Introduction to Grounding Analysis

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FORWARD

Electrical grounding is a broad field, and is a practice applied to semiconductors, commercial applications, industrial applications, power systems and more. In the power industry, "grounding" or "earthing" are used to describe how electrical supply and equipment are referenced to earth. This book serves those in the power industry responsible for analyzing the performance of a grounding (earthing) system, specifically with regard to IEEE Std 80, Guide for Safety in AC Substation Grounding.

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Grounding System Purposes

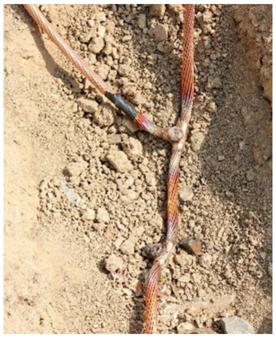
Grounding systems are designed and assessed to improve electrical safety and operation. The primary purposes of a grounding system include:

- Helping to ensure personnel and public safety.
- Facilitating proper equipment operation under normal and faulted conditions (some protection schemes require sufficient ground current to detect and operate for a fault).
- Preventing or reducing equipment damage or fault escalation from a power system fault.
- Preventing or reducing equipment damage from lightning effects.

The following sections will focus on the first bullet concerning personnel and public safety.

Grounding System

A grounding system is a network of ground electrodes, which are simply conductors imbedded into the earth. Grounding systems are an important part of the power infrastructure and are found at substations, switchyards, generation sites, and industrial facilities. As an example bare copper is directly buried into the earth at a substation typically as a grid or mesh, as shown in the image below:



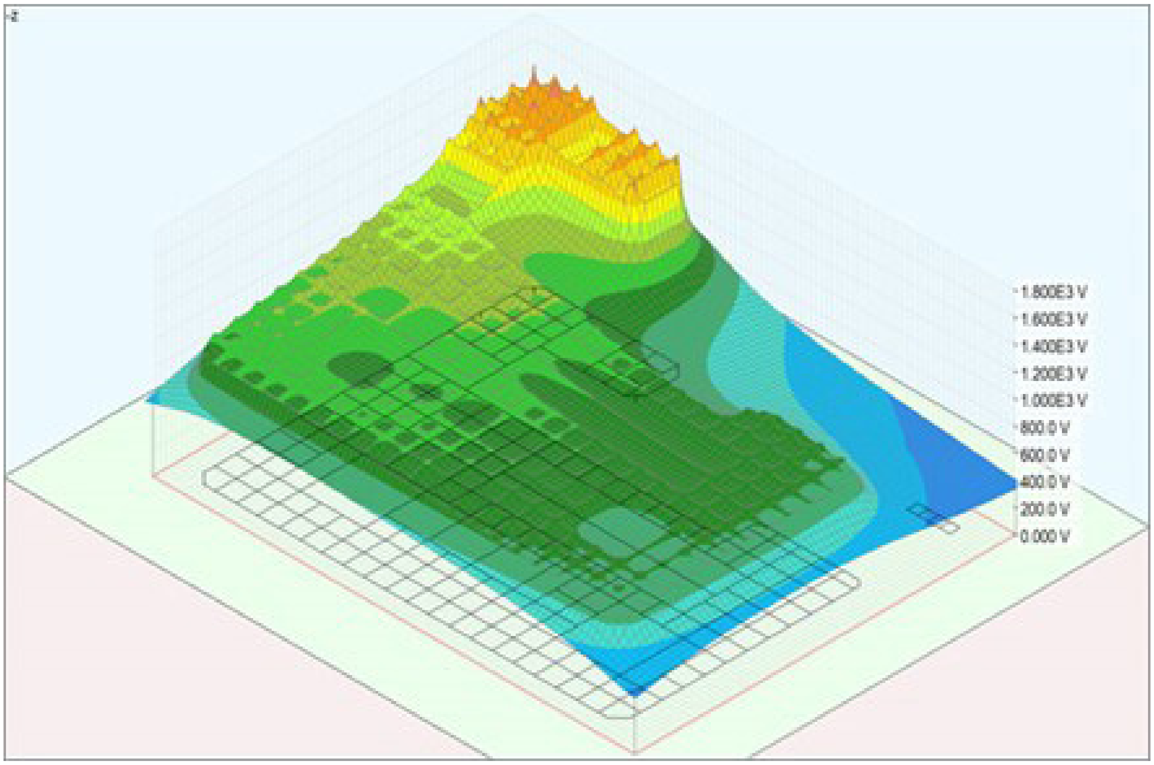
Grounding electrodes are typically horizontally placed bare copper conductor buried 18 – 24 inches below grade. Permanent weld or compressed connected are used to connect the grid. The electrode is backfilled with native soil or low resistivity backfill.

Vertically installed ground rods, commonly 8 – 10 feet long, are typical along the perimeter, near equipment, and at intersections. Depending on the soil strata, deeper ground conductors may be necessary to achieve the grounding system design objectives. Drilled ground wells can extend tens or hundreds of feet expanding a grounding system area and reaching lower resistivity soil strata.

Equipment and metallic objects at a power system are bonded and grounded to the site's grounding system via equipment ground leads.

Grounding Study

A grounding system analysis or study is the evaluation of the grounding system in meeting its design objectives. In the power industry, the primary focus is addressing the aspect of personnel and public safety. IEEE Std 80 provides guidance for safety related to grounding in AC substations. This standard highlights the dangerous conditions that may occur during a ground fault that can severely or fatally injure individuals in the area or in contact with metallic objects.

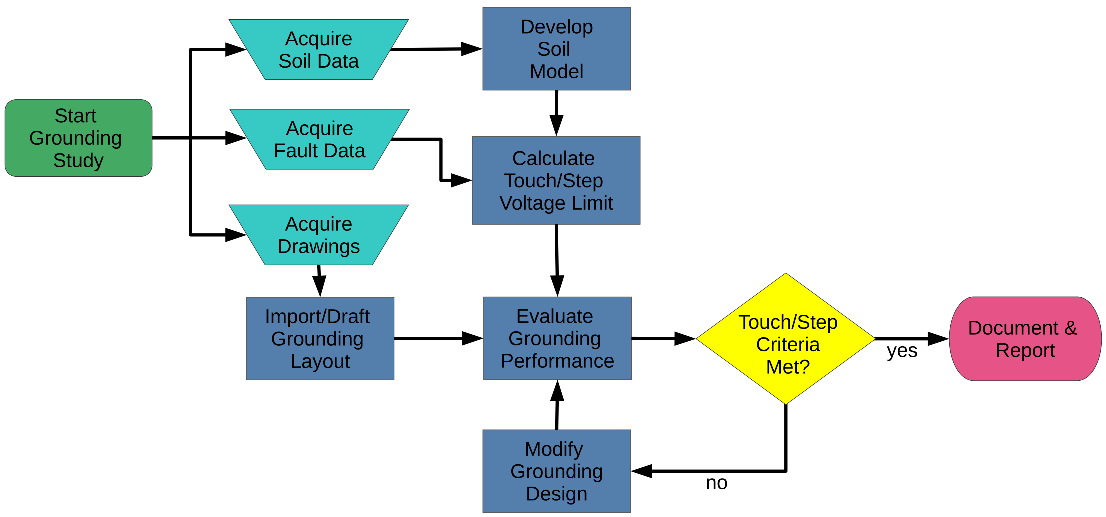


During a ground fault, current flows into or out of a grounding system and the electrical potential of the grounding system and surrounding soil are elevated relative to remote earth. This is referred to as the ground (earth) potential rise, and is illustrated in the image above.

Bonding and grounding equipment at a site elevates all metallic objects to the ground potential rise. Knowing that current will travel in all available paths, sufficient voltage gradients may be present on the earth's surface to produce catastrophic current to flow through personnel or public within the affected area. A lower grounding system impedance results in a lower ground potential rise, but designing to a specific impedance, such as 5 ohms or less, is not a measure of an effective grounding system for personnel safety. Determining the touch and step voltages that may occur at a grounding system, compared to the permissible limits, is the correct measure of a grounding system efficacy for personnel and public safety. Generally, three variables drive the grounding system performance:

- Grounding system physical design and geometry
- Soil electrical characteristics
- Ground fault current magnitude and duration

It is important to note that each component is complex, often varying over time, and significantly affects the conclusions of a grounding analysis. Engineers performing a grounding system study must consider the accuracy of the data and how changes in theses variables can affect a study's conclusion. In addition, the design must verify all equipment is bonded, size the equipment and below grade ground conductors, and possibly evaluate effects on adjacent facilities. A typical grounding analysis process at a high-level is provided below:



These steps are followed at new stations, but it may be less clear when existing sites may need to be evaluated. Appendix I provides some guidance for when to evaluating of an existing system.

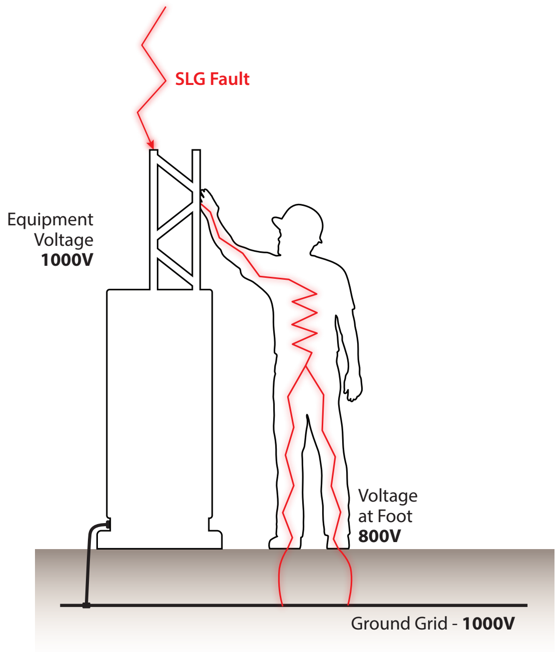
Hand calculations are available for determining a grounding system performance; however, critical assumptions are made that often result in over design or under design of the grounding system. Software is widely available but engineers must be aware of their tools limitations. Fortunately, software such as XGSLab enables engineers to more accurately evaluate these complex variables efficiently improving safety. Appendix II provides a step-by-step view of the analysis process using XGSLab software.

Touch and Step Voltage Calculations

When performing a grounding system analysis, it is critical to evaluate the safety of personnel and the public at the power site. As previously discussed, during a ground fault condition, the grounding system and surrounding soil voltage is elevated. Hazardous conditions may arise for individuals as voltage varies from equipment to various points of the soil surface that they stand on. These voltage differences are characterized as a touch voltage or a step voltage hazard.

Touch Voltage

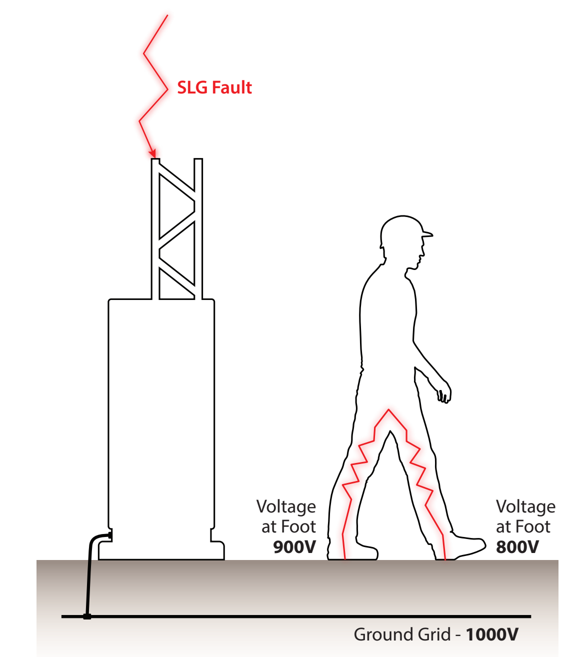
Touch voltage is defined as the potential difference between the ground potential rise of a ground grid or system and the surface potential at the point where a person could be standing while at the same time having a hand in contact with a ground structure.



Touch example: A person has 800 V at his feet, so contact with 1000 V equipment results in a 200 V touch voltage.

Step Voltage

The difference in surface potential that could be experienced by a person bridging a distance of 1 m (3’) with their feet without contacting any grounded object.



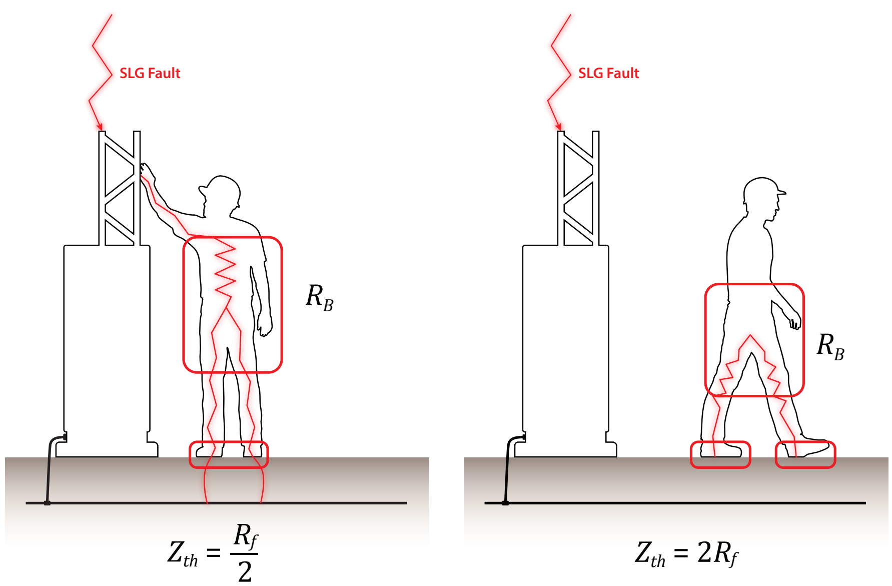
Step example: A person is walking with one foot at 900 V and the other at 800 V, resulting in 100 V step voltage.

Evaluating Touch and Step Voltages

In the event of a ground fault it is impossible to eliminate touch or step voltages as the current will take all paths to return to its source. Fortunately, there are a handful of guides and standards in the world that provide methods to evaluate a permissible touch and step voltage. The focus of these documents is to provide calculations to determine a voltage such that an individual is likely to survive the experience, bearing in mind that minimal current though the heart may cause fibrillation. Below is a table of describing the human experience for varying levels of electric shock.

Current	Human Experience
1 mA	Perception
1 – 6 mA	Unpleasant but able to release energized object
6 – 15 mA	Painful but may be able to release energized object
15 – 23 mA	Painful and impossible to release energized object
50 – 200 mA	Fibrillation possible

Grounding standards and guides refer to the permissible human threshold values as voltages instead of current discussed above. This convention allows for simpler calculation and evaluation of grounding systems, though modern software tools eliminate additional burden of directly calculating current. Regardless, standards convert the threshold current into voltage by considering the total current path impedance (the human body, contact impedance with the earth, and additional impedances like gloves or boots). Below represents a calculation of impedance based on touch and step shock scenarios:



- R_B – Body impedance (assumed 1 kΩ)
- Z_{th} – Equivalent resistance of subject's feet
- R_f – Foot resistance
  - $R_f = \frac{\rho}{4b}$
- ρ – Surface soil (Ω-m)
- b – Disc radius (assumed 0.08 m)

The equation to convert from the body current, using the above impedance is:

$$I_b = \frac{V_{Th}}{Z_{Th} + R_B}$$

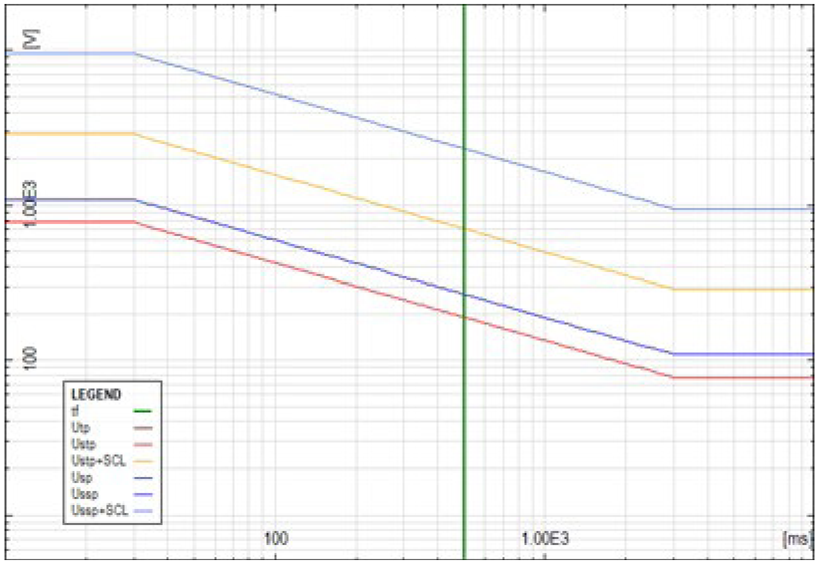
An additional impedance to consider in the permissible voltage threshold is any soil covering layer. Substations, switchyards, and generation sites commonly have areas where crushed rock or asphalt is installed. Crushed rock surfacing typically helps by adding a high resistivity material below an individual's feet, reducing current through the individual during a fault. Not all rock is the same and testing should be performed to verify resistivity.

This surfacing can be considered by inclusion of a surfacing derating value Cs.

$$C_s = 1 - \frac{0.09(1 - \frac{\rho}{\rho_s})}{2h_s + 0.09}$$

- ρ_s – Surfacing resistivity (Ω-m)
- h_s – Surfacing thickness (m)

Frequency, duration, and magnitude have a collective effect on the body's tolerance to shock. The touch and step voltage limits as calculated per IEEE Std 80 calculations follows the Dalziel curve, as the image XGSLab exported chart shows the time (ms) versus voltage threshold (V).



The chart above represents the 50 kg curve, where-

- Ustp – Permissible touch voltage
- Ussp – Permissible step voltage
- Ustp + SCL – Permissible touch voltage with additional surface covering layer
- Ussp + SCL – Permissible step voltage with additional surface covering layer

Where analysis indicates permissible voltages are exceeding tolerable magnitudes, there are many approaches to mitigate, such as:

- Expanding or increasing the grounding system to reduce the ground potential rise.
- Installing additional grounding conductor to reduce voltage differences on the soil surface and equipment.
- Adding or expanding a high resistivity surfacing layer material, such as crushed clean gravel or asphalt to reduce current through the individual on the surfacing.
- Accelerating the clearing time of protective settings to reduce the duration of shock.
- Adding physical barriers to limit access to possible hazardous locations.
- Using personal protective equipment to create equipotential zones and/or increase personnel resistance.

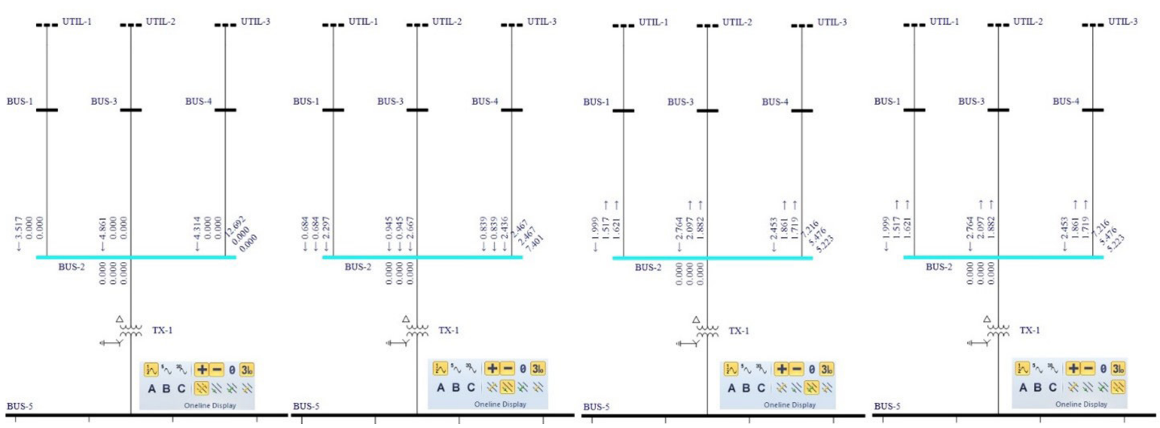
Every station is unique, and the correct approach is an engineering design decision to reduce and limit risks. Grounding system designs should consider how components, like fault current availability, may increase over the 30 or more year lifespan of the system as a part of a growth margin. Similarly, a safety margin may be appropriate to make a grounding system more robust from inaccuracies that can occur in soil resistivity measurements, installation, or other components.

Grounding Analysis – Ground Fault Current

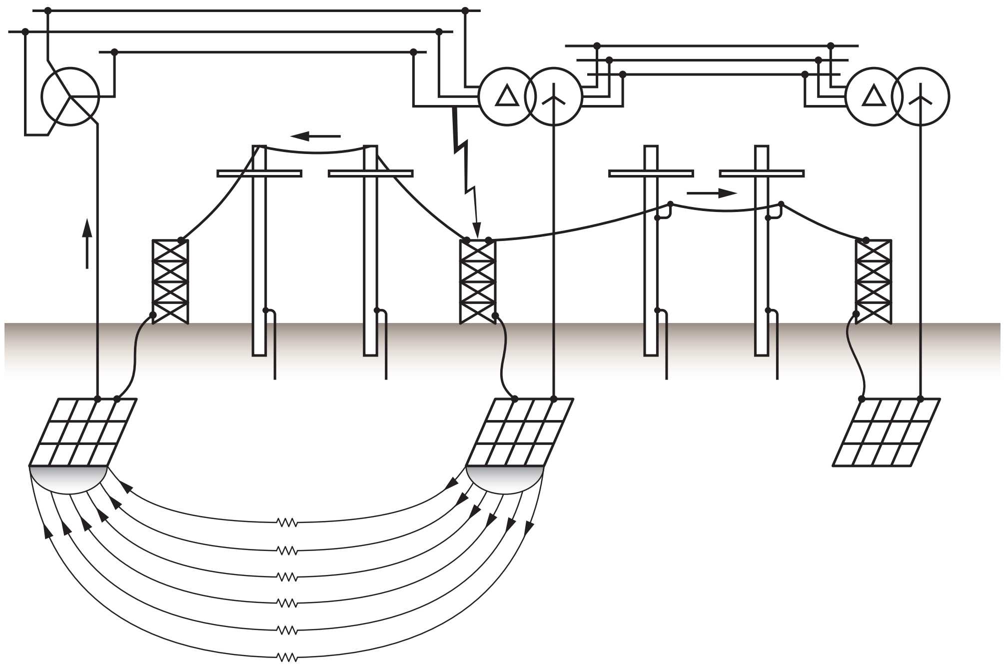
A ground fault at a power system could produce hazardous touch and step shock hazards. Recognizing the multiple aspects that are incorporated into the fault current data for a grounding study is essential to accurately evaluate a substation or other facility's grounding system to reduce these hazards. This section discusses the components of power system fault data as they are applied for grounding system studies.

Ground Fault Scenario

As a condition of a grounding system study, a fault scenario is assumed to occur that provides ground current through the system under investigation, energizing the bonded and grounded components. Referencing symmetrical components concepts, this ground current exists for specific fault types with a zero-sequence component. The zero-sequence component of the fault can pass through the grounding system and through the earth path. Several fault types, shown in EasyPower below, highlight that the zero sequence component is present for the single-line-to-ground (SLG) and double-line-to-ground (DLG) faults:



An illustration below shows an SLG fault at a central substation, where a bonded and grounded structure at the site contacts a phase conductor. The portion of the fault current that flows through the grid will correspond to a ground potential rise (GPR) and this voltage could result in hazardous touch and step shock hazards. As expected, the faulted site experiences a GPR due the impedance of the grounding system and the fault current returning to its remote source.



The current has multiple paths to return to the source, which is commonly referred to as the fault current split and is discussed in more detail later. During the fault, a GPR is simultaneously present at the source site and could produce hazardous touch and step voltages. Evaluating a site, it is important to note that a site's GPR may develop from a fault with a zero-sequence component onsite or at a remote location. Engineers should consider multiple fault scenarios to determine the worst-case conditions for evaluating the grounding system performance.

Ground Fault Current Data

There are three primary aspects of fault data that contribute to the grounding system evaluation:

- Fault current magnitude
- Fault duration
- Fault X/R ratio

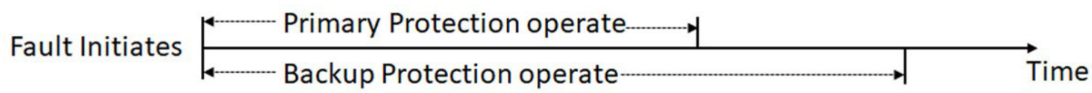
Each fault scenario may have unique factors that influence the fault data as it is incorporated into a grounding study.

Fault Current Magnitude

The fault current magnitude is dependent on the power system interconnection and voltage levels associated with the fault scenario. Grounding studies can consider faults at various voltage levels of the site under analysis to determine the maximum ground current. The maximum ground current will produce the largest GPR, which may be the worst-case scenario for evaluating touch and step voltages. The largest touch and step voltages from the maximum ground fault current may not be the worst-case condition, as the duration of the fault affects the applicable voltage limits.

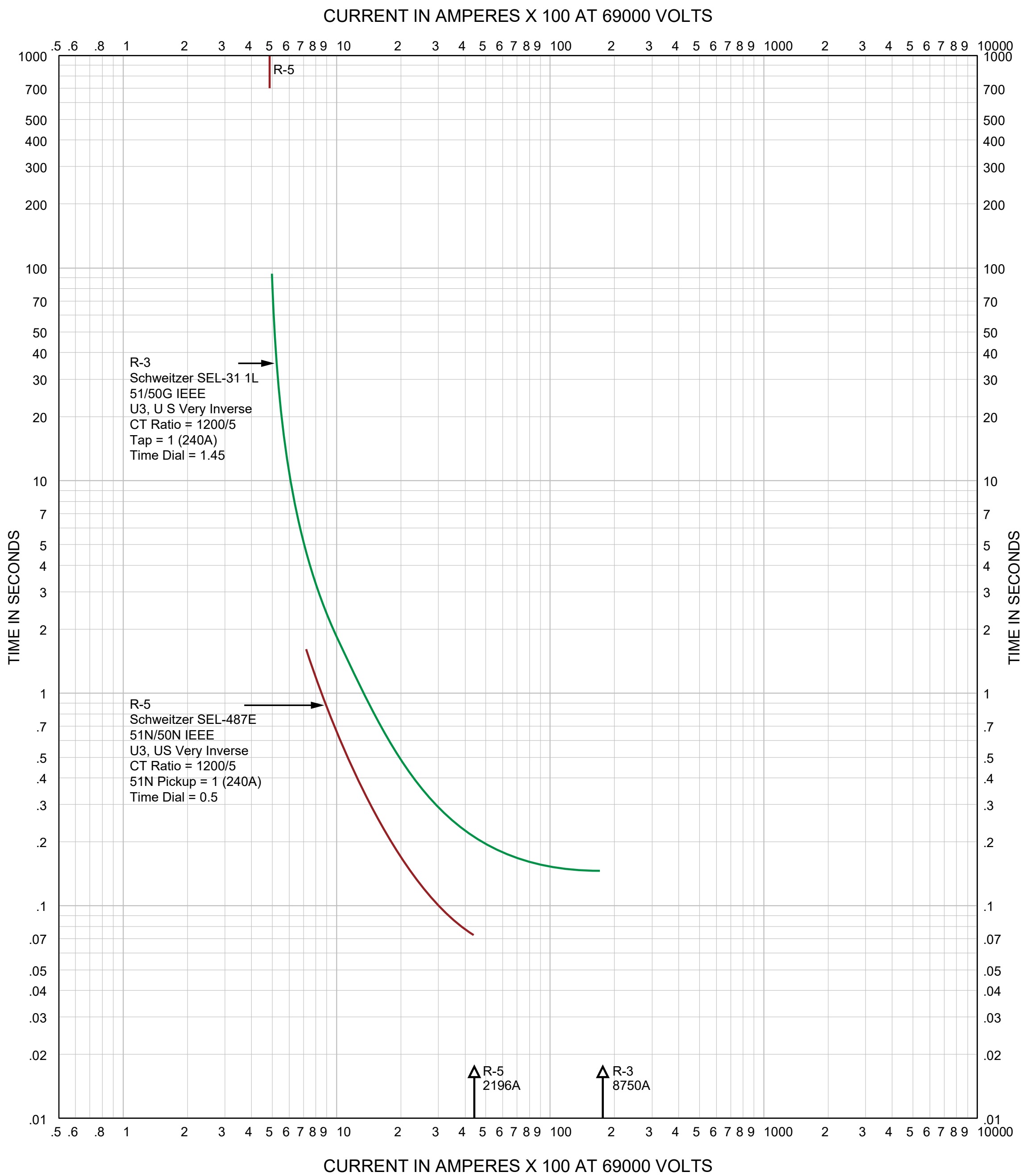
Fault Duration

The duration of a fault is determined by the operation of protective and interrupting devices in the power system. Typical protection schemes include multiple devices and sensing elements to provide fast selective primary protective fault clearing with slower backup protection.



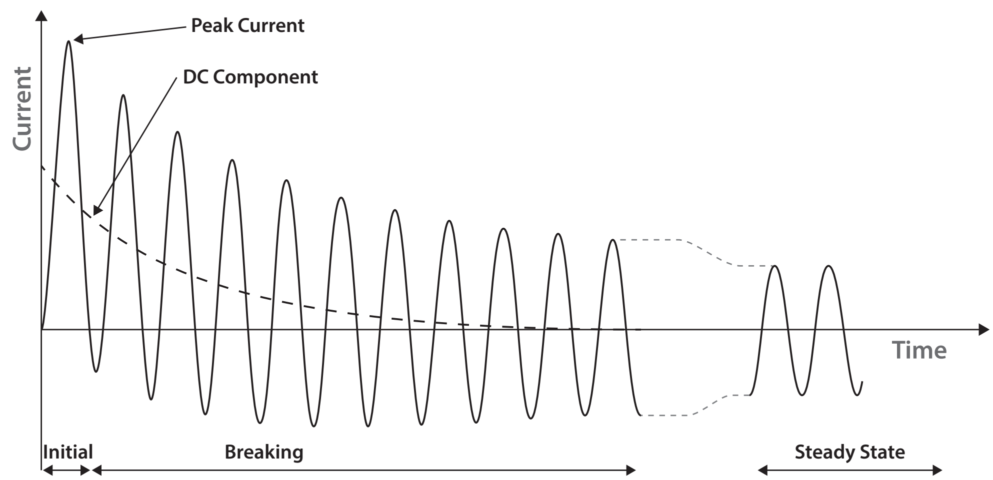
Guidance from IEEE Std 80 finds both primary and backup fault clearing times are acceptable to use for evaluating a grounding system performance, noting that backup clearing times will yield a more conservative result. Historical review of protective relay operation for fault events is recommended to determine the best engineering decision for a utility or facility.

Protective elements for ground fault detection benefit in that they may be set more sensitively and operate more rapidly when compared to phase overcurrent protection. The TCC chart below shows an example of primary and backup ground overcurrent curves that are coordinated for optimal sensitivity and security.



Fault X/R Ratio

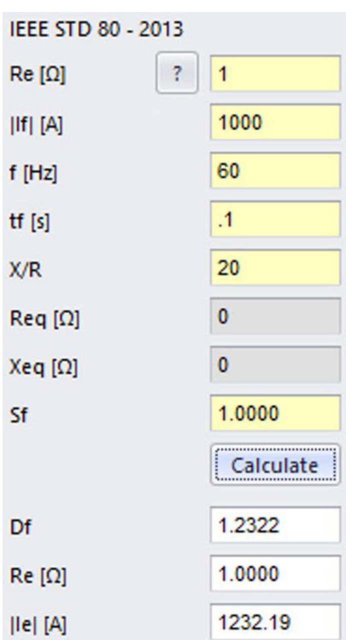
A power system's inductive and resistive impedances may significantly affect the fault current characteristics. Power systems with greater X/R ratio produce a greater DC offset in the event of a fault. A classic visual representation of the DC offset on an AC curve is shown below.



The DC offset may increase the peak current considerably and increases the cumulative fault current through various paths. Regarding a grounding analysis for personnel safety, the cumulative current through the human body could result in fatal touch and step shock hazards and should consider this DC offset's effect. IEEE Std 80 provides a calculation method for considering the cumulative effect of the X/R ratio, described as the decrement factor (Df) and shown below.

$$D_f = \sqrt{1 + \frac{T_a}{t_f}\left(1 - e^{\frac{-2t_f}{T_a}}\right)}$$

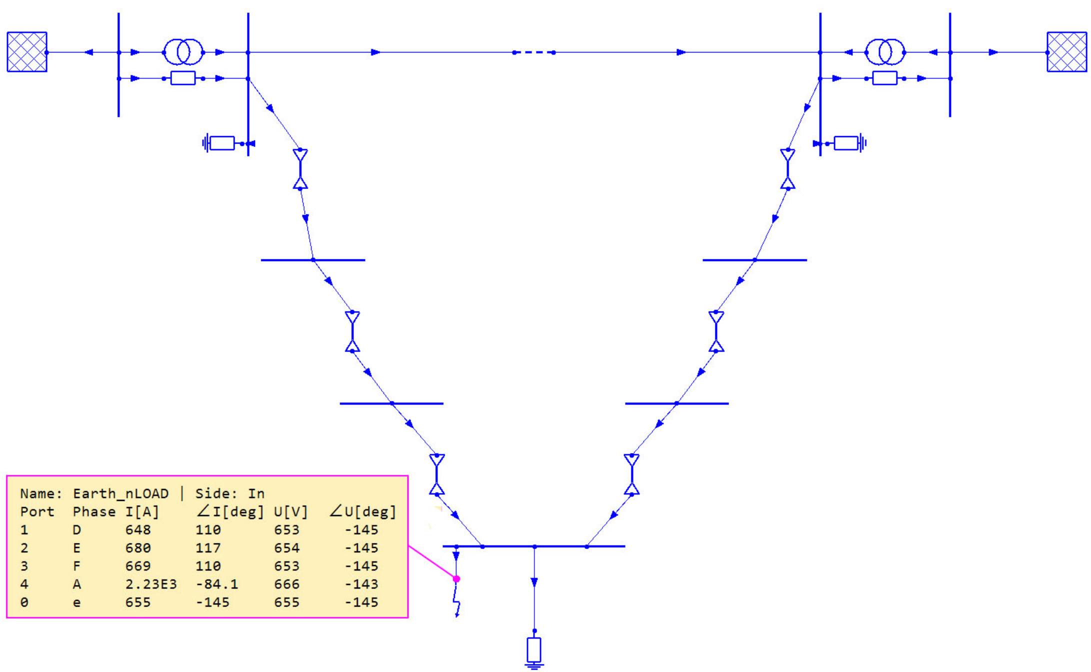
- $T_a = \frac{X}{\omega R} = \frac{X}{120\pi R}$
- t_f = Fault duration



The decrement factor incorporates the X/R ratio, the frequency, and duration of the fault. Essentially this X/R decrement factor is a method to equate the DC offset as an average fault current, thus resulting in greater calculated touch and step voltage hazards. This decrement factor can be implemented through hand calculations or with tools like XGSLab. A screenshot example of the decrement factor calculation shows Df equals 1.23 for a fault cleared in 0.1 seconds with an X/R that is equal to 20.

Fault Current Split

For many ground fault events, a portion of the current will take alternative paths that do contribute to a GPR at the grounding system under analysis. Determining the fault current split provides the percentage of fault current that goes through the grid producing a GPR and the portion that takes alternative paths reducing the maximum GPR. Considering the fault current split allows for a more accurate analysis and more efficient grounding system design. Alternative paths often include a transmission line's overhead wires, distribution neutral wires, and cable shielding and armor. There are several methods for calculating the fault current split, but a common simplified approach is to calculate the equivalent impedance of the alternative paths and enter those Req and Xeq values into the XGSLab split factor tool. Another simplified approach is provided in the IEEE Std 80 Annex C graphical curves, where an engineer can quickly approximate the fault current split with the number of transmission and distribution lines connected to the grid under analysis. More thorough investigation is performed by software, such as NETS, that use the phase component method, to model a complicated meshed power system such as the two stations with an interconnected transmission line and cables feeding a central site. The NETS model below shows that of the 2.22 kA phase A fault, only 691 A will produce a GPR (through e) with the remaining taking the cable shields paths (D,E,F).



Simplified approaches, especially referencing Annex C of IEEE, require engineering judgement to determine if the assumptions included in the methods are applicable to the grounding system under investigation.

With many engineering studies, the quality of data inputs dramatically affects the quality of the output. Understanding the multiple aspects of the fault current data for a grounding system analysis can guide more accurate and efficient designs to reduce personnel and public shock hazards.

Soil Resistivity Information and Field Testing

The evaluation of grounding systems studies requires knowledge of the electrical characteristics of the soil. Typically, engineers are concerned with the soil's allowance of electrical current, characterized as the soil resistivity with an SI unit of Ω-m.

At a fundamental level, the conduction of electricity in the earth is primarily driven by two types of current contribution:

- Ionic (or electrolytic) contribution: movement of free ions in the material
- Electronic contribution: movement of free electrons in the material

Usually, electrolytic conduction is the predominant factor for electric current to flow in soil, and is affected by the soil's moisture, temperature, and chemical content. The factors that promote or inhibit electrolytic solutions in the soil decrease or increase the soils resistivity, respectively. Assessments based on soil classification from literature yield only a rough approximation of the resistivity for a particular site. The great variation, even for soils that are similar in appearance, is shown by the table below:

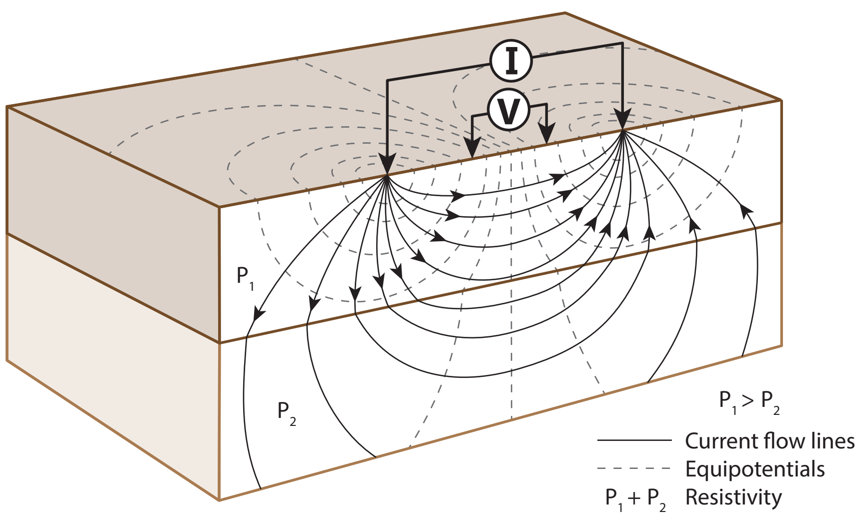
Type of Soil	**Resistivity Range (Ω-m)**
Clay	15-150
Loam	15-150
Sandy Clay	50-300
Sand	200-3000
Gravel and Sand	500-5000
Solid Rock	10000+

Soil resistivity greatly influences the grounding system performance. It drives the system impedance, ground potential rise, and touch/step voltages. Soil resistivity measurements are simple to perform and equipment be may rented several companies rent. Poor data results in a poor design, and wasted material if it doesn't serve the engineering purpose.

Actual soil resistivity measurements are required and should be performed at several locations within the site, or as close as possible. Sites where the soil may be characterized by uniform resistivity throughout the entire area and up to a considerable depth are seldom found. Often, vertical stratification of the soil yields several layers of different resistivity. Lateral changes also occur, but are usually more gradual compared to the vertical changes. Studies show the resistivity of soil layers tens or hundreds of feet deep affect a project's outcome, such as the ground potential rise increasing for a grounding study. We cannot overstate the importance of accurate measurements to the breadth and depth necessary for each specific project.

Four Pin Resistivity

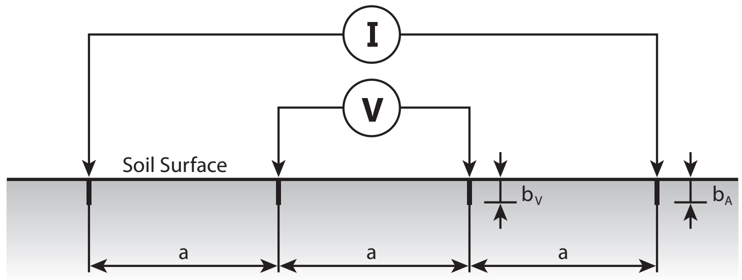
There are many methods to acquire soil resistivity measurements, but the most common are the Wenner and Schlumberger methods, also called the four-pin methods. Regardless of the method, the general concept can be described as injecting a known current into the soil and measuring a voltage. The following figure represents the current flow and the equipotential lines produced by a current that is injected through the ground with two different soil layers.



Soil resistivity measurement

Wenner Method

The Wenner alpha four-pin method is the most commonly used technique for soil resistivity measurements. It is performed by placing four pins at equal distance, injecting a known current on the outermost electrodes and recording the voltage between the interior electrodes. The following figure illustrates the Wenner alpha four-pin method.



Wenner alpha four-pin method

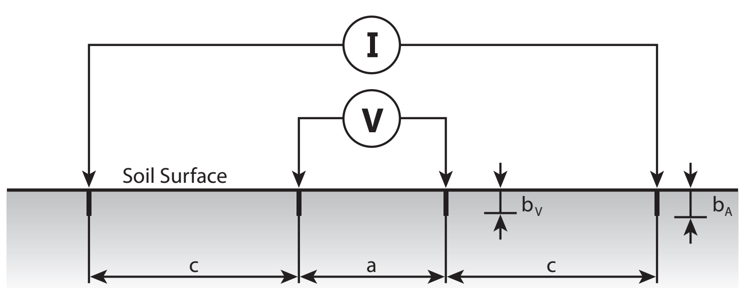
If the depth of the probe, b << a, as is the case of electrodes penetrating the ground only for a short distance (as usually happens), the apparent resistivity can be calculated as follows:

$$\rho_E = 2\pi a \frac{V}{I}$$

Using the Wenner alpha method, the electrode spacing is increased along a path to measure greater depths of soil. This is possible because, as the electrodes spacing is increased, the test source current penetrates greater areas, in both vertical and horizontal directions, regardless of how much the current path is distorted due to the varying soil conditions. Smaller electrode spacing measurements, shallower measurements, are important to characterize the soil with which the grounding system will be in contact. Longer electrode spacing, deeper measurements, are typically taken such that the maximum spacing between pins is equivalent to the maximum dimension of the grounding system to be evaluated. If the resistivity varies appreciably with depth, it is often desirable to increase the range of electrodes spacing to assess the resistivity.

Schlumberger Method

In the Schlumberger method, the distance between the voltage electrodes "a" and the distances from a voltage electrode and a current electrode "c" are different (see figure).



Schlumberger four-pin method

If b << a and b << c (as usually happens), the apparent resistivity can be calculated as follows:

$$\rho_E = \pi \frac{c(a+c)}{a} \frac{V}{I}$$

The configurations with a > c is known as the "Schlumberger – Palmer method" while the configuration with a < c is known as the "Schlumberger method." Compared to the Wenner method, the Schlumberger method is less laborious because it does not require the interior voltage electrodes to be reinstalled for each measurement. The Schlumberger method is also advantageous in that shorter measurement cables, smaller free space, and less time are needed to conduct the testing to acquire resistivity measurement of equivalent depth to the Wenner method.

Compared to the Wenner method on equal terms, using the Schlumberger method with c > a requires more sensitive instruments because the measured resistance is lower, while with c < a the measurement may be easier with a greater measured resistance.

Measurement Challenges

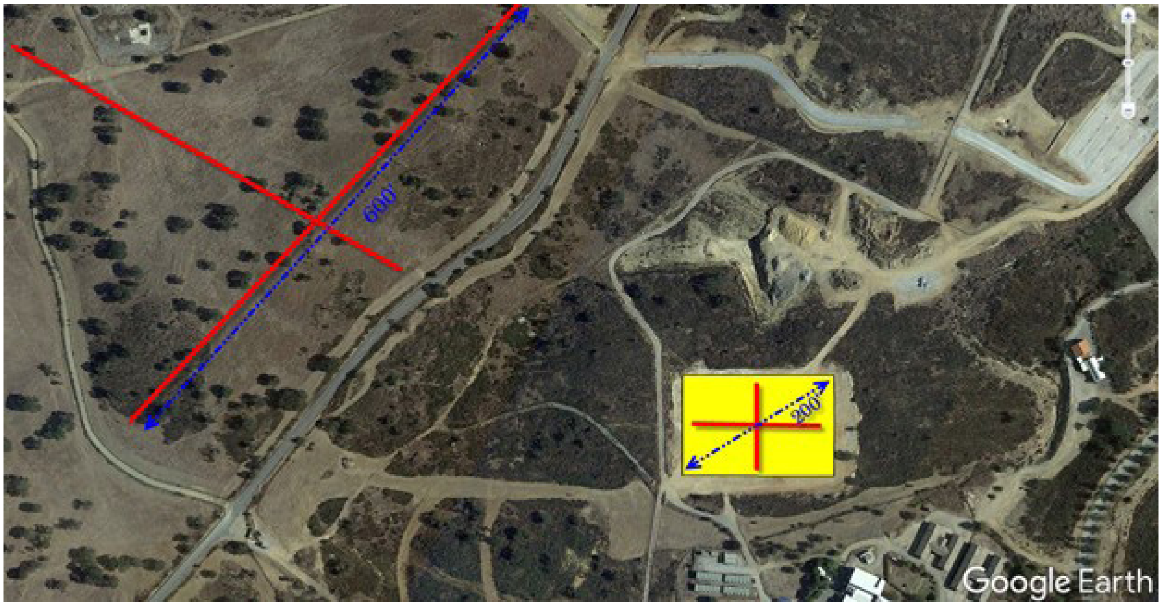
Regardless of the measurement procedure, there are challenges for getting accurate measurements at a site. Typical issues include:

- Electrode/probe continuity
- Buried metallic systems interfering with native soil measurements
- Inductive coupling of testing leads or external sources
- Insufficient power and/or sensitivity of the measurement device

Simple techniques including additional probes, saltwater, or perpendicular measurements can overcome some of the issues above. Symptoms of these issues can be recognized by experienced technicians and engineers performing the test to allow for testing plan modifications.

Field Testing

Prior to the testing, personnel need to outline a test plan to develop goals and mitigate the challenges noted above. As an example, a new site highlighted in yellow below will have a grounding system with a maximum dimension of 200 feet. Using the Wenner Method to acquire soil resistivity measurements, test traverses shown in red provide shallower resistivity at the site, with measurements farther away to access deeper soil resistivity on the order of 200 feet, for a total traverse length of 600 feet.



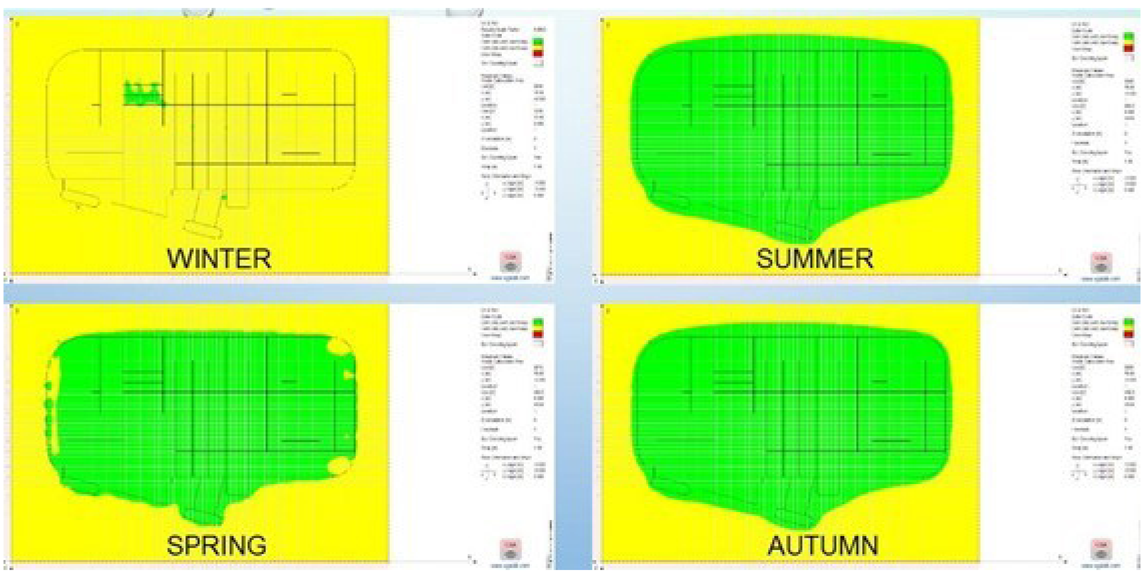
Note that each location includes two perpendicular traverse to help identify interference in measurements.

Often two or more measurements can be performed at a probe spacing that is shallower than the grid depth, such as 9 and 18 inch electrode spacing, which progress to larger electrode spacing to match or exceed the dimension of the grounding system. The image below, courtesy of GreyMatterGlobal, shows this test in the field.

Adequate planning and preparation provide better soil resistivity data to more accurately analyze a grounding system.

Additional Considerations with Soil Data

Performing soil resistivity measurements, like the approaches described above, are pertinent to accurately evaluate various types of studies; however, measurements will provide the electrical characteristic of the soil at a specific time. Factors like temperature, moisture, and chemical content primarily affect shallower soil layers, but can significantly impact an analysis. Chemical content is typically influenced by human interaction, while moisture can vary from day to day due to precipitation. Fortunately, temperature is generally predictable allowing for calculation methods to determine the change in soil resistivity between seasons. In regions where the soil may freeze, ion movement becomes limited, often dramatically increasing resistivity. The Seasonal Analysis tool in XGSLab shows how temperature can influence a grounding system from compliant touch and step voltages in the summer, to hazardous conditions just a few month later (note areas in yellow that indicate non-compliance for touch voltages).



It is important for engineers to understand the accuracy and limitations of the measurements they use for their studies as it has a significant impact on their designs.

Appendix I – When to Perform a Grounding System Study

When a new power system is installed a grounding system study must be performed. With existing power systems, it may be more challenging to determine when a grounding system study is needed. The list below provides some scenarios that would require a new grounding study be performed:

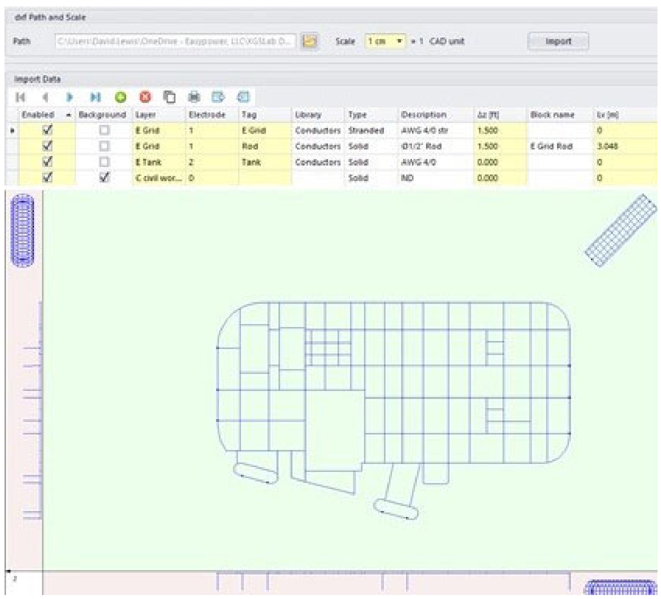
- **Maintenance and field measurements uncover deficiencies**
  - Visual inspection may indicate missing or corroded connections.
  - Grid impedance testing results in grounding system resistance exceeding design value.
  - Elevated point to point measurements indicating discontinuity or weak grounding and bonding.
- **Changes to system protection**
  - Increasing the duration of ground fault current.
- **Changes to short circuit duty**
  - Replacement circuit breakers for short circuit duty purposes.
  - Replacing or adding of transmission lines.
  - Addition or replacement of transformer.
- **Arrangement modifications for equipment and fence**
  - Altering the size of the grounding system can increase the system impedance.
  - Moving the fence can create hazards that are accessible to the public.
  - Removing equipment may result in damage to conductors.
- **Missing design drawings or study documentation**
  - A new grounding analysis is likely necessary to have engineered design to reduce hazards.

Appendix II – Grounding Analysis Process with XGSLab

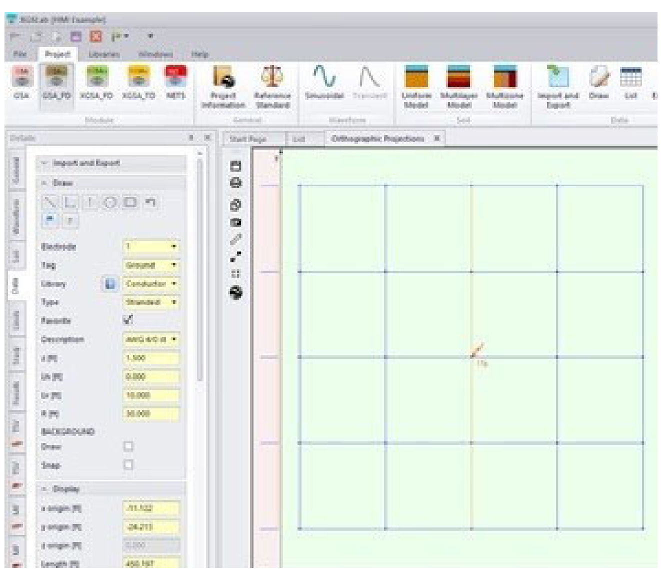
A grounding analysis has a typical process and the images below provide an example for evaluating a grounding system for compliance to IEEE Std 80 Touch and Step voltage criteria. The initial stages illustrate the data entry.

Grounding Layout

The grounding system layout should be incorporated into the software considering the 3 dimensional geometry. This process is generally approached by importing a model for an existing CAD program, or drafting the layout in the XGSLab Draw tool.



Import

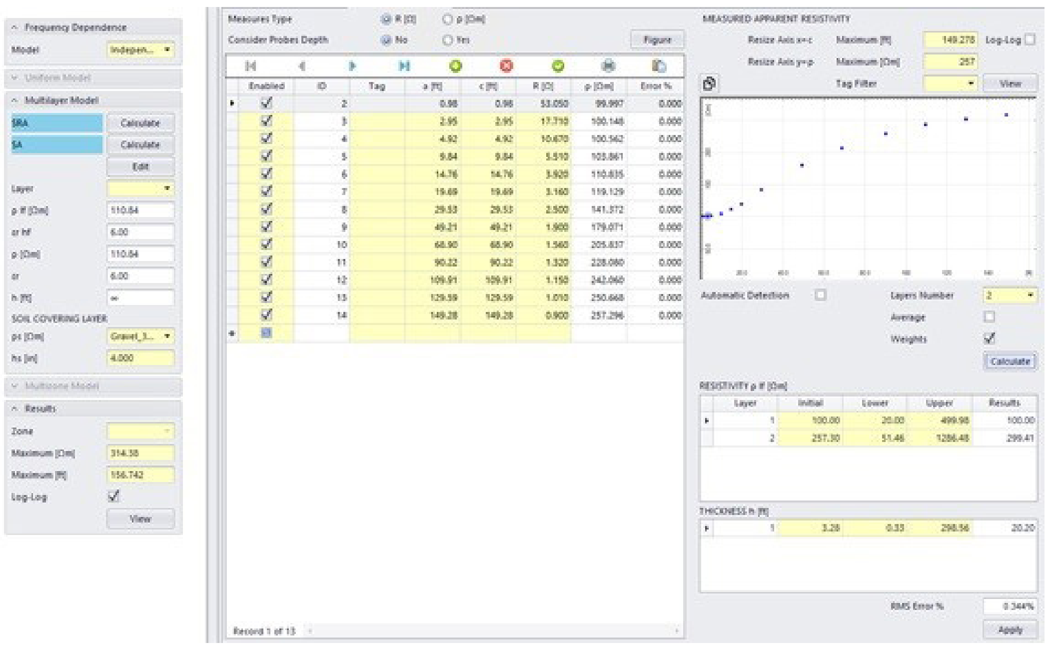


Draft

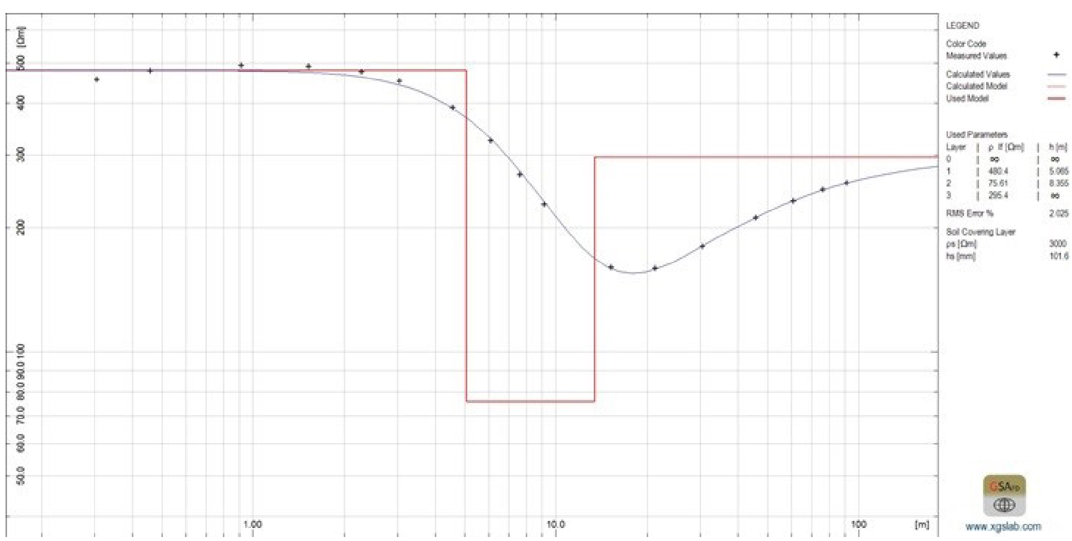
Each conductor is characterized with the corresponding metallic properties (copper, steel, etc.), dimensions, and coating of material where applicable.

Soil Modeling

Various soil resistivity measurements methods can be used to convert measurement trends to a soil model used in XGSLab. Below is a single traverse of soil resistivity measurements entered into the Soil Resistivity Analyzer tool.

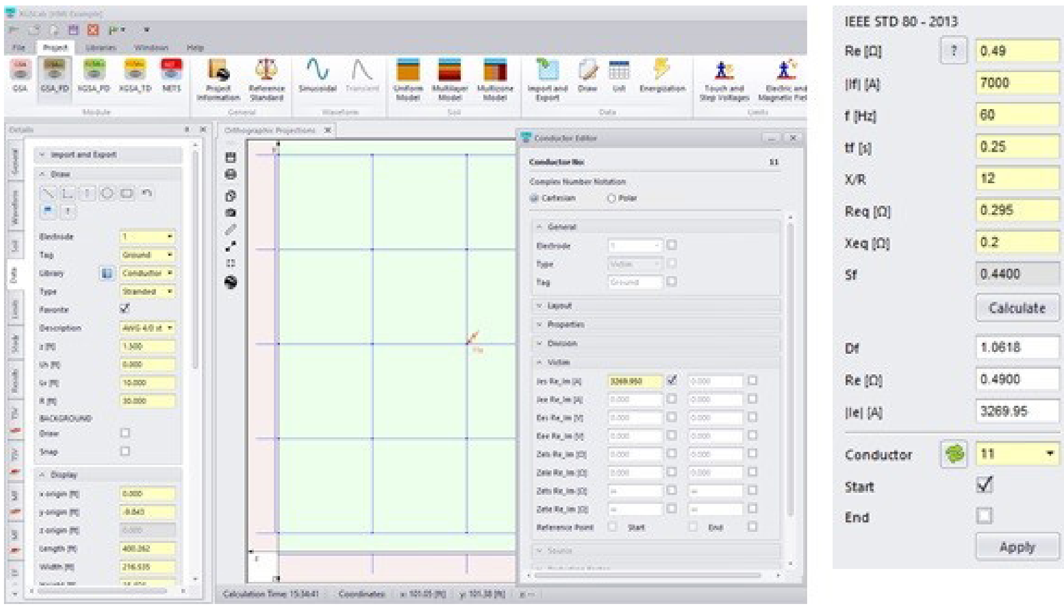


These measurements are used to create a soil model, with a typical chart representing the resistivity and depth for the soil strata.



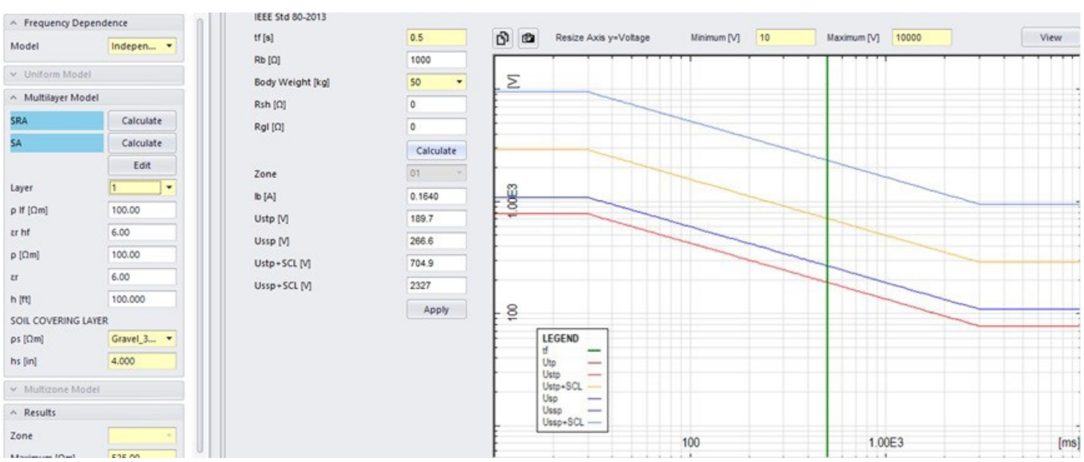
Fault Energization

Entering the fault current data differs from GSA and GSA_FD, as GSA assigns a fault current to a whole electrode while the more accurate GSA_FD assigns the energization to a specific conductor within an electrode. With either process, the engineer must determine if the total available fault current should be used for the analysis or if some fault split should be considered, using hand calculations or tools like NETS.



IEEE Std 80 Compliance Criteria

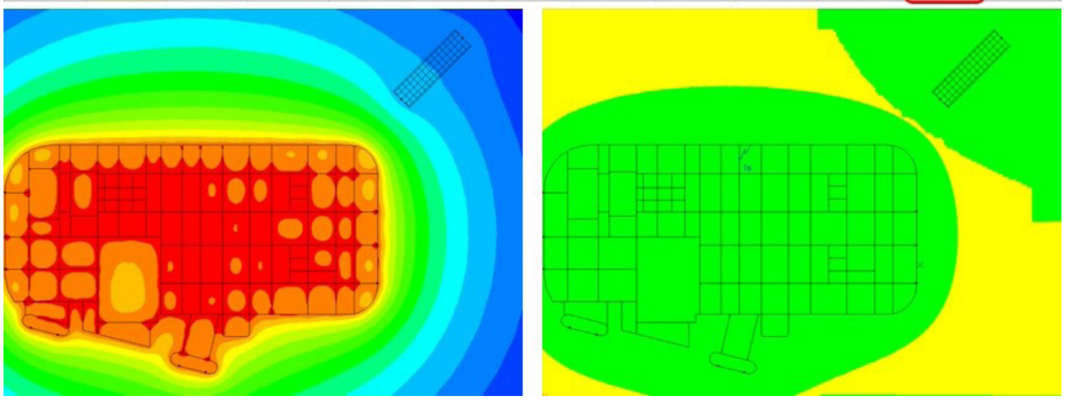
Data entry is generally completed, having entered the system layout, the soil model, and the fault current. The last stage before analysis is calculation of the compliance limits. XGSLab compliance criteria can automatically calculate with IEC, EN, or IEEE criteria. Below illustrates the calculation of touch and step voltage limits with a 0.5 second fault clearing time and 50 kG person.



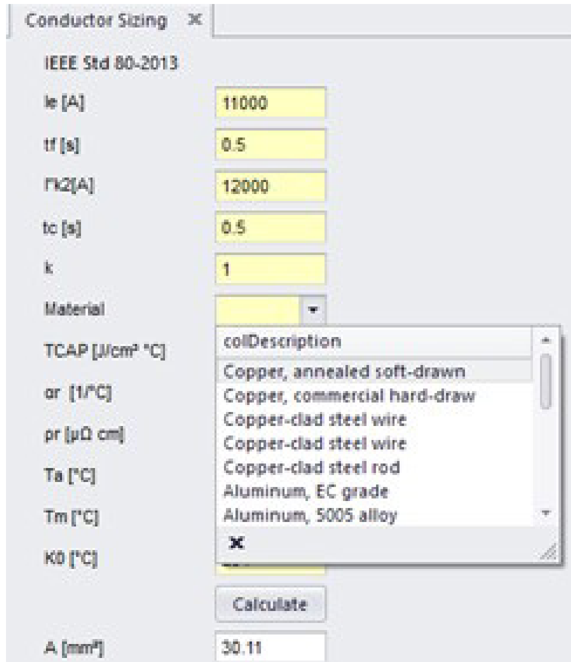
Grounding Analysis Results

Calculating the ground potential rise, touch voltages, step voltages, and compliance areas illustrates the effectiveness of a grounding design. XGSLab provides a very flexible and powerful analysis with useful users tools to determine successful design.

Frequency [Hz]	Reference Point	x [ft]	y [ft]	z [ft]	|Je| [A]	∠Je[deg]	|Ee| [V]	∠Ee[deg]	|Ue| [V]	∠Ue[deg]	|Ue/ΣJe| [Ω]	∠(Ue/ΣJe)[deg]
0.00	1s	131.890	129.985	1.500	1539.400	0.000	0.000	0.000	2319.222	0.000	1.507E+00	0.000

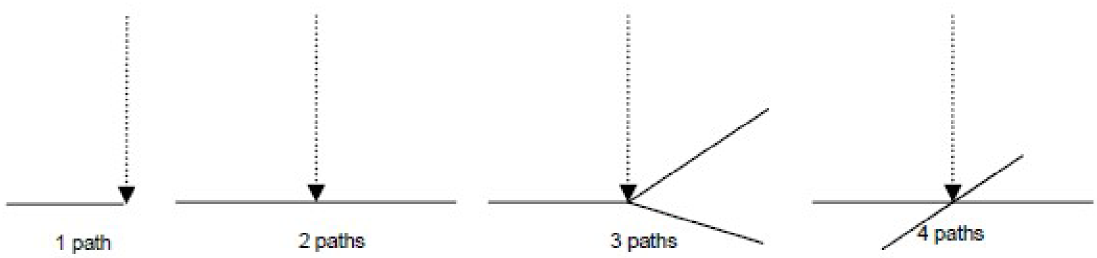


Appendix III – Conductor Sizing



Conductor selection is typically determined by standard procurement at a utility or facility, but designs must verify the material and size of conductor is adequate to withstand the fault current and mechanical stresses. Grounding Systems in North America are predominantly constructed with copper and copper-clad conductors. IEEE Std 80 provides material constants, which is a part of the XGSLab library, to determine the conductivity, fusing temperature, and many more aspects of conductor sizing. This permits users to simply enter the fault current information and select from the data table.

Considering that the grounding system is typically a mesh, the current used for conductor sizing may differ based on the number of paths available. IEC and EN standards provide a k factor for approximating the fault current split in the grid illustrated below:



Where the k factor may be chosen:

- K = 1 for one path
- K = 0.5-0.7 for two paths
- K = 0.35-0.5 for three paths
- K = 0.25-0.35 for four paths

Glossary

- **Ground current** – A current flowing into or out of the earth.
- **Ground electrode** – A conductor imbedded into the earth for collecting and dissipating ground current into earth.
- **Grounding system** – A network of ground electrodes.
- **Ground impedance** – The resistance and reactance of the grounding system and remote earth.
- **Ground potential rise (GPR)** – The maximum electrical potential of the grounding system relative to the potential of remote earth.
- **Remote earth** – A point of earth that has no electric potential and is not affected by the ground potential rise of the system under analysis.
- **Soil resistivity** – a measure of the soil's allowance of electrical current expressed in ohm-meters.

References

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2. IEEE Std 81-2012, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a ground System, New York, NY: IEEE.
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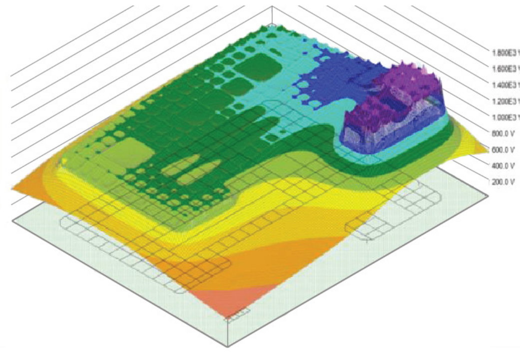
9. M. Kizlo and A. Kanbergs, "The Causes of the Parameters Changes of Soil Resistivity," 50th International Scientific Conference, Power and Electrical Engineering Oct. 2009.

XGSLab Software

XGSLab is one of the most powerful software packages for grounding system analysis, electromagnetic fields, AC interference, and lightning analysis. It is used worldwide for:

- **Grounding System Analysis**
- **Multilayer/Zone Soil Models**
- **Below and Above Ground Systems**
- **Cathodic Protection Systems**
- **Magnetic & Electric Fields**
- **Electromagnetic Interferences**
- **Fault Current Distribution**
- **Lightning Shielding and Analysis**
- **Time and Frequency Domain**



Applications

The following table summarizes the main applications of the available modules.

	GSA	GSA_FD	XGSA_FD	XGSA_TD	NETS	SHIELD
Grounding (equipotential systems)	✓	✓	✓	✓		
Grounding (general conditions)		✓	✓	✓		
Cathodic Protection Systems		✓	✓	✓		
Magnetic Field		✓	✓	✓		
Electric Field			✓	✓		
Electromagnetic Interferences		✓	✓	✓	✓	
Corona Effects			✓			
Switching Transients, Lightning and Fault Transients in GIS				✓		
Steady State Solver for Full Meshed Multi-conductor and Multi-phase Networks					✓	
Short Circuit Current on Full Meshed Multi-conductor and Multi-phase Networks					✓	
Fault Current Distribution on Full Meshed Multi-conductor and Multi-phase Networks					✓	
Lightning Shielding						✓

Contact Sales@EasyPower.com to get answers to any questions or set up a one-on-one free demo of the capabilities of the XGSLab software. You can also request a quote.

You can learn more about XGSLab by visiting our website at: www.easypower.com

For more resources to help you with grounding, lightning and EMF needs, visit the EasyPower website and go to the **Grounding Resource Center**.

www.EasyPower.com/groundingcenter

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