 4.6.2).

4.6.3.2. 230 kV and Above

Metallic sheaths of all control cable in transmission substations 230 kV and above shall be grounded at both ends of the cable at a minimum. A parallel 4/0 copper ground wire shall be installed with the control cable and other low-voltage circuits from the equipment to the control house or to the circuit's point of termination. The control cable sheath and parallel ground wire shall be connected together and grounded at the equipment, in the control house or the point of circuit termination, and at any intermediate junction boxes or manholes through which the circuits run.

CCVTs and free-standing current transformers at a voltage greater than or equal to 230 kV shall be grounded using the following method in order to minimize electrostatic and magnetic coupling of control wire connected to such equipment:

1. Install only shielded control cable in the substation yard. Install a parallel 4/0 copper ground wire with the control cable from the equipment to the control house or to the circuit's point of termination. It is not necessary to install extra parallel ground wires where multiple control cables share the same cable trench. Where control cables branch away from the main cable trench en route to the specific piece of equipment, the parallel ground wire shall be tapped using 4/0 copper wire and extended with the control cable to the equipment.
2. Install galvanized steel conduit from the equipment to the junction box and from the junction box to a point located 18″ below grade. The steel conduit helps attenuate high-frequency transients.
3. Connect the parallel 4/0 copper wire to the ground grid at the equipment and at the control house or the circuit's point of termination.
4. Install a #4 copper parallel ground wire inside the conduit from the equipment cabinet to the junction box or pull box. Connect the #4 copper ground wire to the equipment cabinet, junction box, and parallel 4/0 copper ground wire.
5. Connect the control cable sheath to the ground wire in the equipment cabinet, junction box, control house, or the circuit's point of termination. Grounding two or more locations on the metallic sheaths of control cable shall not be done without installing a parallel 4/0 copper ground wire over the entire length of the control cable. In addition, all ground connections made to the control cable metallic sheaths shall be bonded connections to the parallel 4/0 copper ground wire, either by direct connection or through some other copper wire connection.

A parallel ground wire shall be installed along with the control cable where multiple sheath grounds are required for the following reasons:

- it provides electrostatic shielding from overhead buses
- it minimizes magnetic coupling by reducing the loop area between the ground grid and the control cable sheath
- it prevents large magnitude currents from flowing in the control cable sheath during faults and other transient events
- it equalizes ground grid potential differences over the entire length of the cable

4.6.3.3. Multiple-Voltage Substations

For multiple-voltage substations (or for a single-voltage substation that may change to a multiple-voltage substation in the future) the type of conduit used (PVC or steel), and the method for grounding the conduits and cables in each yard shall be determined by a company standards engineer.

Taking into consideration the substation's ultimate layout and transmission line placements, the standards engineer may require the grounding methods specified in Section 4.6.3.2 (230 kV and Above) of this document, even though the initial design would have called for grounding according to Section 4.6.3.1 (Below 230 kV).

4.7. Switchboard Grounding

All metallic switchboards, bases, supports, and braces shall be connected to the ground grid with a minimum size of #6 copper wire. All meter, relay, and instrument cases and all instrument and control switches that are mounted on insulating panels shall be grounded with #10 copper wire.

4.8. Fence Grounding

All metallic fencing shall be securely tied to the main ground system inside the substation at each gate post, corner post (omit corner tie if 30′ or closer to the grounded gate post), and line posts at intervals of no more than 50′. The main ground grid shall ground to the gate posts, corner posts, and line posts, and fabric shall be grounded on both sides of any line crossing. The peripheral conductor of the main ground grid shall be located both 4′ inside and outside of, and parallel to, the fence and shall be buried 18″ below subgrade. The fence shall be grounded to the main ground grid at intervals of no more than 50′. Ground rods shall be driven along the conductor, and bonded at each fence corner, and at intermediate intervals of no more than 40′.

Fence posts shall be grounded by extending #4 copper wire from the main ground grid to the fence post and connecting the #4 copper wire to the fence post, using a bolted ground connector. The #4 copper wire connected to the fence post shall be extended and connected to the fence fabric using a bronze vise-type connector for #4 copper to #4 Al conductors. The #4 Al or #4 copper ground wire shall be extended toward the top of the barbed wire with connections made to the fabric and each barbed wire strand using bronze vise-type connectors.

Gates shall be grounded by extending #4 copper wire to the gate posts and connecting it to the gate post using a bronze vise type connector. The gate shall be grounded by connecting a flexible braided copper strap, with tin-plated ferrule at each end, between the gate post and gate frame. The #4 copper or #4 Al wire connecting the gate post to the ground grid shall be extended from the gate post to the gate fabric and connected using a bronze vise-type connector. The #4 wire shall then be extended toward the top of the barbed wire with connections made to the fabric and each barbed wire strand using bronze vise-type connectors.

On gates which may be opened outward, an additional ground conductor shall be laid 4i beyond the extreme reach of the gate as it is swung out. Each end of this conductor shall be bonded to the main grid, making it an integral part thereof.

4.9. Control House Grounding

The control house shall be grounded to the main grid at two diagonally opposite corners using 4/0 copper wire. Metal buildings with panel sections which are bonded together by brazed or bolted connections shall be considered adequately grounded. Metal buildings with panel sections which are not bonded together in this manner shall not be considered effectively grounded and shall require an externally placed #4 copper wire along the entire wall length with connections made to each panel section. If the inner and outer walls of the building are isolated from each other and from each panel section, a #4 copper wire shall be placed along the entire wall length of both the interior and exterior walls with connections made to each panel section.

Control buildings or houses with cable trenches shall have a 4/0 copper wire looped through the trench with attachments made to the trench wall using bronze vise-type connectors. Switchboard panels shall be grounded by tapping #6 copper wire off the 4/0 copper loop, terminating at the switchboard panel using a bolted-ground connector.

Control buildings or houses with overhead cable trays shall have a 4/0 copper wire looped through the tray with connections to the tray wall using bronze vise-type connectors. Switchboard panels shall be grounded in a manner similar to the method presented in the previous paragraph.

Cable entrance vaults shall be used for both the cable trench and overhead cable tray designs. In both cases, the looped 4/0 copper wire shall be brought into the control house through the cable entrance vault. In cases where cable termination cabinets are used, the cabinets shall be grounded by tapping #4 copper wire off the 4/0 copper looped wire and connecting to the ground bus bar of the cabinet.

4.10. Multiple Shunt Capacitors Grounding

Where two or more grounded-wye shunt capacitors are located in the same substation, the neutrals of these capacitor banks should be grounded using the “single-point” or “peninsula” grounding methods underlined in IEEE Standard 1036, Section 9.1.2. These grounding methods are intended to protect control cables, relays, and current and voltage transformers from the damage caused by the transients associated with capacitor back-to-back switching.

When using the single-point grounding method, the neutrals of all capacitor banks of a given voltage are connected together with insulated cable and tied to the substation ground grid at only one point. This arrangement prevents high-frequency currents that flow between capacitor banks during back-to-back switching from flowing in the ground grid. IEEE 1036, Figure 25 details this method. IEEE recommends the use of shielded cable between the capacitor bank’s neutral and the single-point ground, with the shields grounded at both ends of the cable to reduce voltage buildup at the end of the capacitor bank neutrals during switching. IEEE 1036 also recommends that voltage transformers used with shunt capacitor banks should have two bushings with the primary connected to the capacitor bank neutral and to the station ground grid.

With peninsula grounding, one or more ground grid conductor(s) are carried underneath the capacitor rack of each phase of each group and tied to the main station ground grid at one point at the edge of the capacitor area. All capacitor bank neutral connections are made to the isolated peninsula ground grid conductor(s) only. This method allows the rise of potential at the capacitor bank neutrals and associated current and voltage transformers, but it reduces these transients in the rest of the substation. This method is detailed in IEEE 1036, Figure 26.

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4.11. Yard Finish Rock Requirements

Yard Finish rock covering is an integral part of the safety system. The substation shall not be energized until the rock covering is installed. If it is absolutely necessary to energize the substation before the covering is completed, all uncovered areas shall be clearly marked with barriers and warning signs. Entry into those areas shall be avoided.

The substation yard, with the exception of roadways, shall be covered with a minimum depth of 4″ of Yard Finish crushed rock. The Yard Finish rock shall be placed under each electrical bus and at least five feet beyond the bus perimeter, five feet beyond any steel structure, five feet on both sides of the exterior substation metallic fence, and five feet on either side of any internal metallic fence. Yard Finish rock shall be placed at least five feet from the perimeter of any steel building.

Security walls constructed of concrete, concrete block, or earthen brick need not have Yard Finish rock placed within five feet.

4.11.1. Gradation (Sieve Analysis According to AASHTO T27)

The size of the crushed rock shall be 1½″ to ¼″ crushed rock. The crushed rock shall meet the sieve requirements specified in Table 2.

Table 2—Yard Finish Rock Sieve Requirements

Sieve Size	Percent Passing
1-½″	100
¾ or ⅝″	0-30
¼″	0-5

4.11.2. Fractured Face

There shall be at least one mechanically-fractured face on 95% of all particles retained on each sieve ¼-inch and above. In addition, there shall be at least three mechanically-fractured faces on 70% ofr the same particles (per AASHTO T 335 or ASTM D5821).

4.11.3. Resistivity

Yard Finish rock shall have a minimum electrical resistivity of 3,000 ohm meters when tested in accordance with industry standards in the saturated wet condition adjusted for the resistivity of the water to 100 ohm meters.

5. Grounding Tests

All grounding systems shall be tested to remote-ground as soon as possible after installation. The results shall be reported promptly to substation engineering. Resistance values of more than one

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ohm shall be brought to the immediate attention of substation engineering. A second test shall be performed during the dry season, after the earth has settled.

6. Dissimilar Metal Requirements

To prevent galvanic action between dissimilar metals, buried copper ground wire shall not be buried adjacent to buried steel pipe or structural steel. If this is unavoidable, both metals shall be painted with a heavy coating of bitumastic paint, or the ground wire shall be enclosed in lengths of nonmetallic conduit at points where dissimilar metals are in close proximity. An exception to this requirement is the substation ground system, which shall be bonded at one point to each water system that may be present within the substation.

When making connections to painted metal, all paint shall be removed prior to making connections to ensure sufficient electrical contact.

7. Issuing Department and Approvals

The engineering standards and technical services department of the company published this document. Questions regarding editing, revision history, and document output may be directed to the lead editor at eampub@pacificorp.com. Technical questions and comments may be directed to Iuda Morar, substation standards engineering, (503) 813-6937. This handbook document shall be used and duplicated only in support of company projects.

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