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Substation Ground Grid Design Standard

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Acronyms and Abbreviations

Term	Definition
AC	Alternating Current
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
AWG	American Wire Gauge
CRU	Control and Receiving Unit
CT	Current Transformer
DC	Direct Current
EPRI	Electric Power Research Institute
FOP	Fall-of-Potential
GIS	Gas Insulated Substation
GOAB	Gang-Operated Air-Break Switch
GPR	Ground Potential Rise
HVDC	High-Voltage Direct Current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
kcmil	k represents kilo or 1000, c represents circular, and mil is 1/1000 of an inch
kV	kiloVolt
kVA	kilovolt-ampere, total apparent power in a system
kvar	kilovar
kW	kilowatt
MGB	Main Ground Bus
MTI	Modulation Transformer Unit
MV	Medium Voltage, 1 kV to 52 kV
MVA	Megavolt-Ampere
NEC	National Electrical Code
NESC	National Electrical Safety Code
OMU	Outbound Modulation Unit
PCA	Protection, Control, and Automation Dept.

Term	Definition
PREPA	Puerto Rico Electric Power Authority
PT	Potential Transformer
rms	Root Mean Square
RTU	Remote Terminal Unit
RUS	Rural Utilities Service
SGT	Smart Ground Test
SLG	Single Line-to-Ground

Definitions

Ampacity: The current capacity of equipment such as transformers, conductors, busbars, circuit breakers, disconnect switches, and batteries, that the equipment can continuously operate without any damage to its electrical, chemical, or mechanical properties.

Asymmetrical Ground Fault Current: Maximum rms value of current after the instant of ground fault initiation, including DC offset.

Exothermic Welding: A welding process employing molten metal to join conductors. The process employs an exothermic reaction of a thermite composition to heat the metal and requires no external source of heat or current.

Fault Duration: Maximum time required to separate the faulted equipment from its current source, including backup protection, plus circuit breaker operating and clearing time.

Grid Current: The portion of the total fault current that returns to its source through the grounding grid. Some current returns to its sources by other means (e.g., overhead shield wires, distribution circuits, and neutral wires).

Ground Grid: A set of bare copper or copper-clad conductors and electrodes effectively connected and installed below grade in a grid pattern in and around a power substation.

Ground Potential Rise (GPR): Maximum sudden voltage between the ground grid and a remote point with potential equal to zero. The voltage that a station grounding grid may attain relative to the potential of remote earth.

Ground Return Circuit: A circuit the earth or an equivalent conducting body uses to complete the circuit and allow current circulation from or to its current source.

Ground Rod: A grounding rod is a ground electrode installed into the earth and connected to the ground grid.

Ground Mat: A solid metallic plate or a system of spaced bare conductors placed below earth grade to minimize the exposure to high step or touch voltages.

Grounding: Electrical conduction path to ground or a conducting body that behaves similarly (e.g., the metal frame of equipment), which can serve as a common return conductor for various circuits.

Grounding Risers: Copper conductor or copper-clad steel conductors that serve as grounding connection between the ground grid and equipment of substations, which include but are not limited to circuit breakers, disconnect switches, transformers, reactors, lightning masts, surge arresters, CTs, and CVTs.

Grounding System: Comprises all interconnected grounding facilities in a specific area.

Inspection of Electrical Installations: Periodic inspection of the construction of electrical works carried out by a specialized engineer or technician guarantees that installations are per codes, regulations, and standards for electrical construction.

Main Ground Bus: A conductor, a system of conductors, or a bar that connects all designated metallic components of a substation to a substation grounding system.

Mesh Potential: Touch potential found within the mesh of a ground grid.

Qualified Personnel: Person who is prepared and has knowledge of the construction, maintenance, and operation of the electrical system, in addition to the rules of the corresponding security.

Soil Resistivity: The measure of the soil's ability to conduct current. Soil resistivity unit of measure is the ohm-meter.

Step Potential: The difference in surface potential by a person bridging a distance of 1 m across their feet without contacting any grounded object.

Symmetrical Ground Fault Current: Maximum rms value of current after the instant of ground fault initiation, excluding DC offset.

Tolerable Step Potential: The maximum voltage that a person can tolerate without triggering ventricular fibrillation

Touch Potential: The difference between a ground grid or system's ground potential rise (GPR) and the surface potential at the point where a person could be standing while simultaneously having a hand in contact with a grounded structure. Touch potential measurements can be an open circuit (without the equivalent body resistance included in the measurement circuit) or a closed circuit (with the equivalent body resistance included in the measurement circuit).

Tolerable Touch Potential: The maximum voltage a person can tolerate without causing ventricular fibrillation

Transferred Voltage: A touch-voltage scenario where a voltage is transferred between a substation and an external point.

X/R Ratio: Ratio of system reactance to system resistance. It is indicative of the rate of decay of any DC offset in a ground fault current waveform. A large X/R Ratio corresponds to a significant time constant and a slow decay rate. Refer to IEEE Std. 80 for a more concise description of X/R Ratios.

1. Overview

1.1 Scope

1.1.1 The purpose of this document is to establish substation grounding design standards for LUMA Energy (LUMA) substations. The standards herein are based on industry-recognized codes and standards such as ANSI, NEMA, NESC, NEC, IEEE, and RUS.

1.1.2 This document provides a guideline for substation ground grid design to ensure the safety of operation and maintenance personnel and the general public inside and outside substations, based on IEEE Std. 80-2013 - IEEE Guide for Safety in AC Substation Grounding.

1.1.3 The main design objectives of a substation ground grid are as follows:

- Ensure safe step and touch potentials inside and outside substations during ground faults.
- Prevent exposure to electric shock above tolerable levels.
- Control the maximum possible ground potential rise to specific limits for personnel and public safety as well as electronic, telecommunications, and other sensitive equipment inside and in the vicinity of substations.
- Reduce the substation or facility grounding system resistance below certain limits to cope with protection requirements.
- Properly determine the size of ground conductors and grounding risers.

1.1.4 Any design professional utilizing this Standard should rely upon their independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of competent engineering professional in determining the appropriateness of use.

1.1.5 This Standard primarily addresses outdoor AC transmission, distribution, generating plants, and substations. This Standard does not include design criteria for HVDC substations or indoor GIS buildings.

1.1.6 Analysis of the effects of lightning surges on substations is beyond this document's scope.

1.2 Safety

1.2.1 Safety is a priority at LUMA Energy and shall take precedence over any requirements in this standards document. If any statement within this document is considered inadequate from a safety point of view, contact LUMA's Project Manager or liaison for corrective action.

2. General

2.1 Approval Signatures

2.1.1 This Standard requires the signature of the following people:

- The Engineering Employee who is overseeing this Standard
- Qualified persons acting as Engineering Reviewers or Contributors to verify the correctness and accuracy of the technical content within this document
- LUMA Managers and Stakeholders

2.2 Standards and Reference Documents

2.2.1 The following is a list of applicable codes, standards, and guidelines to implement design criteria for modernizing and improving the resiliency of the Puerto Rico electrical system:

2.2.1.1 Industry Codes and Standards

Comply with all applicable federal and local industry codes and standards. A summary of the some of the organization's codes and standards is as follows:

- American National Standards Institute (ANSI)
- American Society of Civil Engineers (ASCE)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Electrotechnical Commission (IEC)
- National Electrical Code (NEC)
- National Electrical Safety Code (NESC)
- Governement of Puerto Rico Building Codes
- Rural Utilities Service (RUS)

2.2.1.2 Standard References

Use the following standards in conjunction with this document. When an approved revision supersedes these standards, said revision shall apply:

- IEEE C2-2023, National Electrical Safety Code
- IEEE Std 80-2013, IEEE Guide for Safety in AC Substation Grounding
- IEEE Std 81-2012, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System
- IEEE Std 367-2012, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise, and Induced Voltage from a Power Fault
- IEEE Std C37.122-2021, IEEE Standard for High-Voltage Gas-Insulated Substations Rated Above 52 kV
- IEEE Std C37.122.1-2014, IEEE Guide for Gas-Insulated Substations Rated Above 52 kV

3. Substation Ground Grid Design

3.1 Design Criteria

3.1.1 An adequately designed substation ground grid provides a safe path to carry electric currents into the earth under fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service. It also reduces the risk of a person in the vicinity of grounded facilities to the danger of electric shock. Ground grids are designed for low-frequency faults and must be able to dissipate 100% of the three-phase-to-ground, double-phase-to-ground, or single-phase-to-ground fault currents, whichever is higher.

3.1.2 To design a ground grid for greenfield substations or extend a ground grid for brownfield substations, follow the below procedures:

Perform soil resistivity measurements using the Wenner Four-Point Method described in IEEE Std.

81-2012. An engineering soil resistivity report shall be performed and sealed by a professional engineer registered in Puerto Rico.

LUMA's System Planning Department shall provide the following data for the grounding study:

- Single-phase-to-ground fault currents at the planned substation (for either greenfield or brownfield expansion/retrofit projects)
- Three-phase-to-ground fault currents at the planned substation (for either greenfield or brownfield expansion/retrofit projects)

Table 3-1 shows typical fault clearing times. Any update on fault clearing times provided by either LUMA's PCA or System Planning departments takes precedence over the data in the table below.

Table 3-1. Typical Single-Line-to-Ground (SLG) Fault Clearing Times

Voltage Level	Typical fault clearing times
230 kV SLG faults	300 ms
115 kV SLG faults	350 ms
38 kV SLG bus faults	500 ms
38 kV SLG line faults	TBD

For substations with multiple voltage levels, use the longest fault clearing time in Table 3-1.

3.1.3 The grounding study determines the tolerable touch and step potential limits for a person standing in a substation. Perform the study IEEE Std. 80-2013 using the following criteria:

- A 50 kg (110 lb) person's weight
- Fault clearing times as shown in Table 3.1 or as determined by LUMA's PCA and System Planning Departments
- Four (4) inches of isolation layer of crushed rock with minimum wet resistivity of 3,000 ohm-meters
- Crush rock shall extend 5 ft beyond the fence and fully open gates.

3.1.4 Although a minimum of 6" of crushed rock is specified, a 4" depth shall be used in the analysis.

The crushed rock utilized for the ground grid shall comply with the following requirements:

- The top isolation layer shall be 6" of crushed rock (4" only used for analysis) graded within the substation fence and extended 5 ft beyond the fence, and the maximum extent of the swing of all gates, plus 3 ft.
- 5/8" to 3/4" diameter crushed rock granite gravel meets the minimum requirement of 3,000 ohm-meters resistivity when wet.

3.1.5 The design value limit for the maximum allowable ground potential rise (GPR) is 5,000 volts.

3.1.6 Every metal structure in the substation, including non-energized ones, shall be connected to the ground grid.

3.1.7 Ground wells may be included in the design to control surface gradients and lower grid resistance when ground rods are inadequate.

3.1.8 Ground grid designs must cover the entire substation area and extend 1 meter beyond the fence. In existing substations where the ground grid cannot be extended at least one meter from the fence line, there are two alternatives:

- Move the fence and gate inward one meter from the existing substation fence line, or
- Modify the substation design to maintain touch and step voltages at the fence at tolerable levels

3.1.9 Grounding Conductors:

- Use bare copper conductors for all below-grade grounding
- Use Copper-Clad Steel (CCS) conductors with an anti-theft coating (i.e., Copperweld Camo wire or equivalent) for all above-grade and exposed conductors

3.1.10 The size of equipment grounding conductors shall be calculated based on the fault current as part of the grounding study.

3.1.11 Connect each pole within the substation to the grounding grid.

3.1.12 Table 3-2 shows typical values for impedance and resistance for the ground grid design:

Table 3-2. Maximum Resistance

Facility	Maximum Resistance (Ω)*
Generation facility	1.0
Transmission substation	1.0
Other substations	1.5–5.0
Throwover and electric facilities with fences outside of substations	10
Transmission lines	10
Distribution lines	5
Communication towers	5

*For solidly grounded systems

Use SESTech CDEGS software for ground grids analysis, studies, and design. Software native files and a grounding study report, signed and sealed by a registered professional engineer in Puerto Rico, shall be submitted to LUMA for review and approval.

3.2 Substation Structure Grounding

3.2.1 Equipment Support Structure Grounding

Ground grid pigtails shall connect to the base of equipment support structures using either exothermic welding, copper compression clamps, or bolted connections via 2-hole NEMA lugs.

Each equipment or device shall be grounded in one location for single-leg structures and two diagonally opposite legs for four-leg structures.

Grounding connections for vendor-provided support structures, e.g., circuit breakers, shall be connected using 2-hole NEMA lug connectors.

Bond all above-grade equipment to the substation ground grid.

3.2.2 Fence Grounding

Bond the perimeter fence posts using 4/0 AWG stranded, theft-deterrent copper-clad steel (CCS) grounding conductor from the station ground grid. Bond fence posts at every third section of continuous fence or every 3rd post, and all end posts, corner posts, and gate posts, and where each overhead transmission phase conductor (when applicable) crosses the fence.

3.2.3 Cable Trench Grounding

Two external ground conductors, conductor size determined by the grounding design, shall be installed to run parallel (each side) of the cable trench's entire route.

3.2.4 Control Enclosure Grounding

The control enclosure shall be connected and bonded to the grid at a minimum at two opposite locations.

Overhead cable trays in the control enclosure shall have a 4/0 AWG-stranded copper conductor run in all parts of the tray systems. The cable tray systems shall be bonded and connected to the interior perimeter grounding system and cable trench ground conductors.

Connect all wall-mounted electrical equipment to the internal ground bus with 2 AWG 600 V green insulated copper wire. Ground battery with two (2) 2 AWG 600 V green insulated copper wires.

Connect the ground bus in P&C, SCADA, RTU, and Telecom panels to the main interior bus with a minimum of 2 AWG 600 V green insulated copper wire.

3.2.5 Cast-in-place Control Enclosures

Install four (4) 4 in. x ¼ in. copper ground bars through the control enclosure's concrete foundation connecting the station ground grid to all control enclosure equipment and components. Connect each ground bar to the station ground grid in two locations.

An internal 4/0 AWG stranded copper ground conductor shall be installed in four corners of the enclosure and connect to the copper ground bars embedded in the foundation.

3.2.6 Prefabricated Control Enclosures

Use a NEMA 2-hole tinned or silver-plated ground pad at each of the base frame's four (4) corners at the exterior of the control enclosure and connect to the ground grid. Coordinate with Vendor for exact locations and other recommendations.

A bare copper bar, 2 in x ¼ in, shall be routed continuously along the base of the interior enclosure walls to act as the main ground bus enclosure. The interior ground bus shall form one continuous conductor and shall be field bolted where necessary due to shipping splits.

Connect the interior ground bus to the exterior station grounding grid system, utilizing at least four (4) 4/0 AWG stranded copper, 600 V insulated cables.

For control enclosures housing Gas Insulated Switchgear (GIS) equipment, follow the GIS vendor's specific grounding requirements for transients, thermal stress, and personnel touch protection. The control enclosure manufacturer shall closely coordinate with the GIS equipment vendor in the detailed design phases to ensure all specific grounding requirements are fully satisfied.

3.3 Grounding Measurement

3.3.1 Fall-of-Potential (FOP) or Slope Method

The Fall-of-Potential Method requires that a current test probe is located outside the interfacing hemisphere of the ground grid being tested and installed at a distance greater than five (5) times the length of the substation's largest diagonal ground grid measurement. The resistance is then measured using a 62 percent rule. The substation must be de-energized and disconnected for this type of testing.

3.3.2 Smart Ground Test

Another method for energized substations is a Smart Ground Test (SGT) method. SGT works well for measuring large and complex ground grids found at generating stations and remote substations within a compact area while being energized.

The SGT method provides numerous advantages over the Wenner and FOP methods, as shown in Table 3.3:

Table 3-3. Advantages of SGT Testing over FOP Testing

Advantages of SGT Testing over FOP Testing:
The distance between leads for the voltage and current probes is not excessive, requiring only two (2) times the diagonal length of the ground grid instead of the five times (5x) requirement for the Fall-of-Potential (FOP) method.
SGT compensates for electrical background noise and interferences.
SGT quantifies the confidence levels of the test results.

LUMA recommends using an independent NETA-Certified testing company to determine if the ground grid is within the step and touch potential limits using the SGT method before upgrading or rebuilding at brownfield substation sites.

3.4 Soil Resistivity Testing

3.4.1 Wenner Four-Point Method

The Wenner Four-Point method is one of the most common soil resistivity testing methods. While the Wenner array is one of the most labor-intensive of all the grounding tests, it is considered one of the more reliable methods for testing soils to deeper depths. The Wenner method is well-suited for the analysis of greenfield sites.

The Wenner method cannot be completed inside an existing substation due to the ground grid. The presence of metallic conductors will invalidate the results.

Ideally, the Wenner method should be completed at least one full traverse distance away from buried conductors (metallic gas or water pipelines, electric cables, grounding conductors, communication cables, etc.).

Take measurements when the area is dry and has not experienced precipitation for at least 2 weeks. If this cannot be met, the appropriate correction factors must be applied to the obtained values per IEEE Std. 80-2013 and IEEE Std. 81-2012.

3.5 Soil Resistivity Test Results

3.5.1 Provide a soil resistivity test report for approval before performing a ground study. The professional engineer in charge of the grounding study should examine the soil resistivity report and ensure the test method and setup follow IEEE Std 81-2012. If the grounding design engineer rejects the soil resistivity test report, repeat the measurement following IEEE Std 81-2012 and the comments of the grounding design engineer. After approving the test report, the grounding design engineer shall input the data of traverses in the CDEGS soil module and develop a proper soil model. The model error should not exceed 15%.

4. Grounding Studies

4.1 Analysis Procedure

4.1.1 The ground grid simulation used for the study must represent the entire substation site grounding system and include the actual soil resistivity. Include the equivalent resistance value of the grounding system in the simulation and results report.

4.1.2 LUMA's System Planning Department shall provide the maximum total ground-fault current contribution from remote sources (lines).

4.1.3 The simulation must evaluate the behavior of the step and touch voltages in the entire area of the substation, considering the maximum ground-fault current and analyzing the step and touch voltage compliance to ensure the safety of people and the equipment in the substation.

4.1.4 Consult with LUMA's Engineering team If necessary to perform soil treatment with manufactured products, replace soil layers, use non-conventional electrodes, or other non-conventional methods.

4.1.5 The final report must include the technical background of the proposed solution, its relationship with the simulations carried out, and any certifications from manufacturers or suppliers.

4.2 General Requirements

4.2.1 The Grounding Study Report must include the soil resistivity measurement results and values using the format in Table 4-1:

Table 4-1. Soil Resistivity Measurements

Measurement Coordinates	

Date and Time		
The equipment manufacturer and model utilized		
Equipment's most recent calibration date		
The method utilized for resistivity measurements		
MEASUREMENT RESULTS		
Sample Number	Electrode Spacing, m (ft)	Apparent Soil Resistivity (ohm-meters)

4.2.2 Include Soil model information (at least two layers) in the report (Table 4-2).

Table 4-2. Soil Multilayer Resistivity

Layer Number	Resistivity, Ohm-m	Thickness, m (ft)

4.2.4 The ground grid-equivalent design resistance must establish a low-resistance pathway to drain any fault currents within the substation to the ground. It must meet the grounding requirements of all equipment installed in the substation.

4.2.5 If the results exceed the values in Table 3.2, it must be proven that the design of the substation protection system is capable of operating correctly with the estimated resistance value.

4.3 Existing Substation Expansion Projects

4.3.1 Perform soil resistivity and ground grid resistance measurements to understand the current condition of the grounding system. Use previous soil resistivity measurements (less than 5 years old) if deemed adequate.

4.3.2 The ground grid extension must be connected to the existing ground grid by exothermic welding at least two points, preferably more.

4.3.3 The simulation must consider the grounding system of the entire site (old and new).

4.3.4 It is acceptable to keep the existing ground grid conductor size if it exceeds the calculated values from IEEE Std. 80-2013.

4.4 Grounding Study Report Data Requirements

4.4.1 LUMA shall be provided with all data to validate the results in the report. Include the simulation data in native files (CDEGS format) as part of the deliverables.

4.4.2 Include the below items and format in the report (Table 4-3 through Table 4-7):

Table 4-3. Design Resistance

Substation	Copper Grounding Conductor Length (m)	Grounding Rods Quantity	Design Resistance (ohms)

Table 4-4. Tolerable Maximum Potentials

Substation	Design Resistance (ohms)	Ground Fault Current (kA)	Max Step Potential $E_{S\ MAX}$ (V)	Max Touch Potential $E_{T\ MAX}$ (V)

Table 4-5. Calculated Maximum Potentials

Substation	Ground Fault Current (kA)	Calculated Step Potential $E_{S\ CAL}$ (V)	Calculated Touch Potential $E_{T\ CAL}$ (V)

Table 4-6. Step Potential Verification

Substation	Copper Grounding Conductor Length (m)	Max Step Potential $E_{S\ MAX}$ (V)	Calculated Step Potential $E_{S\ CAL}$ (V)	Compliance $E_{S\ MAX} > E_{S\ CAL}$

Table 4-7. Touch Potential Verification

Substation	Copper Grounding Conductor Length (m)	Max Touch Potential $E_{T\ MAX}$ (V)	Calculated Touch Potential $E_{T\ CAL}$ (V)	Compliance $E_{T\ MAX} > E_{T\ CAL}$

4.5 Deliverables

Include the below items in the Grounding Study Report and its deliverables in the corresponding order:

Table 4-8. Grounding Study Report Minimum Contents

Item	Title	Description
1	Cover Page	Identifying the Project Number, Project Title, Contracting Firm, and Individuals Involved

Item	Title	Description
2	Summary	Description of the work to be performed, objective, and other relevant information about the study
3	Introduction	Summary of the project, stage, and outcome (as it pertains to the grounding system). This section could include any diagrams/drawings.
4	References	Identify the industry standards and other technical references utilized in the study and report.
5	Definitions and Acronyms	List of definitions and acronyms used in the report.
6	Assumptions and Clarifications	List any assumptions, report clarifications, or other information that could clarify the report.
7	Study Data	Provide the parameters and technical characteristics of the equipment and installations considered in the study.
8	Analysis Procedure	Detailed and clear explanation of the study and analysis
9	Results	Results of the analysis are not limited to those shown in section 4.5
10	Conclusion	Detailed conclusion of the study results and recommendations (if any)
11	Attachments	As needed.
12	Database	Data used to develop and achieve the conclusion, including any field data. Provide an electronic version of the model in the native file of the software. The naming of the file should be: ProjectID_StudyType_SubstationNumber_Date The date format is DD/MM/YYYY

5. Substation Equipment Grounding Practices

This section describes typical practices for connecting substation equipment to the ground grid. IEEE Std. 80-2013 shall be applied when specifying these connections.

5.1 Transformers

5.1.1 Transformer neutral terminal cable: One bare copper-clad steel cable, sized according to the short circuit study. The cable shall be installed inside a PVC conduit to avoid contact with the transformer tank and other grounded metallic surfaces.

5.1.2 High voltage surge arrester cable: One bare copper-clad steel grounding cable, 4/0 AWG or as specified in the short circuit study. The cable shall be installed inside a PVC conduit to avoid contact with the transformer tank and other grounded metallic surfaces.

5.1.3 Low voltage surge arrester cable: One bare copper-clad steel grounding cable, 4/0 AWG or as specified in the short circuit study. The cable shall be installed inside a PVC conduit to avoid contact with the transformer tank and other grounded metallic surfaces.

5.1.4 Transformer tank grounding: Use two bare copper-clad steel grounding cables, 4/0 AWG minimum or as specified in the short circuit study, connected on diagonally opposite sides of the transformer.

5.1.5 Transformer control enclosure grounding: Use one bare copper-clad steel grounding cable, 4 AWG minimum, crimped with a Type C connector to the closest grounding conductor

5.2 Circuit Breakers

5.2.1 Use two bare copper-clad steel grounding cables, 4/0 AWG minimum, connected on diagonally opposite sides of the circuit breaker supporting structure to the ground grid. Connect the grounding conductors to the circuit breaker support structure, preferably using two NEMA two-hole hyseal lugs.

5.2.2 The control ground bus inside the circuit breaker control cabinet shall be connected using 4 AWG bare CCS grounding cable, crimped with a Type C connector to the closest grounding conductor.

5.3 Instrument Transformers

5.3.1 Use one bare copper-clad steel grounding cable, 4/0 AWG minimum or as specified in the short circuit study, connected to the instrument transformer housing.

5.3.2 The secondary neutral of the instrument transformer shall be grounded in the protection panel ground bus located inside the control room or outdoor metering cabinet, with a 10 AWG minimum copper conductor.

5.4 Surge Arresters

5.4.1 Use one bare copper-clad steel grounding cable connected to the surge arrester base, 4/0 AWG minimum or as specified in the short circuit study.

5.5 Gang-Operated Air-Break (GOAB) Switches

5.5.1 The GOAB operating handle shall be connected to the operating shaft by a flexible braided copper conductor such as Burndy Type B. The operating shaft shall connect to the grounding grid with a flexible braided copper conductor. Connect the flexible braid to the ground grid with a 4/0 AWG minimum bare copper-clad steel grounding cable.

5.5.2 Install ground plates for each gang-operated air-break switch below the manual operating mechanism. The grounding plate shall be connected to the operating handle and the ground grid to maximize personnel protection from touch potentials.

5.5.3 Grounding plates must be solid galvanized steel (preferred) or corrugated aluminum, with a minimum thickness of ¼". Grating-type plates are not acceptable. Design the grounding plate's overall size considering the operating handle radius.

5.5.4 Grounding plates shall be installed on a concrete base with a minimum thickness of 4 in. above the crushed-rock level. Grounding plates shall be connected to ground grid pigtails at two places.

5.5.5 The GOAB switch assembly frame shall be connected to the ground grid using a 4/0 AWG minimum bare copper-clad steel grounding cable.

5.6 Substation Structure

5.6.1 Connect metallic structure to the ground grid at each support base with 4/0 AWG minimum bare CCS grounding cable.

5.6.2 Provide 4/0 AWG minimum bare copper-clad steel grounding cable that runs from the top of the structure to the base for connecting overhead ground wires and lightning rods to the ground grid.

5.7 Control Buildings

5.7.1 The control building's main ground bus shall be connected to the substation ground grid with 4/0 AWG minimum bare copper-clad steel grounding cable in at least two points, as indicated by the building's manufacturer drawings.

5.7.2 Connect metallic overhead cable trays to the main ground bus with 2 AWG minimum bare-stranded copper cable.

5.7.3 Provide copper busbar connections for HV Gas-Insulated Switchgear (GIS) equipment or as the equipment manufacturer recommends.

5.7.4 Install a non-conductive PVC nipple that extends from the fence up to 20 feet outside of the substation fence line in incoming metallic-pipe potable water service connections.

5.8 Protection, Control, and Communication Systems

5.8.1 Provide 2' x 2" x 1/4" busbars for grounding equipment at each control panel. The busbar shall be installed inside the panel at a maximum height of 4" from the floor. Connect adjacent panel busbars with 1/0 AWG minimum bare-stranded copper cables and eyebolt connectors (hyseal lugs).

5.8.2 Protection, control, metering, and data communication equipment and devices shall be grounded using 12 AWG minimum copper wire with green insulation.

5.8.3 Connect the following equipment to the main ground bus using the following conductor gauges as a minimum:

- Remote Terminal Unit – 6 AWG stranded copper wire with green colored insulation
- Battery Rack – 2 AWG stranded copper wire with green colored insulation
- Battery Chargers – 6 AWG stranded copper wire with green colored insulation
- Distribution Panels – 2 AWG stranded copper wire with green colored insulation

Connect the above-listed equipment to an auxiliary ground bus when located in a separate room. A bare copper conductor shall be used to connect the auxiliary bus to the main ground bus.

5.8.4 Connect the main ground bus to the substation ground grid at least two points using 4/0 AWG minimum bare copper-clad steel grounding conductors and hyseal lug-type connectors.

5.8.5 Install an overhead, halo-type auxiliary ground bus composed of a 1/4 inches x 4 inches copper bar for telecommunications and data communication equipment rooms. Install the auxiliary bus at least 6 inches from the ceiling and separate at least 2 inches from the wall. The auxiliary bus must run across the entire perimeter of the room. Doors and windows of the enclosure shall also be connected to the auxiliary bus using a minimum of 6 AWG copper 600V green insulated wire. The auxiliary bus shall be connected to the main ground bus if the telecom equipment room is inside the control house or directly to the substation ground grid in a separate building from the main control house.

5.8.6 Telecom tower grounding systems shall be solidly bonded to the substation ground grid at least two points when the tower is inside the substation's perimeter.

5.9 Mobile Substations

5.9.1 The mobile substation's secondary neutral (X0) terminal shall be connected to the substation ground grid using a 4/0 AWG minimum, copper-clad steel grounding cable. The cable shall be installed inside a PVC conduit to avoid contact with the mobile transformer tank and other grounded metallic surfaces.

5.9.2 Connect the mobile substation X_0 terminal to the neutral conductor of the distribution system if the mobile substation is outside the premises of a substation. At least four (4) 5/8" x 8' ground rods shall be driven into the ground immediately surrounding the mobile substation. The rods shall be interconnected with a 4/0 AWG minimum copper-clad steel grounding cable to form a temporary ground grid around the mobile substation. The mobile substation ground bus and trailer frame shall be connected to the temporary ground grid using 4/0 AWG minimum bare copper-clad steel (CCS) grounding cable in at least two diagonally-opposed points. Use ground cable reel if provided in the mobile substation equipment.

5.9.3 Connect the temporary security fence to the ground grid system.

5.10 Capacitor Banks

5.10.1 Wye-connected shunt capacitor banks with solidly-grounded neutral shall be connected to a single point in the substation ground grid using copper-clad steel grounding cable, gauge selected according to the short circuit study. The base frame of the capacitor bank, the grounding switches, and their support structures shall be connected to the substation ground grid using 4/0 AWG minimum bare copper-clad steel grounding cable.

5.10.2 **Do Not** connect the grounding conductors of a capacitor bank to the fence grounding conductors.

5.11 Automatic Meter Reading System

5.11.1 Provide the following connections for grounding the Automatic Meter Reading System, also known as the Remote Metering System:

- The transformer tank and primary neutral of the Modulation Transformer Unit (MTU) shall be connected to the substation ground grid using 4/0 AWG minimum copper-clad steel grounding cable.
- The aluminum housing and neutral bus of the Outbound Modulation Unit (OMU) shall be bonded together and connected to the substation ground grid using 4/0 AWG minimum copper-clad steel grounding cable.
- Bond the primary neutral of the MTU and the neutral bus of the OMU together using 4/0 AWG copper, 600V black insulated cable.
- Bond the secondary neutral of the MTU and the neutral bus of the OMU together using 4/0 AWG copper minimum, 600V black insulated cable.
- The Control and Receiving Unit (CRU) shall be connected to the substation ground grid using 2 AWG minimum CCS grounding cables.

5.12 Emergency Generators

5.12.1 Use a 2 AWG minimum copper-clad steel grounding cable to connect the generator frame to the substation ground grid at a single point.

5.12.2 Connect the manual or automatic load-transfer switch to the main ground bus in the control building with a 6 AWG copper minimum, 600V green insulated wire.

5.13 Connection of Non-Energized Equipment to the Ground Grid

5.13.1 Substation entrance gates shall be connected to the ground grid using a 4/0 AWG copper-clad steel grounding cable.

5.13.2 Galvanized fence tubes shall be connected to the substation ground grid with Burndy® GAR-type connectors, sized to fit.

5.13.3 4 AWG bare copper-clad steel grounding cable shall be woven through the galvanized fence a minimum of three times using compression connectors. The cable shall then be connected to each barbed wire run on the top of the fence using compression connectors.

5.13.4 Provide a connection between the entrance gate and its base using a flexible braided copper conductor connected to the galvanized post with a GAR-type connector, sized to fit.

5.13.5 In sliding-type gates, connect both ends of the guide channel to the substation ground grid using a 4/0 AWG copper-clad steel grounding cable.

6. Amendments, Exceptions, and Revisions

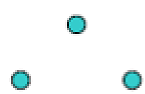
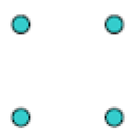
6.1.1 Coordinate amendments and exceptions to this document's contents with LUMA's Transmission and Substation Standards and Materials Department subject matter experts

6.1.2 Revisions and updates to this document are the sole responsibility of the LUMA Transmission and Substation Standards team.

7. Appendix A: Base Resistance Calculations

7.1 Separation Greater Than Length

Base Resistance Calculation for grounding rod configurations in which the separation between them is greater than their length is as follows:

Number of Rods	Configuration $A = r$	Base Resistance (Ohms) $R_B = \frac{3.28\rho \ln\left(\frac{2L}{r}\right)}{2\pi NL}$	
		5/8" x 8' Ground Rod **S > 8'** **D = 0.625"**	**3/4" x 10' Ground Rod** **S > 10'** **D = 0.75"**
2		$R_B = 0.2095\rho$	$R_B = 0.1687\rho$
3		$R_B = 0.1397\rho$	$R_B = 0.1124\rho$
4		$R_B = 0.1047\rho$	$R_B = 0.0843\rho$

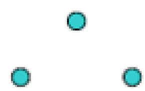
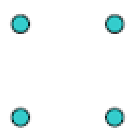
A: Geometric Median Distance
ρ: Apparent resistivity of soil (Ohms-meters)
L: Length of rod
S: Rod separation
r: Rod radius
N: Number of rods
D: Rod Diameter

Note: The base resistance for configurations of one rod is calculated as follows:

1. 5/8" x 8', S<8', D=0.625"; R_B=0.4190ρ (ohms)
2. 3/4" x 10', S<10', D=0.75"; R_B=0.3373ρ (ohms)

7.2 Separation Less Than Length

Base Resistance Calculation for the ground rods for configurations with a separation that is less than their length is as follows:

Number of Rods	Configuration $A = \sqrt[N]{rS_1S_2 \dots \dots \dots . S_{N-1}}$	Base Resistance (Ohms) $R_B = \dfrac{3.28\rho \ln\left(\frac{2L}{A}\right)}{2\pi L}$	
		5/8" x 8' Ground Rod **S < 8'** **D = 0.625"**	**3/4" x 10' Ground Rod** **S < 10'** **D = 0.75"**
2		$R_B = 0.06525\rho \ln\left(\frac{99.15}{\sqrt{S}}\right)$	$R_B = 0.0522\rho \ln\left(\frac{113.14}{\sqrt{S}}\right)$
3		$R_B = 0.06525\rho \ln\left(\frac{53.98}{\sqrt[3]{S_1S_2}}\right)$	$R_B = 0.0522\rho \ln\left(\frac{63.50}{\sqrt[3]{S_1S_2}}\right)$
4		$R_B = 0.06525\rho \ln\left(\frac{39.83}{\sqrt[4]{S_1S_2S_3}}\right)$	$R_B = 0.0522\rho \ln\left(\frac{47.57}{\sqrt[4]{S_1S_2S_3}}\right)$
A: Geometric Mean Distance ρ: Apparent resistivity of soil (Ohms-meters) L: Length of rod S: Rod separation		r: Rod radius N: Number of rods D: Rod diameter	

Note: The base resistance for configurations of one rod is calculated as follows:

1. 5/8" x 8', S<8', D=0.625"; R_B=0.4190ρ (ohms)
2. 3/4" x 10', S<10', D=0.75"; R_B=0.3373ρ (ohms)

8. Appendix B: Grounding System Bill of Materials

Grounding System Bill of Materials

Description	Catalog Identification Number
HYSEALUG 4/0 AWG Burndy Type YGHA, YGA, or similar	038-00786
HYSEALUG 2 AWG Burndy Type YGHA, YGA, or similar	002-09833
Cable TW 12 AWG, Green	040-00774
Cable 1/0 AWG, Copper	040-00287
Cable 4 AWG, Copper	040-00162
Cable 6 AWG, Copper	040-00440
Ground Rod 5/8” x 8’	002-02465
Ground Rod 5/8” Connector	002-13595
Ground Rod 3/4” x 10’	TBD
Ground Rod 3/4” Connector	TBD
Galvanized Steel Grounding Plate, 3’ x 4’ x 1/4"	002-07753
Copper Flexible Tape, Burndy Type B or similar	TBD
Burndy Connector type GAR or similar	TBD
Exothermic Welding System, Cadweld or similar	TBD
Cable 4/0 AWG Bare Stranded Copper, Hard-Drawn	006-01526
Cable 4/0 AWG, Copper-Clad Steel Grounding Cable	TBD
Cable 2 AWG, Copper-Clad Steel Grounding Cable	TBD
Cable 4 AWG, Copper-Clad Steel Grounding Cable	TBD

4801.003 Substation Ground Grid Design Standard

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