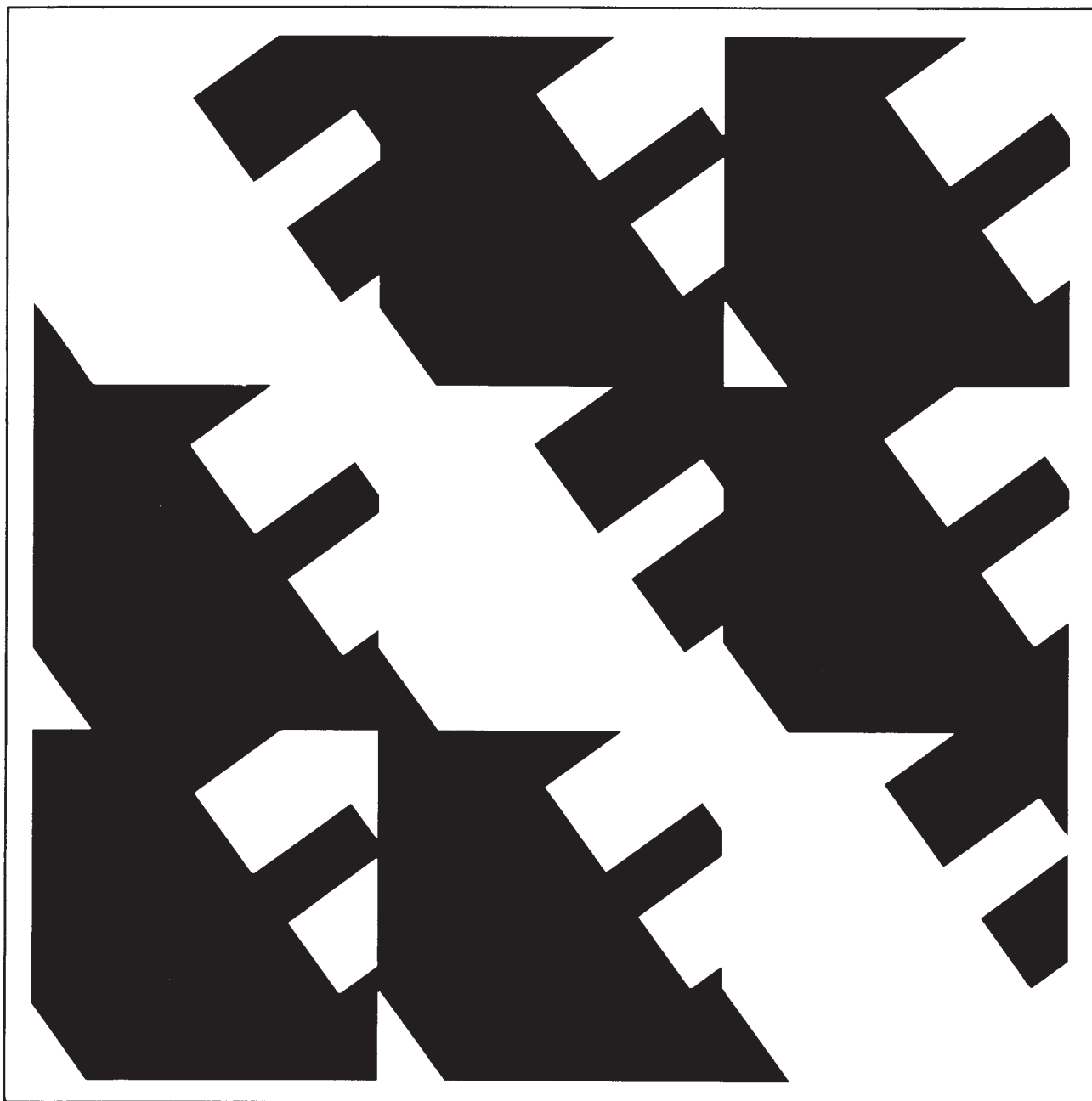


IEEE Guide for Generating Station Grounding

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IEEE Guide for Generating Station Grounding

1. Purpose and Scope

This application document was developed to identify generating station grounding practices that generally have been accepted by the electric utility industry as contributing to a safe and effective grounding system.

This document is intended to provide a guide for the design of generating station grounding including the interconnection of the station and substation grounding systems.

2. Introduction and References

2.1 Introduction. This document pertains to grounding practices applied to generating station indoor and outdoor structures and equipment. It identifies the principal parameters in the selection of acceptable practices for personnel safety and equipment protection. It applies to all generating stations, and it generally reflects current grounding practices in the electrical utility industry. It is intended for use in conjunction with ANSI/IEEE Std 80-1986 [1]¹ and ANSI/IEEE Std 81-1983 [2].

It is not intended that this document provide test methods, mathematical analysis, grounding design, or quantitative analysis of the effects of lightning surges. This document should not be interpreted as requiring any specific design for a particular installation, but is a guide that the designer should recognize and consider.

This document is equipment oriented and includes coverage of grounding practices in four parts:

Grounding of the high-voltage system and generator.

Grounding of generating station auxiliaries, electrical equipment.

Grounding of and lightning protection for generating station structures.

Grounding of buried structures.

A bibliography is also included to provide supplemental information and to document sources of information included herein.

2.2 References. This standard shall be used in conjunction with the following publications:

[1] ANSI/IEEE Std 80-1986, IEEE Guide for Safety in AC Substation Grounding.²

[2] ANSI/IEEE Std 81-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System.

[3] ANSI/IEEE Std 142-1982, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.

[4] ANSI/IEEE Std 487-1980, IEEE Guide for the Protection of Wire-Line Communications Facilities Serving Electric Power Stations.

[5] ANSI/NFPA 50A-1984, Gaseous Hydrogen Systems.³

¹ The numbers in brackets correspond to those of the references listed in 2.2.

² ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Service Center, Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

³ ANSI/NFPA publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from Publication Sales, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

- [6] ANSI/NFPA 77-1982, Static Electricity.
- [7] ANSI/NFPA 78-1983, Lightning Protection Code.
- [8] ANSI/UL 96-1981, Safety Standard for Lightning Protection Components.⁴
- [9] BROWN, G. W. Lightning Performance I—Shielding Failures Simplified. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-97, no 1, Jan/Feb 1978.⁵
- [10] FAGEN, E. J. and LEE, R. H. The Use of Concrete-Enclosed Reinforcing Rods as Grounding Electrodes. *IEEE Transactions on Industry and General Applications*, vol IGA-6, no 4, July/Aug 1970.⁵
- [11] SVERAK, J. G. Simplified Analysis of Electrical Gradients Above a Ground Grid. *IEEE Transactions on Power Apparatus and Systems*, vol PAS 103, no 1, Jan 1984.

3. Definitions

bolted fault. A short circuit or electrical contact between two conductors at different potentials, in which the impedance or resistance between the conductors is essentially zero.

bonding. The permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed.

bonding jumper. A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.

continuous enclosure. Refers to a type of isolated-phase bus in which the enclosure is elec-

trically continuous over the full length of the bus. All enclosures are electrically tied together at each end of the bus.

equipment-grounding conductor. The conductor used to connect the noncurrent-carrying metal parts of equipment, raceways, and other enclosures to the service equipment, the service power source(s) ground, or both.

four-wire systems. A three-phase system consisting of three phase conductors and a neutral conductor.

grid mesh. Any one of the open spaces enclosed by the grid conductors.

ground grid (grid). A buried geometric network of interconnected bare conductors.

high-voltage system. An electric system having a maximum root-mean-square ac voltage above 72.5 kV.

isolated-phase bus. A metal-enclosed bus in which each phase conductor is enclosed by an individual metal housing separated from adjacent conductor housings by an air space.

metal-enclosed bus. An assembly of rigid conductors with associated connections, joints, and insulating supports within a grounded metal enclosure.

noncontinuous enclosures. Refers to a type of isolated-phase bus in which the enclosure is sectionalized with insulation between sections to block the longitudinal flow of current in the enclosure.

nonsegregated-phase bus. A metal-enclosed bus in which all phase conductors are in a common metal enclosure without barriers between the phases.

overhead ground wire. An overhead ground wire is a grounded, bare conductor suspended horizontally between supporting rods or masts to provide protection from lightning strokes for structures, equipment, or suspended conductors within the zone of protection created by the masts and overhead ground wire combination.

segregated-phase bus. A metal-enclosed bus in which phase conductors are in a common metal enclosure but are segregated by metal barriers between phases.

station. For the purpose of this document, station is synonymous with generating station.

⁴ ANSI/UL publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from Publication Stock, Underwriters Laboratories, Inc, 333 Pfingsten Rd, Northbrook, IL 60062.

⁵ IEEE publications can be obtained from the Service Center, The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

supplementary equipment ground. A grounding conductor used to connect the equipment frame to local grounding system to minimize potential difference.

tolerable voltage difference. The maximum potential difference that would cause a body current to flow of such value as not to cause ventricular fibrillation.

transferred voltage. This is a special case of touch voltage. It is that voltage between points of contact, hand to foot or feet, in a station where the conductor touched is grounded at a remote point or touching at a remote point a conductor connected to the station ground grid. Here the voltage rise encountered due to ground fault conditions may be the full voltage rise of the ground grid and not the fraction of this total, which is encountered in the usual touch contact.

zone of protection. The zone of protection provided by a grounded air terminal, mast, or overhead ground wire is the adjacent space that is essentially immune to direct strokes of lightning.

4. Design Objectives

It is intended that this document identify grounding practices directed toward the achievement of the following design objectives:

- (1) Maintain safe voltages across the station area during high-voltage system transients.
- (2) Provide a low-impedance ground-fault current return path.
- (3) Maintain safe voltages within station structures during electrical transients.
- (4) Minimize noise interference in instrumentation systems.
- (5) Minimize the effects of lightning surges on equipment and structures.

5. Detailed Design Considerations

5.1 Grounding of the High-Voltage and Generator-Voltage Systems

5.1.1 General. The purpose of this section is to provide guidance in the design of the generating station ground grid and station-to-substation ground grid interconnection.

5.1.2 Available Ground-Fault Current. The ground grid design should be based on the maximum

ground-fault current that is expected to occur during the design life of the station. In designing the grid layout, for step and touch voltages the maximum ground-fault current expected to flow between the grid and the earth should be considered.

The total ground-fault current should be separated into the generating station and transmission/distribution system contributions. The ground grid layout should be based on the larger of the two.

The step and touch voltages are determined by the current per meter of ground grid conductor that actually takes an earth path.

When there is a system ground fault remote from the station ground grid, the ground currents from the remote sources do not enter the station grid and therefore do not develop step and touch voltages in the grid area.

Step and touch voltages are not affected by ground-fault current to the generator main transformer(s) when the fault is within the station ground grid, since the current has a metallic return path. However, there may be significant step and touch voltages on the transformer and nearby structures due to the system contribution and metallic path impedance.

No consideration is given in this section to ground-fault currents resulting from the generating station auxiliaries. Faults fed from the secondaries of the unit auxiliaries transformer or the start-up transformer have metallic paths between the source and the fault and thus cannot contribute to ground gradients.

The maximum total ground-fault current availability should be determined for a bolted fault on the substation bus having the highest available fault current in order to size the ground conductors.

The sum of the ground-fault current contributed by the transmission/distribution system and generating station should be considered for sizing the grounding conductors connecting to the ground grid.

Typical values currently range between 35 kA and 45 kA with some systems being designed for 100 kA. These are typical values for large stations, and lesser values may be encountered.

5.1.3 Time to Clear the Ground Fault. Design of bus relaying follows well-established technical procedures. Therefore, the time to clear the initial bus fault plus the time for backup relaying to operate are firm numbers. These numbers should be used in the design. A

typical time to clear a ground fault by backup relays on a high-voltage transmission system is $\frac{1}{3}$ second (20 cycles).

Unrealistic values for time to clear a ground fault result in an excessive amount of buried copper in the ground grid.

5.1.4 Soil Resistivity. One of the most important parameters in designing the station grounding system is the resistivity of the soil in the station area. There are two resistivity values required for the design of a grounding system; one is the resistivity of the surface soil and the other is the average (apparent) resistivity of large volumes of soil. To obtain these values, an extensive soil resistivity survey should be conducted in the station area. The most common test methods are the Wenner Four-Probe Method, which is used to measure large volumes of soil, and the Soil Box Method, which is used to measure soil samples.

Very early in the generating station construction phase, extensive soils exploration is required. Hence, soil boring logs are usually available. Invariably, either a formal soils report is available or a cognizant civil engineer has knowledge of subsurface conditions and the plans for final grading. Frequently, test pits are dug and there is an opportunity to measure subsurface soils directly.

In most temperate regions, it is impractical to design a ground grid where the total length of the conductor (or the equivalent length of ground rods) lies below the frost line. However, experience has shown that ground grids buried at nominal depths of 0.5 to 0.6 m (18 to 24 in) are safe. As an added precaution, the perimeter conductor may be buried below the frost line, or perimeter ground rods may be driven, penetrating the frost line. This has the effect of keeping the overall resistance to earth essentially constant when the ground is frozen.

5.1.5 Preliminary Ground-Grid Layout. A preliminary ground-grid layout may be established once the arrangement of the station is established. No calculations are required for this layout.

Each building should be ringed with a grounding conductor. This conductor can then be used to tie the building steel into the ground grid.

Generally, one or more high-voltage substations are located on the site of the station. The grounding system of the substations should be tied into the generating station ground grid where practical.

An estimate of the length of grounding conductor to be installed within the substation should be obtained.

Where practical, the ties between the station ground grid and the substation ground grid should include grounding conductors installed directly under the tie line to the generator transformer.

Occasionally, the high-voltage substations are located thousands of feet from the generator transformer, and it becomes impractical to tie the substation ground grid and generating station ground grid together. This can present some potentially serious problems, as discussed in 5.4.6.

Assuming the substation ground grid is designed to be separate from the generating station ground grid, the generating station ground grid should be designed for a ground fault on the high-voltage side of the generator transformer.

Any interconnections between the two ground grids (control wiring, multiplexing leads, telephone lines, etcetera) can be subjected to the difference in potentials between the two ground grids. Under fault conditions, potential differences of 5 kV or more are not uncommon.

Even if the remote substation ground grid is tied to the generating station ground grid, there may be significant potential differences between the two grids due to inductive effects.

Interconnecting the ground-grid perimeter, buildings, and substation completes the preliminary design.

5.1.6 Resistance to Earth. The design resistance is useful in estimating the magnitude of voltage expected to appear between the station equipment and equipment located external to the station area.

Some designers prefer to limit the overall voltage rise to 5 kV. However, in high-resistivity soils this limit may require excessive ground grid area. Limiting the grid to some voltage rise rarely improves the safety of the grid, since safety is largely a function of available step and touch voltages. However, some telephone companies may request a specific limit to safeguard their equipment. The full grid voltage rise appears between the plant telephone system and the off-site telephone lines. Telephone lines are also affected by line induction during fault conditions.

Ground-grid resistance is calculated using the ground-grid area and length of grounding con-

ductors of the preliminary layout coupled with the assumed value of soil resistivity.

The effect of other buried materials is discussed in 5.1.17.

5.1.7 Ground Rods Versus Ground Grid.

Some designers prefer to use a ground grid that consists entirely of bare conductors; others prefer a combination of bare conductors with ground rods, while still others prefer to use deep rods with insulated conductors. All methods are acceptable, but the calculations required for ground rod system analysis are more difficult, and care should be taken to ensure that tolerable step and touch voltages are achieved, particularly where insulated conductors are used. Confirmation of a ground rod system design can best be obtained by simulated ground fault tests.

Consideration should be given to the selection of grounding materials that will minimize corrosion.

5.1.8 Touch Voltage. The maximum touch voltage (the mesh voltage) within a grid mesh is the voltage difference between the grounding conductor and the earth in the center of that grid mesh. An example would be a person standing equidistant from surrounding grounding conductors and operating a valve on an above-ground pipe.

The tolerable touch voltage difference depends on many variables such as the resistivity of the soil (or other material such as rock or concrete) on which the person is standing, the clearing time of the fault, etcetera.

The actual touch voltage can be calculated and depends on the resistivity of the soil surrounding the grounding conductor, the ground fault current, the length of buried grounding conductor and two coefficients, K_m and K_i , as referenced in 5.1.10.

Safe design requires the calculated touch voltage to be less than the tolerable touch voltage.

If the preliminary design is not adequate, then additional length of grounding conductors should be added to lower the value of mesh voltage and make the design safer.

5.1.9 Step Voltage. The tolerable step voltage difference depends on many variables such as the resistivity of the soil (or other material) in contact with the feet, time duration of the fault, etcetera.

Step voltages rarely become a design consideration because the tolerable touch voltage difference is so much lower. However, step voltages at the grid perimeter should be calculated to

confirm this.

The actual step voltage can be calculated given the soil resistivity in contact with the feet, the ground fault current, the length of buried grounding conductors and two coefficients, K_s and K_i , as referenced in 5.1.10.

For a safe design, the calculated step voltage should be less than the tolerable step voltage difference.

5.1.10 Calculation Coefficients K_m , K_s , and K_i .

K_m , K_s , and K_i are coefficients that are defined and used in various formulas appearing in ANSI/IEEE Std 80-1986 [1]. $K_m K_i$ are used in calculating the touch voltage. $K_s K_i$ are used in calculating the step voltage.

ANSI/IEEE Std 80-1986 [1] allows the determination of step and touch voltage coefficients by three methods: based on suggested values, based on models, and based on equations.

Laurent suggests a value of 0.1 to 0.15 for $K_s K_i$. Niemann suggests a value of about 1.2 to 1.3 for K_i . Laurent recommends values of 1 for $K_m K_i$.

Experiments with models of various ground grid configurations indicate maximum values of $K_m K_i$ ranging between 1.73 and 2.23.

Equations are given in ANSI/IEEE Std 80-1986 [1] and in other references such as "Simplified Analysis of Electrical Gradients Above a Ground Grid" [11] for the determination of K_i , K_m , and K_s . However, great care should be taken with these equations because they yield considerably higher coefficients for large grid meshes typically over 150 m (500 ft) wide, which are associated with generating stations covering large areas.

5.1.11 Voltage Gradients Under Transmission Lines. Voltage gradients in the substation and particularly where the transmission lines cross the station perimeter grounding conductor will be much steeper than at locations remote from the high-voltage bus and lines.

This is the result of ground fault current tending to concentrate itself in close proximity to the power conductor feeding the fault. Grounding conductors within the ground grid should therefore be provided under all high-voltage lines, where practical.

5.1.12 Overhead Ground Wires. Incoming transmission lines generally have one or two overhead ground wires for lightning protection of the lines.

Some utility systems electrically isolate the overhead ground wire from the generating sta-

tion ground grid by means of a series insulator in the overhead ground wire, between the substation structure and the first tower outside the ground grid. Although there may be valid reasons for isolating the overhead ground wire from the ground grid, it should be noted that steep gradients can be expected at the bases of the first few towers outside the ground grid that result from the overhead ground wire fault current being forced into the ground at the base of the tower.

When the overhead ground wire is tied into the ground grid, the first tower outside the ground grid may still carry considerable ground fault current.

It is permissible to deduct the overhead ground wire current from the ground fault current for step and touch voltage calculations if the overhead ground wire is tied directly to the ground grid. Methods exist for these calculations and they should be available from the transmission line designers, who check the ground wire current-carrying capability under fault conditions.

5.1.13 Grounding Conductor Size. Wire size may be calculated using ANSI/IEEE Std 80-1986 [1]. This implies that any conductor and its joints in the grid are capable of conducting the entire ground fault current without exceeding a specified temperature, depending on the type of connectors used.

Smaller conductor sizes or conductors of materials other than copper can be justified if division of ground currents within the grid can be determined.

For mechanical reasons, grounding grid conductors are rarely smaller than 4/0.

5.1.14 Transferred Voltages. Voltages can be transferred outside the ground grid by railroad tracks, metallic pipes, conduit, low-voltage neutral circuits, communication circuits, and fence sections that may extend past the limits of the ground grid. While the main concern is with the transfer of ground grid voltage outside the station, transfer of voltages can also occur within a generating station site, particularly if the site is quite extensive.

Where the possibility of transferring voltages exists, a means of ensuring safe values of step and touch voltages should be provided. Insulating structures at the perimeter of the ground grid is one possibility (for details see 5.4 and Fig 3).

5.1.15 Crushed Rock. It is common in the design of substation ground grids to specify high-resistivity crushed rock surfacing for the entire substation area. While this is both effective and practical for the limited area of the substation, it is not practical for the entire generating station area.

5.1.16 Testing. Frequently, test requirements for a completed ground grid consist of measurement of the final resistance to ground. As indicated earlier, resistance to ground is rarely a measure of the safety of the grid. When the safety of the grid design is questioned, the touch and step voltages should be tested.

The most commonly used test method to determine resistance to ground is the Wenner Three-Pin Method. The measurement of touch and step voltages most frequently employs a simulated ground fault test.

The Wenner Three-Pin Method consists of connections to the ground grid, a current pin, and a potential pin.

Great care should be used when testing using the three-pin method. It is not uncommon to have completed grid resistances in the low hundredths of an ohm (even though calculations may suggest tenths of an ohm). This makes instrument and measurement techniques critical.

Buried water pipes or railroad tracks paralleling or crossing the test leads can result in inaccurate measurements. Great measurement distances out from the perimeter of the ground grid are required; distances of over 900 m (3000 ft) are not uncommon. Railroad tracks, trees, roads, and lay-down areas (areas used for storage of large equipment prior to installation) frequently make this test difficult.

The use of modern, high-resolution ground-resistance testers overcomes many of the problems associated with taking measurements on large, low-resistance ground grids.

Frequently, in the construction of a generating station, there are opportunities for simulated ground fault testing utilizing new transmission lines built but not yet energized.

Ideally, simulated ground fault testing requires a source of ground fault current (one phase of a 480 V construction power transformer can be used), a remote ground for grounding the transformer phase such as an unenergized transmission line that can be grounded at least 7 or 8 km (4 or 5 miles) from the station, and a connection to remote ground (another unenergized