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***Diploma Seminar***

**DISEÑO DE SISTEMAS DE CONEXIÓN A  
TIERRA EN EDIFICIOS. UTILIZACIÓN DEL  
SOFTWARE Win-IGS**

(Design of Earthing Systems in buildings. Use of  
Win-IGS program tool)

In order to get:

**DEGREE IN INDUSTRIAL ENGINEERING**

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**Design of Earthing Systems in buildings. Use of Win-IGS program tool**





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## **1. INTRODUCTION**

The thesis presents the process of design and calculates of earthing system also called grounding system in buildings.

The purpose of the grounding system is to provide a low-impedance electrical contact between the neutral of an electrical system and earth. Ideally, the potential of the neutral of a three-phase system should be the same as that of the earth. In this case, human beings and animals are safe whenever they touch metallic structures connected to the system neutrals. Unfortunately, the impedance of the grounding system to earth is always a finite number. Thus the potential of grounded structures may become different than the potential at various points on earth during abnormal operation. Abnormal operation includes highly unbalanced operating conditions or fault conditions.

The main purpose of this thesis is to obtain using the Win-IGS software the specific value for the ground system resistance that we design which is also a difficult parameter to be obtained using numerical methods or other types and more complicated program tools. Other important aspect we are going to consider is the value of the soil resistivity. This parameter can be also computed easily using the Win-IGS program. This software will usefully contribute to our Diploma expectations.

Depending on the level of the potential difference between earth points and grounded structures, a hazardous condition may be generated for human beings. This condition may result from two distinct possibilities:

- A person touching a grounded structure which has a potential that is different from that of the point of earth at which the person is standing. In this case, the person is subjected to a voltage that will generate an electric current through his or her body. The voltage to which the human body is subjected is called the touch voltage.
- A person walking on the surface of the earth will experience a voltage between his or her feet. This voltage will generate electric body current. In this case, the voltage to which the person is subjected is called the step voltage.

These electrical parameters are referring to the connection of all the conductive parts of devices inside a building which are connected to the PE conductor. Although the touch and step voltages are analysed in the interior of the building we have designed, they are also parameters we are going to consider but they are not as important as the previous one which is to calculate the ground resistance. In addition, they can be computed using the Win-IGS program tool too.

The flow of electric current through the human body is a source of danger. Standards define limits on body currents that can be caused by touching grounding structures under adverse conditions. Consequently, grounding system should be designed such

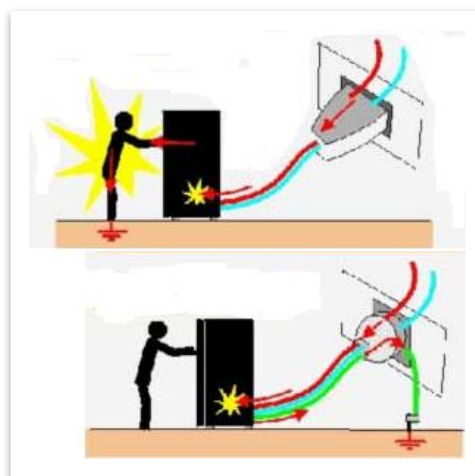
that the possible electric body current in an operator or bystander should not exceed this limit under any foreseeable adverse conditions.

## 2. MAIN REASONS FOR GROUNDING

Electric power systems are grounded, connected to earth by means of earth-embedded electrodes, for a number of reasons:

- To assure correct operation of electrical devices.
- To provide safety during normal or fault conditions.
- To stabilize the voltage during transient conditions and therefore to minimize the probability of a flashover during transient.
- To dissipate lighting strokes.
- Electrical Noise Reduction. Proper grounding aids in electrical noise reduction and ensures:
  - The impedance between the signal ground points throughout the building is minimized and the voltage potentials between interconnected equipment are minimized.
  - That the effects of electrical and magnetic field coupling are minimized.

In general, a structure is called grounded if it is electrically connected to earth-embedded metallic structures. The earth-embedded metallic structures will be called the grounding system and provide a conducting path of electricity to earth. A typical substation grounding system consists of a ground mat, ground rods and other earth-embedded metallic structures. A typical transmission tower grounding system consists of rings, counterpoises, ground rods and so on. A typical transmission pole grounding system consists of ground rods, butt straps, counterpoises and additional equipment. In the case of this thesis, the typical grounding system for a house (building) consists of one or more ground rods.



*Figure 1. No grounding system against grounding system. Current flow.*





### **3. GROUNDING SYSTEM COMPONENTS**

#### **3.1 GROUND CONDUCTORS**

There are two basic criteria for grounding conductor selection:

- The physical characteristics of the conductor must be of a robust nature, sufficient for the environment.
- The cross sectional area of the conductor must be of sufficient size, so that it shall successfully conduct the maximum fault current for a period, which allows the operation of protection equipment (or the dissipation of this energy).

##### **3.1.1 PHYSICAL CHARACTERISTICS**

The most common ground conductor is a soft drawn, stranded copper conductor. Flat copper strip/tape is also popular because it offers a large surface area, resulting in lower impedance.

In some circumstances, the maximum fault current for the installation is small. While a conductor of correspondingly small size could be used, a minimum cross section often set by governing authority or applicable standards body (to minimize potential damage likely to occur from any future excavation on the site), is applied.

##### **3.1.2 MAXIMUM FAULT CURRENT**

The normal operating conditions of an electric power system are occasionally disrupted because of faults. A fault occurs because of insulation failure or when a conducting medium shorts one or more phases of the system. In general, the causes of faults are many: lightning, tree limbs falling in on lines, wind damage, insulation deterioration, vandalism, and so on. The design of the protective system requires knowledge of the fault current levels. Where higher fault conditions exist, the conductor size is determined by considering the circumstances required to avoid fusing (melting) the conductor.

##### **3.1.3 THEFT DETERRENT COMPOSITE CABLE**

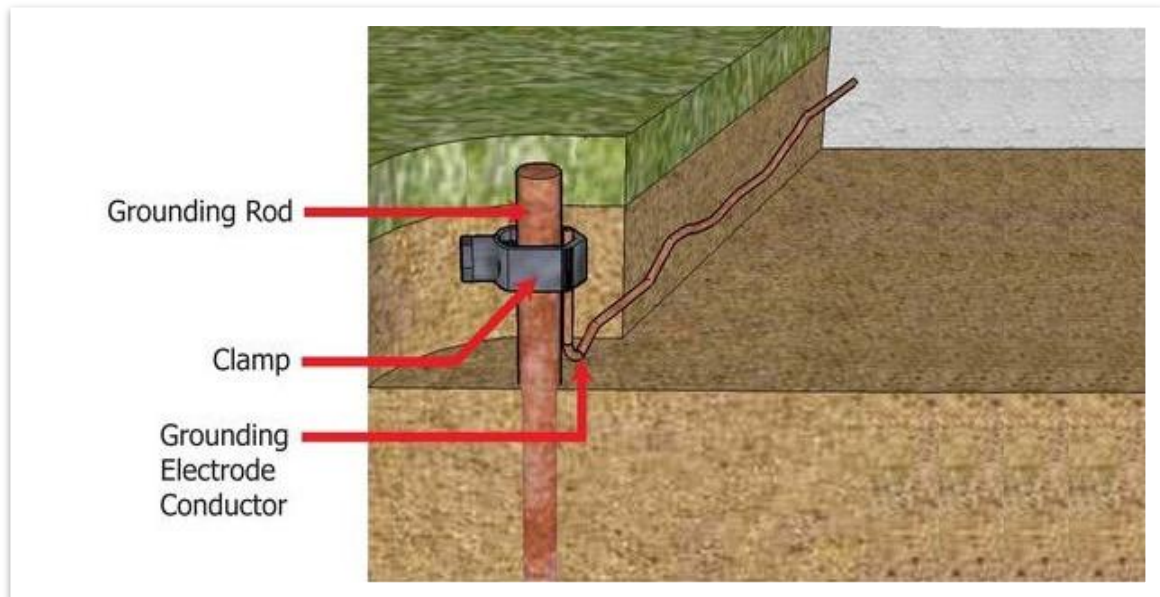
Theft deterrent composite cables are bare or insulated concentric stranded conductors that consist of peripheral galvanized steel stranding, which protects and conceals the internal tinned copper strands. These conductors are for exposed electrical distribution grounding leads where copper theft may occur. These conductors are difficult to cut with hand tools and the outer steel stranding is magnetic, which further deters thieves looking for copper.



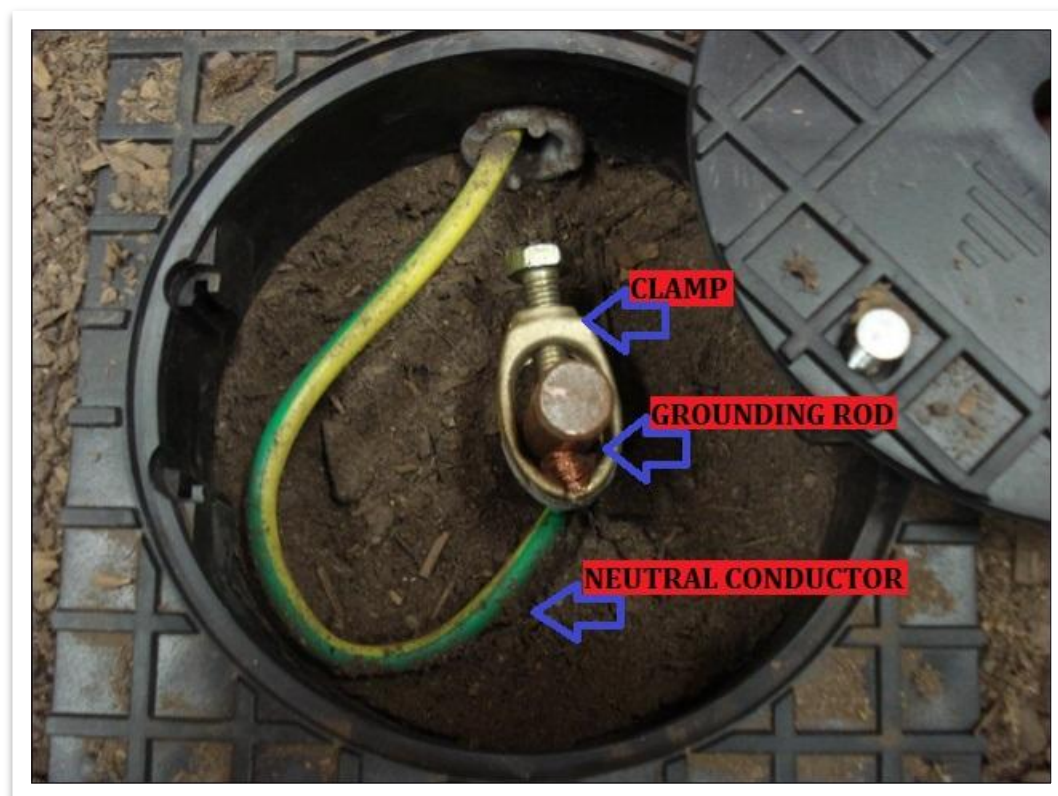
### **3.2 GROUND RODS AND COUPLERS**

The ground electrode is a critical component of the grounding system. Many different types of electrodes are available, some “natural” and some “made”. The natural types include metal underground water pipe, the metal frame of a building (if effectively grounded), a copper wire or reinforcing bar in a concrete foundation or underground structures or systems. Consideration should be given to bonding of natural earths to ensure electrical continuity with a facility’s other “earths”. “Made” electrodes are specifically installed to improve the system grounding or earthing. These earth electrodes must ideally penetrate into the moisture level below the ground level to reduce resistance. They must also consist of metal conductors (or a combination of metal conductor types), which do not corrode excessively for the period of time they are expected to serve. Made electrodes include rods or pipes driven into the earth, metallic plates buried in the earth or a copper wire ring encircling the structure. Underground gas piping or aluminium electrodes are not permitted for use as ground electrodes. Ground rods are often selected on the basis of their resistance to corrosion. The other major factor is cost. All too often, the cost of a product is seen as the initial up front price, but the real cost is determined by the serviceable life of the ground rod. Acceptable options consist of the following standard list:

- A copper, aluminium, or copper-clad aluminium conductor. This conductor shall be solid or stranded; insulated, covered, or bare; and in the form of a wire or a busbar of any shape.
- Rigid metal conduit (RMC).
- Intermediate metal conduit (IMC).
- Electrical metallic tubing (EMT).
- Listed flexible metal conduit (FMC).
- Flexible metal tubing (FMT).
- Type AC cable (BX).
- Listed liquid-tight flexible metal conduit (LTFC).
- Mineral insulated sheathed cable (MI).
- Type MC Cable.
- Cable trays.
- Cablebus framework.
- Other listed electrically continuous metal raceways.
- Surface metal raceways listed for grounding.



*Figure 2. Schematic grounding system basic components.*



*Figure 3. Real grounding system.*



### **3.2.1 GROUND ROD DIAMETER**

Ground rod diameter must also be considered. Although larger diameter rods are more rigid and less prone to whip or bending, they may have a greater drag than smaller diameter rods when being driven. It must also be noted that increasing the ground rod diameter has relatively small impact on grounding system resistance when compared to length. Standards nominate a minimum diameter or periphery and thickness if not cylindrical, mainly based on mechanical strength.

### **3.3 COMPRESSION COUPLING**

Couplings enable ground rods to be driven quickly and easily without the risk of rod separation. They are generally tapered so when the rod is driven into the coupling, the two parts compress to form a conductive connection.

### **3.4 GROUND ENHANCEMENT MATERIAL**

The concept of GEM, Ground Enhancement Material, makes reference to a superior conductive material that improves grounding effectiveness, especially in areas of poor conductivity (rocky ground, areas of moisture variation, sandy soils). It has two main characteristics:

- Effective:
  - Can dramatically lower earth resistance and impedance measures.
  - Typically, resistivity in range from 12-18 Ohm-cm.
  - Once in its “set form”, maintains constant resistance for the “life” of the ground system.
  - Performs in all soil conditions, even during dry spells.
- Permanent:
  - Does not dissolve, decompose nor leach out with time.
  - Does not require periodic charging treatments or replacement.
  - Does not require maintenance.
  - Does not require continuous presence of water to maintain effectiveness.
  - Freezing will increase resistivity only 10 - 15 per cent.

## 4. SIMPLE GROUNDING SYSTEMS

Practical grounding structures consist of ground rods, strips, rings, disks, ground mats, and so on as we described in previous sections. Some of the simplest practical grounding electrodes are illustrates.

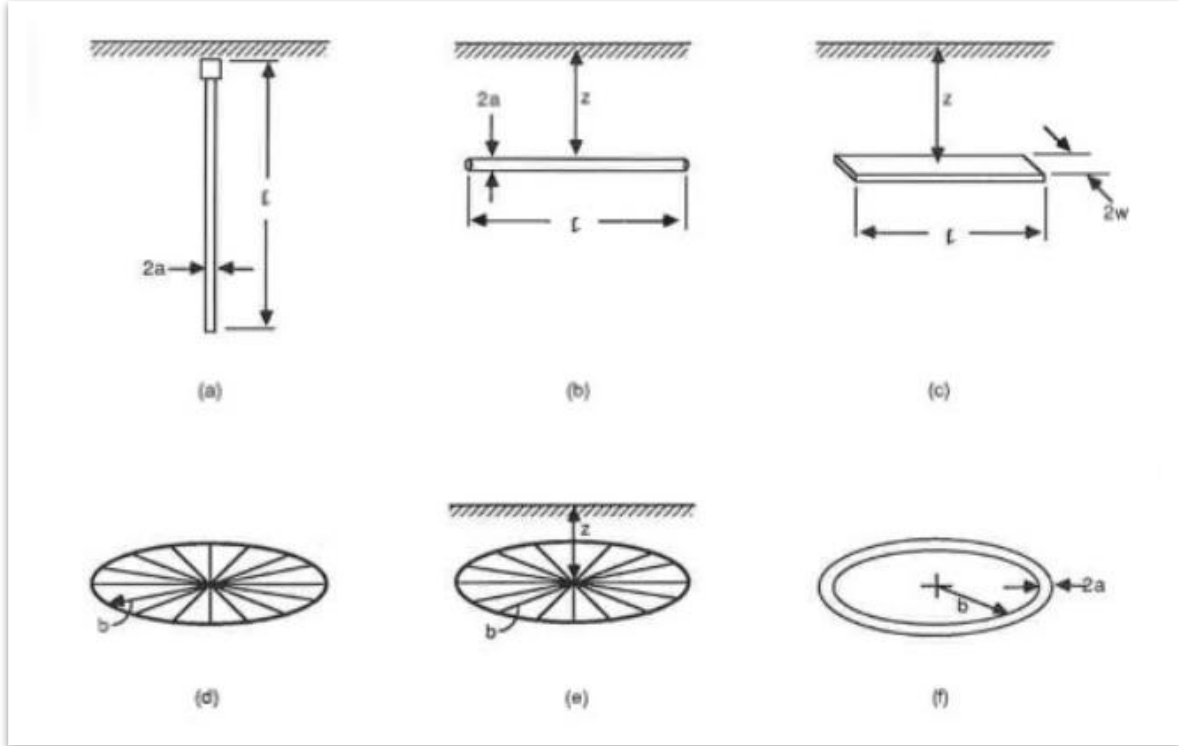


Figure 4. Simple grounding systems: a) Ground rod; b) buried wire; c) buried strip; d) thin plate in infinite medium; e) thin plate near the soil surface; f) ring in infinite medium.

Often it is necessary to estimate the resistance of grounding system with simplified formulas. Such formulas for the simple grounding systems of Figure 4 are as follows:

Ground rod (Fig 4.a):

$$R = \frac{\rho}{2\pi l} \ln \frac{2l}{a}$$

Buried wire (Fig 4.b):

$$R = \frac{\rho}{2\pi l} \left( \ln \frac{l}{a} + \ln \frac{l}{2z} \right) ; z \geq 6a$$

Buried strip (Fig 4.c):

$$R = \frac{\rho}{2\pi l} \left( \ln \frac{2l}{w} + \ln \frac{l}{2z} \right) ; z \geq 3w$$



Disk in infinite medium (Fig 4.d):

$$R = \frac{\rho}{8b}$$

Disk near the soil surface (Fig 4.e):

$$R = \frac{\rho}{4b}$$

Ring in infinite medium (Fig 4.f):

$$R = \frac{\rho}{4\pi^2 b} \ln \frac{8b}{a}$$

Where  $\rho$ , is resistivity;  $l$ , is the length of the rod;  $a$ , half-thickness;  $z$ , distance from rod to oil;  $w$ , width;  $b$ , disk radius.

The ground resistance depends on two main factors: The earth resistivity and the electrode structure.

The earth resistivity is a material property and defining its ability to conduct the electric current. Determining soil resistivity is a complicated task due to the following factors:

- It depends on soil composition (Clay, gravel, sand...).
- It can vary even for small distances due to the presence of different materials.
- It depends on the mineral content (i.e. salts).
- Varies with compression and It can change with the time passing due to the sedimentation.
- Resistivity also changes with temperature. Therefore, the resistivity increases when the temperature decreases.
- May be affected by buried metal pipes deposits, steel reinforcements, etc.
- Varies with depth. Specifically, the resistivity decreases with depth. Thus, a way to reduce the ground impedance is to place the electrode at a higher depth.

In case of various rods, other key aspect for increasing the electrode efficiency is to put each rod out of the influence area of each one. As a general rule each rod should have a distance between each other higher than its height. The distance recommended is the double of its height.

Grounding systems designed for areas which typically have very dry soil and arid climates may need to use enhancement materials or other means to achieve lower soil resistivity.



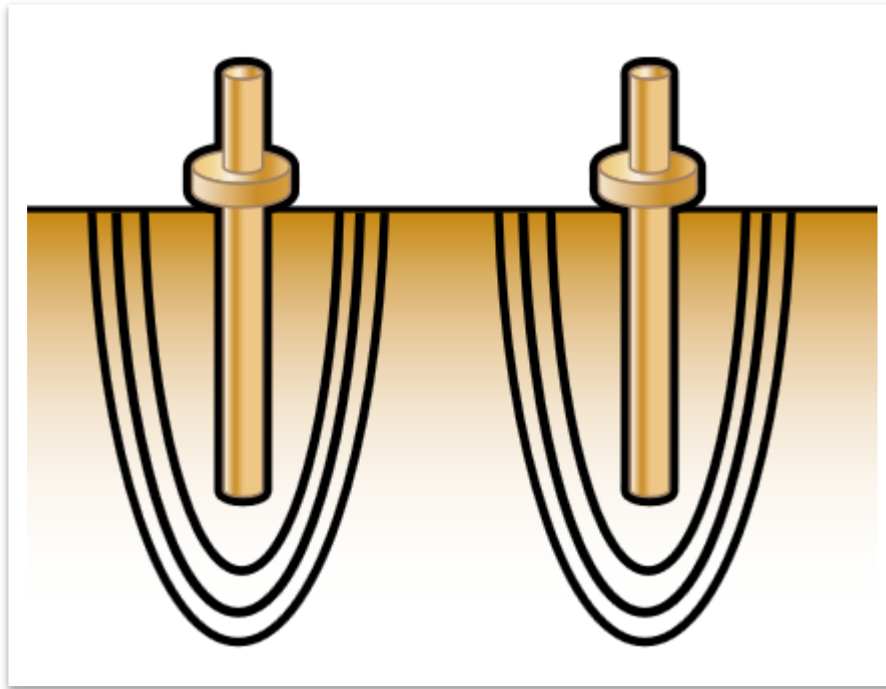


Figure 5. Influence area of a pair of rods.

## 5. EARTH RESISTIVITY

Thus, the earth resistivity is a critical parameter. The correct design of an earthing system is dependent upon knowledge of the local ground resistivity.

The techniques for measuring soil resistivity are essentially the same whatever the purpose of the measurement. However, the interpretation of the recorded data can vary considerably, especially where soils with non-uniform resistivities are encountered. The added complexity caused by non-uniform soils is common, and in only a few cases are the soil resistivities constant with increasing depth.

Table 1 shows the resistivity values for various soils and rocks. Usually there are several layers, each having a different resistivity. Lateral changes may also occur, but in general, these changes are gradual and negligible at least in the vicinity of the site concerned.

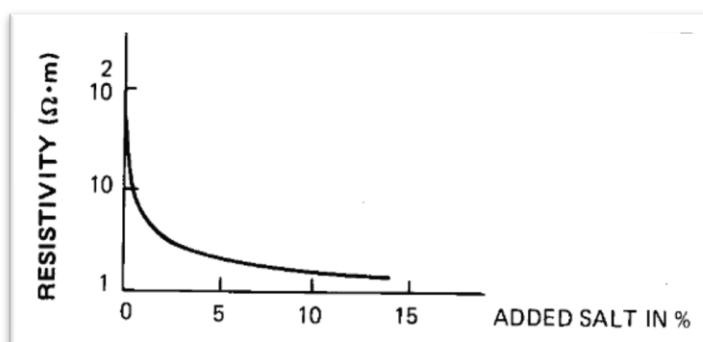
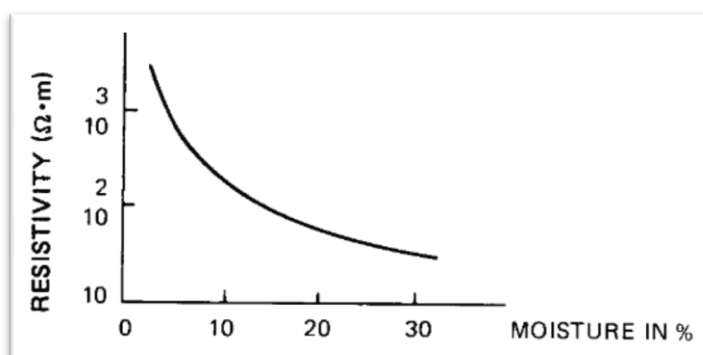
Earth resistivity varies not only with the type of soil but also with temperature, salt content, and compactness. It is showed in the figure 5.

The resistivity of earth increases slowly with decreasing temperatures from 25°C to 0°C. Below 0°C the resistivity increases rapidly. In frozen soil, as in the surface layer in winter the resistivity may be exceptionally high.



Earth Resistivity Ohmmeters	Quarternary	Cretaceous Tertiary Quarternary	Carboniferous Triassic	Cambrian Ordovician Devonian	Pre-Cambrian and Cambrian	
1 Sea water						
10 Unusually low		Loam Clay Chalk	Chalk			
30 Very low			Trap Diabase Shale	Shale		
100 Low			Limestone	Limestone		
300 Medium			Sandstone	Sandstone		
1000 High				Dolomite		Sandstone
3000 Very high						Quartzite
10000 Unusually high		Slate				
	Coarse Sand and Gravel in surface layers			Granite		
				Gneisses		

*Table 1. Geological Period and formation.*





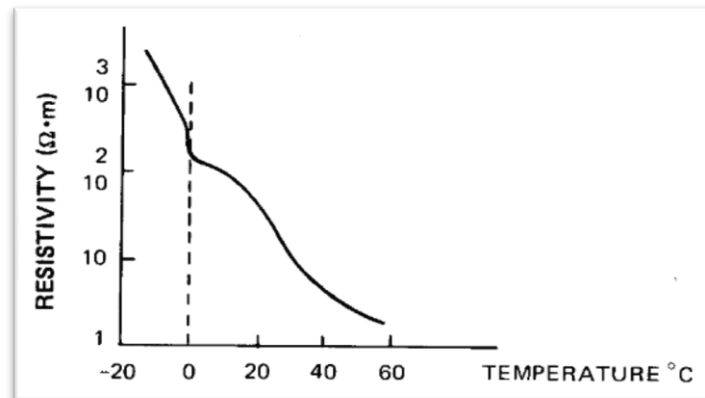


Figure 6. Resistivity variations.

## 6. METHODS OF MEASURING EARTH RESISTIVITY

### 6.1 GEOLOGICAL INFORMATION AND SOIL SAMPLES

Often, at the site where a grounding system is to be installed, extensive civil engineering work must be carried out. This work usually involves geological prospecting which results in a considerable amount of information on the nature and configuration of the site soil. Such data could be considerable help to the electrical engineer who should try to obtain this information.

The determination of soil resistivity from the values of resistance measured between opposite faces of a soil sample of known dimensions is not recommended since the unknown interfacial resistances of the soil sample and the electrodes are included in the measured value.

A more accurate determination is possible if a four-terminal resistance measurement of the soil sample is made. The potential terminals should be small, relative to the sample cross-section, and located sufficiently distant from the current terminals to assure near-uniform current distribution across the sample. A distance equal to the larger cross-section dimension is usually adequate for the purpose of the determination.

It is difficult, and in some cases impossible, to obtain a useful approximation of soil resistivity from resistivity measurements on samples. This is due to the difficulty of obtaining representative, homogeneous soil samples, and in duplicating the original soil compaction moisture content in the test cell.



## **6.2 VARIATION OF DEPTH METHOD**

This method, sometimes called a three-point method, is a ground-resistance test carried out several times, each time the depth of burial of the tested electrode is increased by a given increment. The purpose of this force more test current through the deep soil. The measured resistance value will then reflect the variation resistivity at increased depth. Usually the tested electrode is a rod. Rods are preferred to other types of electrodes because they offer two important advantages:

- The theoretical value of ground-rod resistance is simple to calculate with adequate accuracy (as we have seen before); therefore, the results are easy to interpret.
- The driving of a rod into the soil is normally an easy operation.

The variation of depth method gives useful information about the nature of soil in the vicinity of the rod (5 to 10 times the rod length). If a large volume of soil must be investigated, it is preferable to use the four-point method, since the driving of long rods is not practical.

## **6.3 TWO-POINT METHOD**

Rough measurements of the resistivity of undisturbed earth can be made in the field with the shepard-soil resistivity meter and similar two-point methods. The apparatus consists of one small and one smaller iron electrode, both attached to an insulating rod. The positive terminal of a battery is connected through a milliammeter to the smaller electrode and the negative terminal to the other electrode. The instrument can be calibrated to read directly in ohm-centimetres at nominal battery voltage. This type of apparatus is easily portable and with it a number of measurements can be made in a short time on small volumes of soil by driving the electrodes in the ground or in the walls or bottom of excavations.

## **6.4 FOUR-POINT METHOD**

The most accurate method in practice of measuring the average resistivity of large volumes of undisturbed earth is the four-point method. Small electrodes are buried in four small holes in the earth, all depth " $b$ " and spaced at intervals " $a$ ". A test current  $I$  is passed between the two outer electrodes and the potential  $V$  between the two inner electrodes is measured with a potentiometer or high-impedance voltmeter. Then  $V/I$  give the resistance  $R$  in ohms.

Two different variations of the four-point method are often used:

- Equally Spaced or Wenner Arrangement. With this arrangement the electrodes are equally spaced as shown in figure 6. Let  $a$  be the distance between two adjacent electrodes. Then, the resistivity  $\rho$  in the terms of the length units in which  $a$  and  $b$  are measured is:

$$\rho = \frac{4\pi aR}{1 + \frac{2a}{\sqrt{a^2 + 4b^2}} - \frac{a}{\sqrt{a^2 + b^2}}}$$

It should be noted that this does not apply to ground rods driven to depth  $b$ ; it applies only to small electrodes buried at depth  $b$ , with insulated connecting wires. However, in practice, four rods are usually placed in a straight line at intervals  $a$ , driven to a depth not exceeding  $0.1a$ . Then we assume  $b=0$  and the formula becomes:

$$\rho = 2\pi aR$$

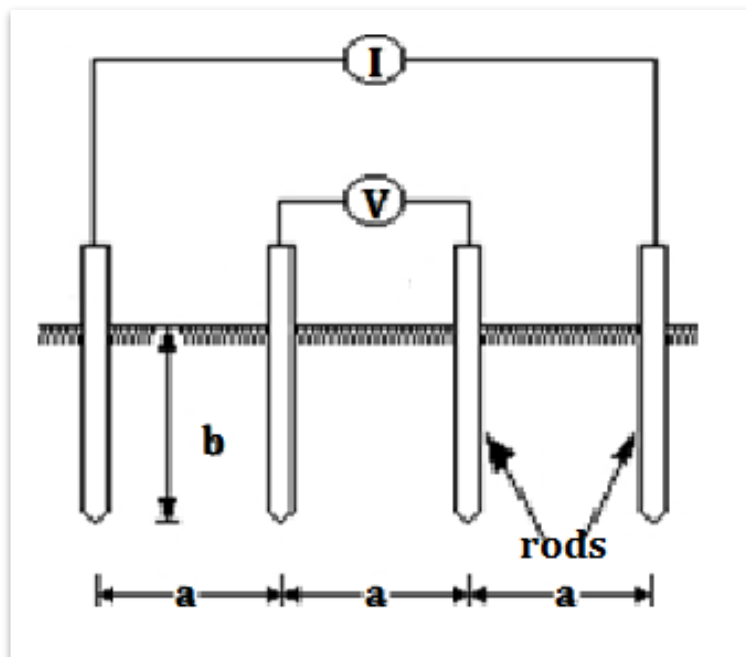


Figure 7. Wenner arrangement.

A set of readings taken with various probe spacing gives a set of resistivities which, when plotted against spacing, indicates whether there are distinct layers of different soil or rock and gives an idea of their respective resistivities and depth.

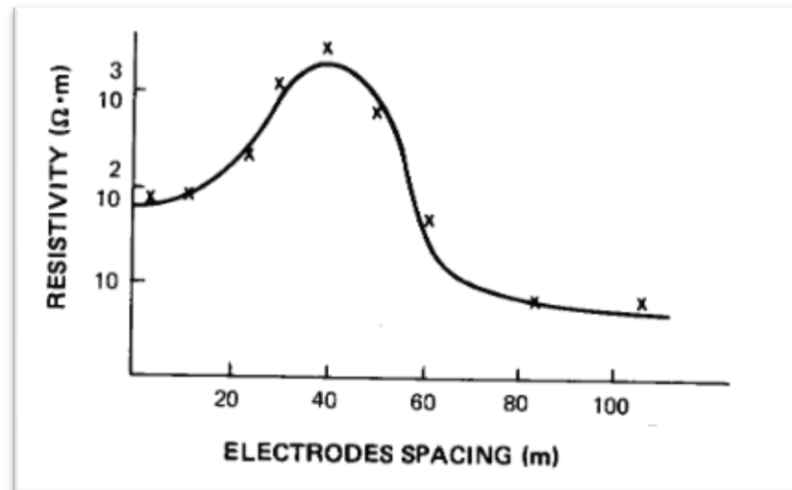


Figure 8. Typical resistivity curve.

- Unequally-spaced or Schlumberger-Palmer arrangement. One shortcoming of the Wenner method is the rapid decrease in magnitude of potential between the two inner electrodes when their spacing is increased to relatively large values. The formula in this case, considering the depth of burial of the electrodes  $b$  small compared to their separation  $d$  and  $c$ , then the measured resistivity can be calculated as follows:

$$\rho = \frac{\pi c(c+d)R}{d}$$

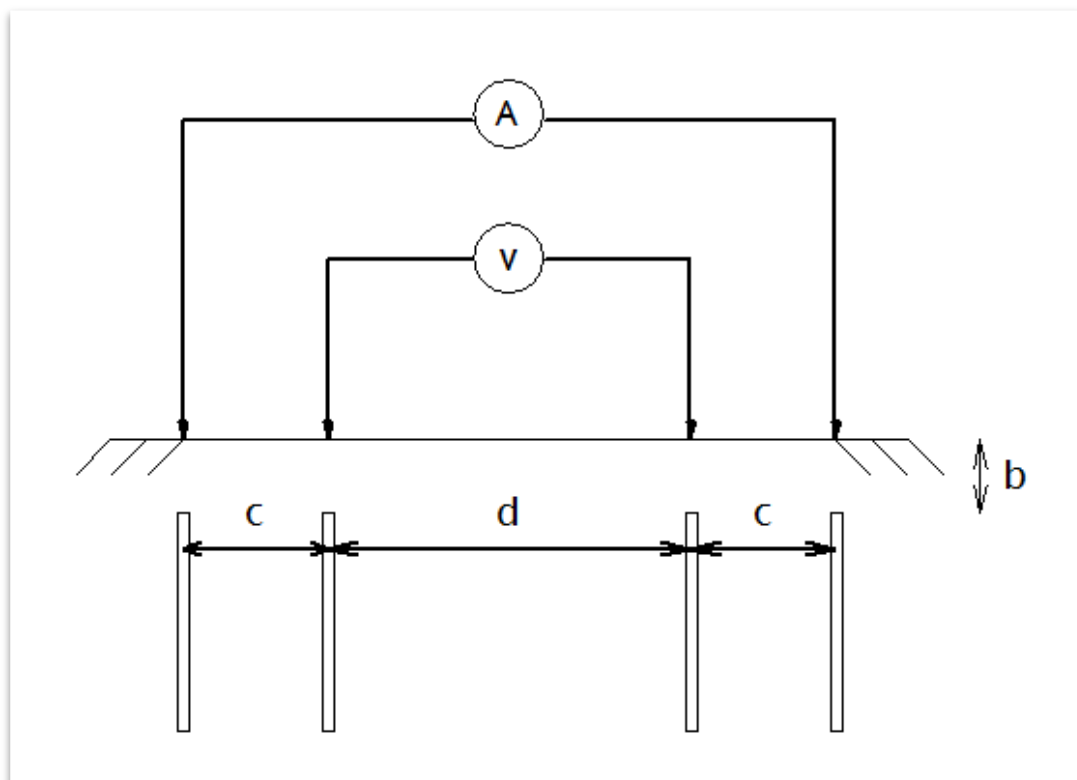


Figure 9. Unequally-spaced arrangement.



## **6.5 INTERPRETATION OF MEASUREMENTS**

The interpretation of the results obtained in the field is perhaps the most difficult part of the measurement program. The earth resistivity variation is great and complex because of the heterogeneity of earth. Except for very few cases it is essential to establish a simple equivalent to the earth structure. This equivalent depends on:

- The accuracy and extent of the measurements.
- The method used.
- The complexity of the mathematics involved.
- The purpose of the measurements.

For applications in power engineering, the two-layer equivalent model is accurate enough without being mathematically too involved.

## **6.6 GEOLOGICAL INFORMATION AND SOIL SAMPLES**

Special tools or mathematical equations are not necessary to interpret such information, which are mainly given in the figures and tables provided by geological explorations. As shown in Table 1 determining an accurate soil model from simple classifications of types of soil is difficult. The classifications simply give a crude estimation of the resistivity of different types of soils.

## **6.7 VARIATION OF DEPTH METHOD AND FOUR-POINT METHOD**

We assume that the tested ground is a rod driven to various depths. For each length of the rod the measured resistance value determines the apparent resistivity value which plotted against the length provides a visual aid for determining earth resistivity variation with depth. However, driving rods to great depth can be difficult and expensive. Moreover, the variation of depth method fails to predict earth resistivity at large distances from the area where the test rod is embedded. For large areas, several rod locations can give an indication of significant lateral changes in soil resistivity.

The interpretation of the four-point method is similar to the interpretation of depth method. In the case of Wenner arrangement the measured apparent resistivity is plotted against the electrode spacing and the resulting curve then indicates the soil structure.



## 7. GUIDANCE ON PERFORMING FIELD MEASUREMENTS

### 7.1 INTERFERENCES

When making measurements using the variation-of-depth or four-point methods, be careful to avoid interferences from nearby structures or circuits. These interferences might be passive or active. Passive interferences include, but are not limited to, metallic fences, transmission or distribution line pole grounds, large building foundations, buried conductive objects, and metallic pipes. These passive interferences can act as a short circuit to distort the potentials created in the soil from the injected test current. Active interferences include, but not limited to, parallel transmission or distribution lines, parallel communication circuits and stray dc currents. Use test probes made of a material that will minimize galvanic voltages between the probes. These active interferences can be a source of current that is added to or subtracted from the injected test current, again, distorting this potentials at the potential probes.

A second, and more important, reason for avoiding parallel active sources of current is the possible hazardous voltage that can be coupled onto the test wire via electromagnetic induction.

### 7.2 PROBE SPACING INFLUENCE ON TEST ACCURACY

Depending on the actual soil resistivity variations with depth, the probe spacing for the Wenner method can significantly influence the accuracy of the computed soil model. Table 2 shows the range of errors in resistance and step voltages for a ground grid. This analysis is based on a number of “perfect” two-layer soil models with the apparent resistivity versus probe spacing computed using a computer program. Therefore, there is no source of error between the two-layer model layer and depth parameters versus the actual soil structure.

Probe spacing (% grid length)	Error range (%)	
	Grid resistance	Touch and step voltage (in % of grid GPR)
40%	-50% to +30%	-20% to +110%
100%	-33% to +9%	-8% to +50%
300%	-17% to +9%	-8% to +20%

Table 2. Error range based on probe spacing.

That table demonstrates that probe spacing on the order of ground grid dimensions should give sufficient model accuracy for computing touch and step voltages, whereas probe spacing of more than three times the grid length are required for conservative predictions of the grid resistance.



## **8. GROUND IMPEDANCE**

Resistance measurements of a ground grid or ground electrode have been performed since the early 1950s and are still the most popular tests in the electric utility industry. The resistance data provides a quick estimate of the ground potential rise of the ground electrode.

Connection to earth has complex impedances that include resistive, capacitive and inductive components, all of which affect their current-carrying capabilities. The resistance of the connection to remote earth is of particular interest to those concerned with power frequencies because it is affected by the resistivity of the earth in the area of the connection assuming the grounding system is small enough that the resistance dominates the overall impedance. The capacitance and inductance values are of interest to those concerned with higher frequencies, such as radio communications and lighting applications, or very large grounding systems when the resistance does not dominate the overall impedance.

The impedance of grounding systems largely depends on the resistivity of the surrounding soil and the extent and configuration of the buried electrode as we have described on chapter 4. Consequently, the grounding impedance can vary with the season as the temperature, moisture content, and density of the soil change. After the installation of a grounded system, the settling of the soil with annual cyclical weather changes tends to reduce the ground impedance during the first year or two.

The impedance of a grounding electrode is usually measured in terms of resistance because the reactance is generally negligible with respect to the resistive component. The reactive component increases with the size of the ground grid and especially when the ground grid is interconnected with grounded neutral and shield wire systems. Determination of the reactive component is necessary when the analysis involves surge or impulse currents.

The resistance will not usually vary greatly from year to year after the first year following its installation. Although the ground grid can be buried only half a meter below the surface, the resistance of a ground grid seems to bear little relationship to the changes in the resistivity at the burial level. The lack of correlation between grid resistance and burial depth resistivity is especially true for grids equipped with long-driven rods in contact with deep soil. This will not be true for ground grids buried over a high-resistivity stratum such as a rock bed or grids buried in permafrost.

### **8.1 THEORETICAL VALUE OF GROUND RESISTANCE**

Calculated or theoretical values of resistance of an electrode to remote earth can vary from the measured value because of the following factors:



- Inadequacy of the analytical methods used in the calculations of the resistance.
- Earth resistivities at the time of the resistance measurement being different from those assumed in the calculations.
- Inaccurate or insufficient extent of resistivity survey; for example, number and dispersal of tests, probe spacing, and inadequacy of the instrumentation used.
- Presence of buried metallic structures and ground wires in the proximity of testing site, which can divert a substantial amount of the test current.
- Clamp-on meter readings might contain large error if the reactance in the test is significant compared to the resistance of the test circuit or if the filters are inadequate to filter out 50 Hz/60 Hz frequencies caused by stray currents.

The difference between the measured and calculated values of the resistance can be minimized if the soil resistivity and ground grid resistance measurements are obtained under similar weather conditions.

Similarly, for the ground grids that are influenced by the seasonal changes, it is prudent to perform the soil resistivity measurements during adverse weather conditions to obtain conservative values for the location.

## **8.2 METHODS OF MEASURING GROUND IMPEDANCE**

We are referring to the measured impedance value as resistance, even though it contains a reactive component. The reactive component can be very significant for large or interconnected grounding systems. The resistance of a ground electrode usually is determined with alternating or periodically reversed current. Thus minimizes the effect of galvanic voltages that can be present at the probes and interference from direct currents in the soil from cathodic protection or telluric currents. Applying test currents that operate at a frequency different from power or harmonic frequencies will minimize interference from possible currents.

### **8.2.1 TWO-POINT METHOD**

In this method, the resistance of the subject ground electrode is measured in series with an auxiliary ground electrode. The resistance of the auxiliary ground is presumed to be negligible in comparison with the resistance of the subject ground. The measured value then represents the resistance of the subject ground.

One application of this method is to measure the resistance of a driven ground rod with respect to a nearby residential house. Typically, a residential house has a low-impedance grounding system due to its tie with the neutral conductor of the power supply system. Using such a grounding system as an auxiliary ground can produce a test result with reasonable accuracy.





### 8.2.2 THREE-POINT METHOD

This method involves the use of two auxiliary electrodes with their resistances designated as  $r_2$  and  $r_3$ . The resistance of the subject electrode is designated  $r_1$ . The resistance between each pair of electrodes is measured and are designated  $r_{12}$ ,  $r_{13}$  and  $r_{23}$ .

Where:

$$r_{12}=r_1 + r_2; r_{13}=r_1 + r_3; \text{ and } r_{23}=r_2 + r_3;$$

Solving the three simultaneous equations, it follows that:

$$r_1 = \frac{r_{12} + r_{13} + r_{23}}{2}$$

By measuring the series resistance of each pair of ground electrodes and substituting the resistance values in the equation, the value of the resistance can be established. If two auxiliary electrodes are of materially higher resistance than the electrode under test, then the errors in the individual measurements will be greatly magnified in the final result.

This method becomes more difficult to apply as the grounding electrode system becomes large and complex and other methods are preferred, especially if higher accuracy is desired.

### 8.2.3 FALL-OF-POTENTIAL METHOD

The Fall-of-Potential test method is used to measure the ability of an earth ground system or an individual electrode to dissipate energy from a site.

First, the earth electrode of interest must be disconnected from its connection to the site. Second, the tester is connected to the earth electrode. Then, for the 3-pole Fall-of-Potential test, two earth stakes are placed in the soil in a direct line, away from the earth electrode. The distance for the potential probe is often chosen to be 62% of the distance of the current probe when current and potential probes are in the same direction. It is called the 62% rule. This distance is based on the theoretically correct position for measuring the exact electrode impedance for a soil with uniform resistivity.

Once the criteria for the current probe are satisfied, the location of the potential probe is critical to measuring accurately the resistance of the ground electrode. The location needs be free from any influence from both the ground electrode under test and the current probe. A practical way to determine whether the potential probe is free from

other electrodes influences is to obtain several resistance readings by moving the potential probe between the ground grid and the current probe. Two to three consecutive constant resistance readings can be assumed to represent the true resistance value.

### 8.2.4 62% RULE

If we consider the 62% method, as we commented before, we can reduce the number of measures to be taken, as follows:

- A simple electrode is checked (not an electric mesh or a large plate).
- It is possible to place the current spike at a distance equal or greater than 30 meters from the electrode under test.
- The field is uniform. In these conditions, the current spike can be connected from a distance equal or greater than 30 meters from the electrode under test and the voltage reference spike from a 62% of that distance. And we have to do three measurements; One with the energize reference probe one meters closer to the electrode under test and another one meter away.

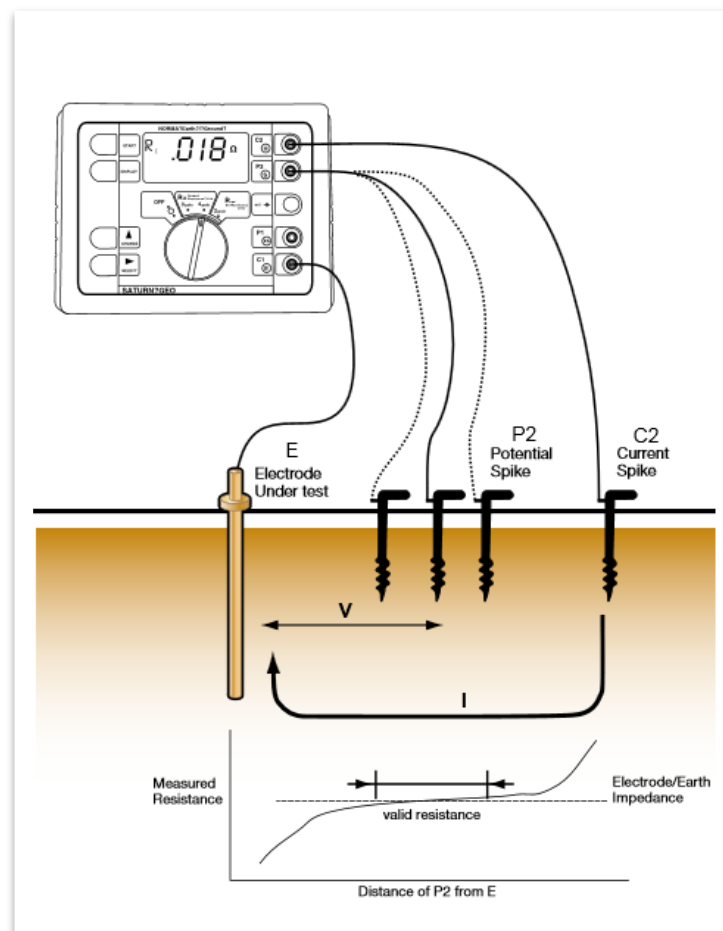


Figure 10. Earth Meter connection.

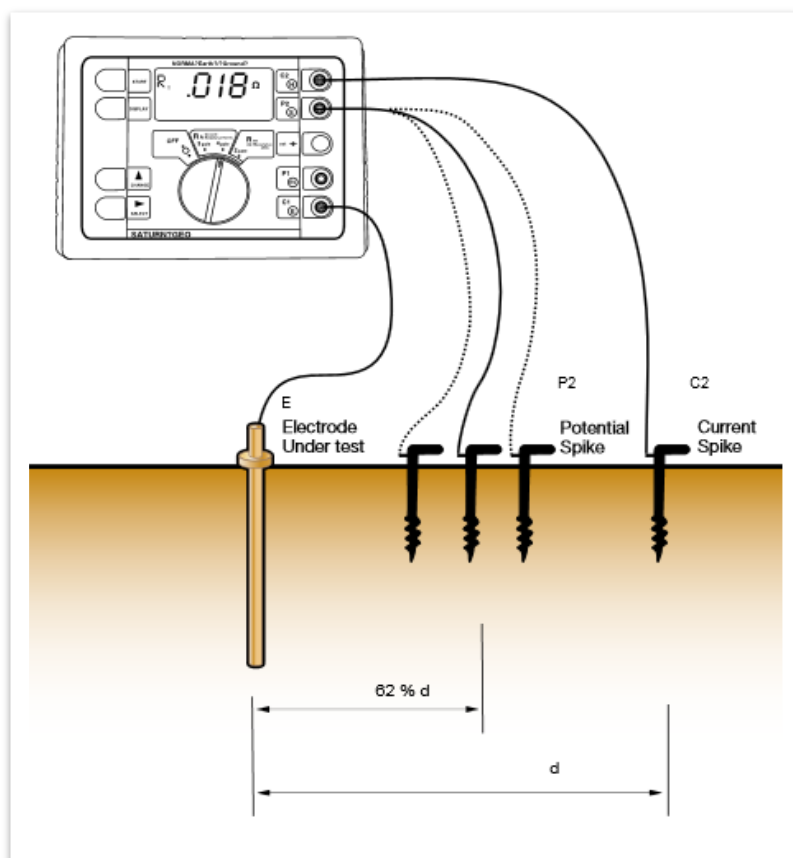


Figure 11. Earth Meter connection considering 62% rule.

To achieve the highest degree of accuracy when performing fall-of-potential method test, it is essential that the probe is placed outside the sphere of influence of the ground electrode under test and the auxiliary earth.

If you do not get outside the sphere of influence, the effective areas of resistance will overlap and invalidate any measurements that you are taking. The Table 3 is a guide for appropriately setting the probe (inner stake) and auxiliary ground (outer stake).

Depth of the ground electrode (m)	Distance to the inner stake (m)	Distance to the outer stake (m)
2	15	25
3	20	30
6	25	40
10	30	50

Table 3. Reference distance values.



## **8.2.5 STAKELESS MEASUREMENT**

This test type is useful to measure earth ground loop resistances for multi-grounded systems using only current clamps. This test is also named clamp-on method. The test technique eliminates the dangerous, and time consuming activity of disconnecting parallel grounds, as well as the process of finding suitable locations for auxiliary ground stakes. You can also perform earth ground tests in places you have not considered before like inside buildings, on power pylons or anywhere you do not have access to soil.

With this method, two clamps are placed around the earth ground rod or the connecting cable and each are connected to the tester. Earth ground stakes are not used at all. A known voltage is induced by one clamp, and the current is measured using the second clamp. The tester automatically determines the ground loop resistance at this ground rod. The advantage of having one clamp per function is that you can perform measurements on conductors where the earth clamp is not suitable, because of its clamping capacity or its thickness. If there is only one path to ground, like at many residential situations, the Stakeless method will not provide an acceptable value and the Fall-of-Potential test method must be used.

The test measurement works on the principle that in parallel/multi-ground systems, the net resistance of all ground paths will be extremely low as compared to any single path (the one under test). So, the net resistance of all the parallel return path resistances is effectively zero. Stakeless measurement only measures individual ground rod resistances in parallel to earth grounding systems. If the ground system is not parallel to earth then we will either have an open circuit, or be measuring ground loop resistance.

For earth loop measurements, there are several pitfalls to avoid and several points that need to be checked:

- Number of earth electrodes in parallel. This method is only applicable if there is a low-impedance path parallel to the electrode tested. For this reason, it is advisable to assess the equivalent resistance of the total electrodes in parallel and check that its value is genuinely negligible.
- Identification of the circuit measured. If there is no low-impedance path parallel to the electrode tested, as in the case of a house with only one earth electrode, earth loop measurement is not possible because there is no path for the current to loop back. If the values measured are extremely low, we must check that the earth clamp has not been positioned on an equipotential bond.

## 9. BUILDING GROUNDING

The earthing system in a building can give trouble. Electrical ground faults, short circuits, lighting and other transients can and often do occur in building electrical distribution systems. This requires that the grounding system be constructed to achieve the lowest practical impedance. Many factors determine the overall impedance of the grounding systems. Building components, such as structural steel and interior piping systems, can be used to create an effective grounding system. The manner in which these components are installed and interconnected can have a dramatic effect on the overall effectiveness of the grounding system. One of the primary factors that can increase the impedance of the grounding system is the type and manner in which the electrical connections to the grounding system are made. Interconnected electronic equipment, such as telecommunication systems and computer systems, also require a low-impedance grounding system. The Figure 12 below includes the major subsystems of facilities grounding. Later additions and/or modifications to the system can be very costly so we have to be strict in the grounding process.

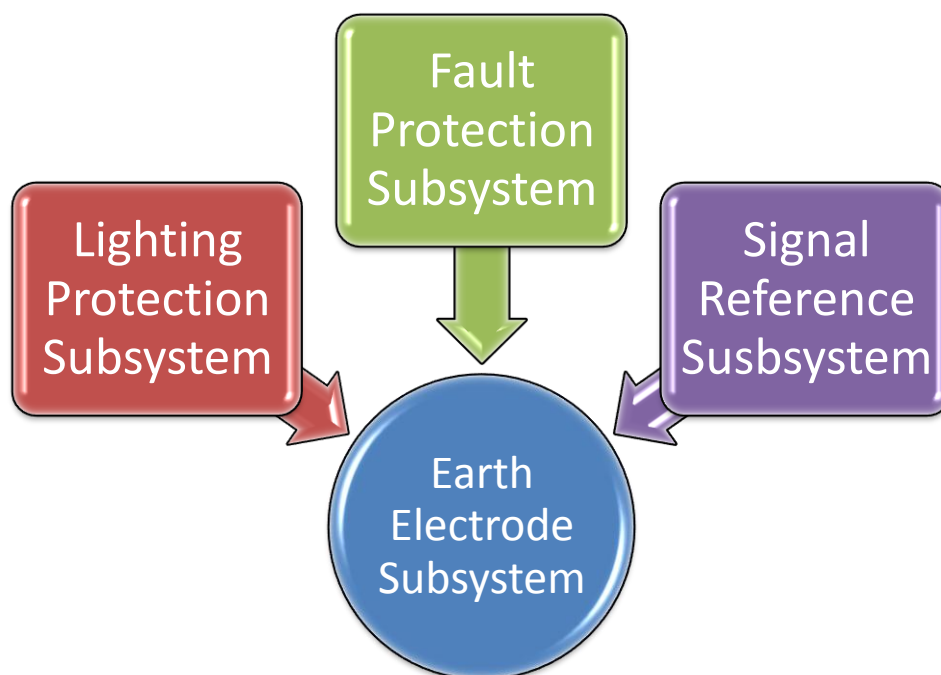


Figure 12. Grounding subsystems.

As we have seen before, many factors come into play in determining the overall effectiveness of the grounding system, especially the resistance of the earth itself (earth resistivity). To properly design a grounding system, this parameter must be measured following one of the methods explained.

Building grounding components can be broken down into several subdivisions:

- Building exterior grounds.
- Electrical service grounding.
- Building interior bonding.
- Equipment grounding and bonding.
- Lighting protection.

It is usually used a copper conductor that is directly buried in the earth and installed around the perimeter of the building. The steel building columns are bonded to this conductor to complete a simple grounding system. The columns around the perimeter of the building are excellent grounding electrodes and provide a good path into the earth for any fault currents that may be imposed on the system.

When grounding large buildings, and all multiple building facilities, perimeter grounding provides an equipotential ground for all the buildings and equipment within the building that are bonded to the perimeter ground. The purpose of this perimeter grounding is to ensure that an equipotential plane is created for all components that are connected to the perimeter ground system. The size of the ground ring will depend upon the size of the electrical service. In some cases, an electrical design requires ground rods to be installed in addition to the perimeter ground ring. The use of ground rods helps to minimize the effects of dry or frozen soil on the overall impedance of the perimeter ground system. As we know, this is because the ground rods can reach deeper into the earth where the soil moisture content may be higher or the soil may not have frozen.

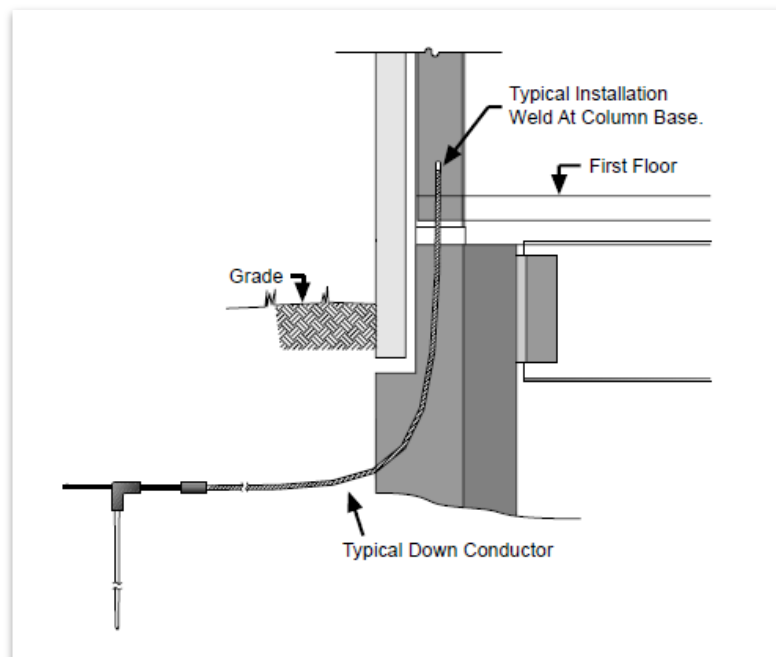


Figure 13. Building exterior grounds.

The perimeter ground system needs to be provided with a water stop for each grounding conductor that passes through a foundation wall. This is especially important when the grounding conductor passes through the foundation wall at a point that is below the water table. The water stop ensures that moisture will not enter the building by following the conductor strands and seeping into the building. When inspection wells are required to expose points from which to measure system resistance, several methods are available. Ground access wells are used to gain easy access to underground grounding connections. They can be used with ground rods, ground plates and counterpoise grounding. They come with a steel cover for easy inspection of exothermic or mechanical grounding connection and testing of the continuity of the grounding system. If the grounding conductors do not have to be disconnected from the rod, the conductors can be welded to the rod, and a plastic pipe, a clay pipe or a commercial box can be placed over the rod as shown in Figure 14.

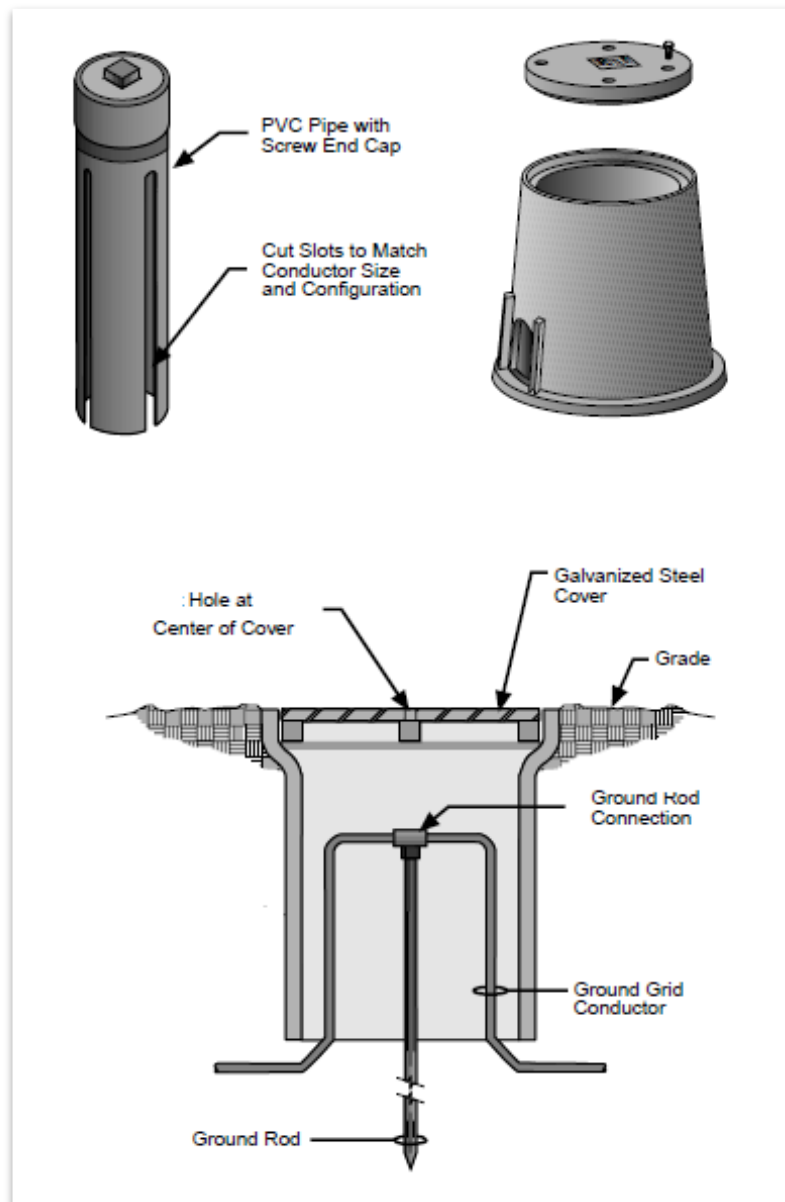


Figure 14. Plastic pipe, clay pipe and box.

## 10. TYPES OF EARTHING SYSTEMS IN BUILDINGS

To determine the characteristics of the protection measures against electric shock in case of fault (indirect contacts) and against overcurrents as well as the specifications of the switchgear using for electrical applications will be necessary to consider the electric power network used. On one hand, the distribution schemes are set according to the grounding of the power network. On the other hand, are set according to the grounding system of the exposed-conductive-parts of the installation.

The letter codes used have the following meanings:

<b>First letter – Relationship of the power system to earth</b>	
<b>T</b>	Direct connection of one point to earth
<b>I</b>	All live parts isolated from earth, or one pint connected to earth through a high impedance
<b>Second letter – Relationship of the exposed-conductive-parts of the installation to earth</b>	
<b>T</b>	Direct electrical connection of exposed-conductive-parts to earth, independently of the earthing of any point of the power system
<b>N</b>	Direct electrical connection of the exposed-conductive-parts to the earthed point of the power system
<b>Subsequent letter(s) (if any) – Arrangement of neutral and protective conductors</b>	
<b>S</b>	Protective function provided by a conductor separate from the neutral conductor or from the earthed line
<b>C</b>	Neutral and protective functions combined in a single conductor (PEN conductor)

Table 4. Letter code.

### 10.1 TN SYSTEM

TN power systems have one point directly earthed at the source, the exposed-conductive-parts of the installation being connected to that point by protective conductors. Three types of TN system are considered according to the arrangement of neutral and protective conductors, as follows:

- TN-S system with separate neutral conductor and protective conductor throughout the system (Figure 15).



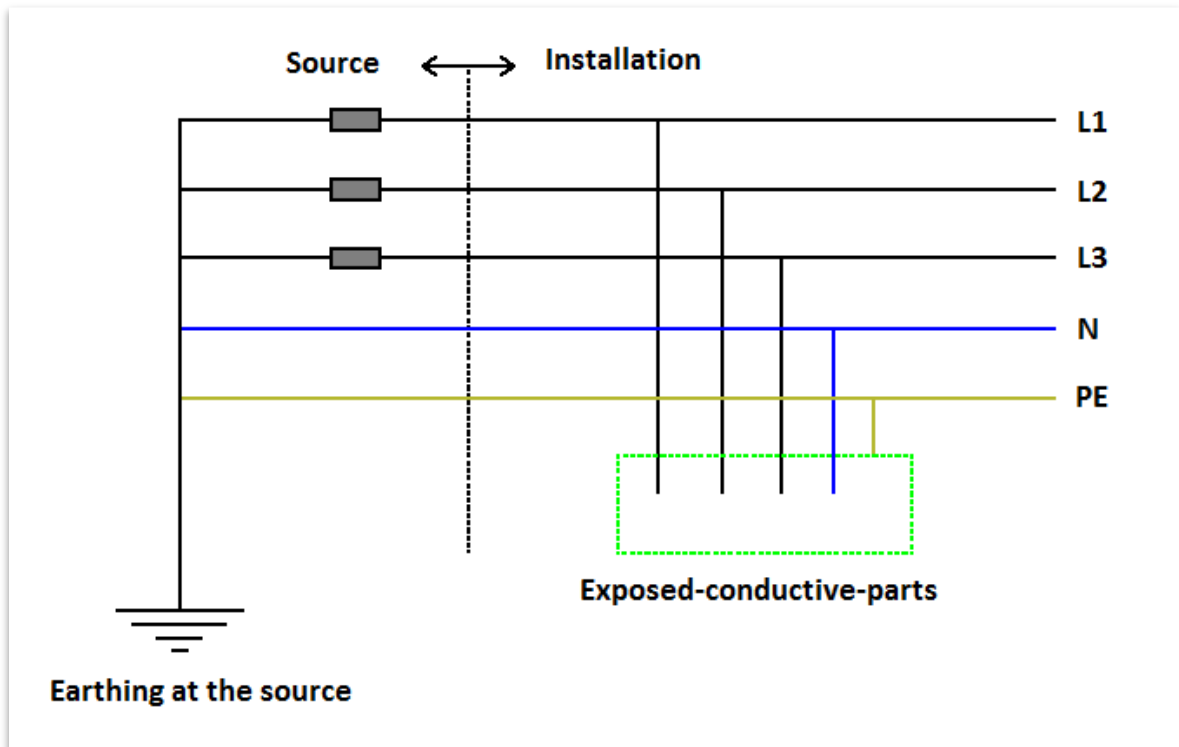
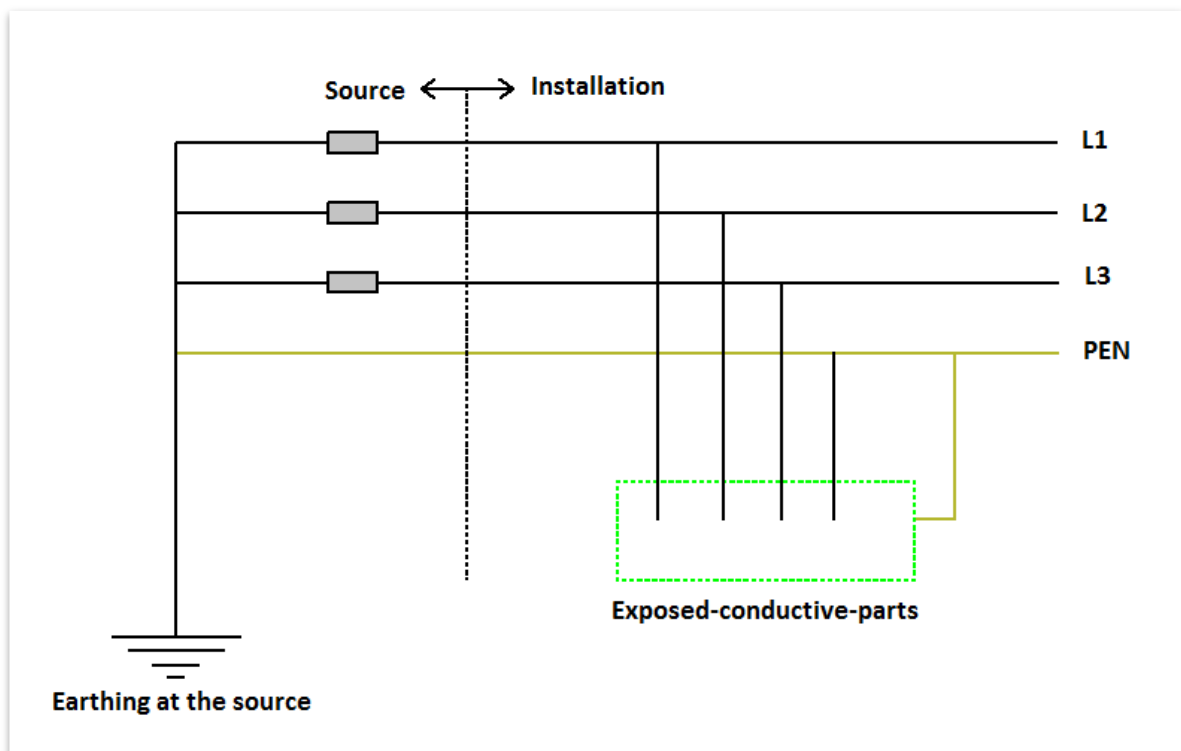


Figure 15. TN-S system.

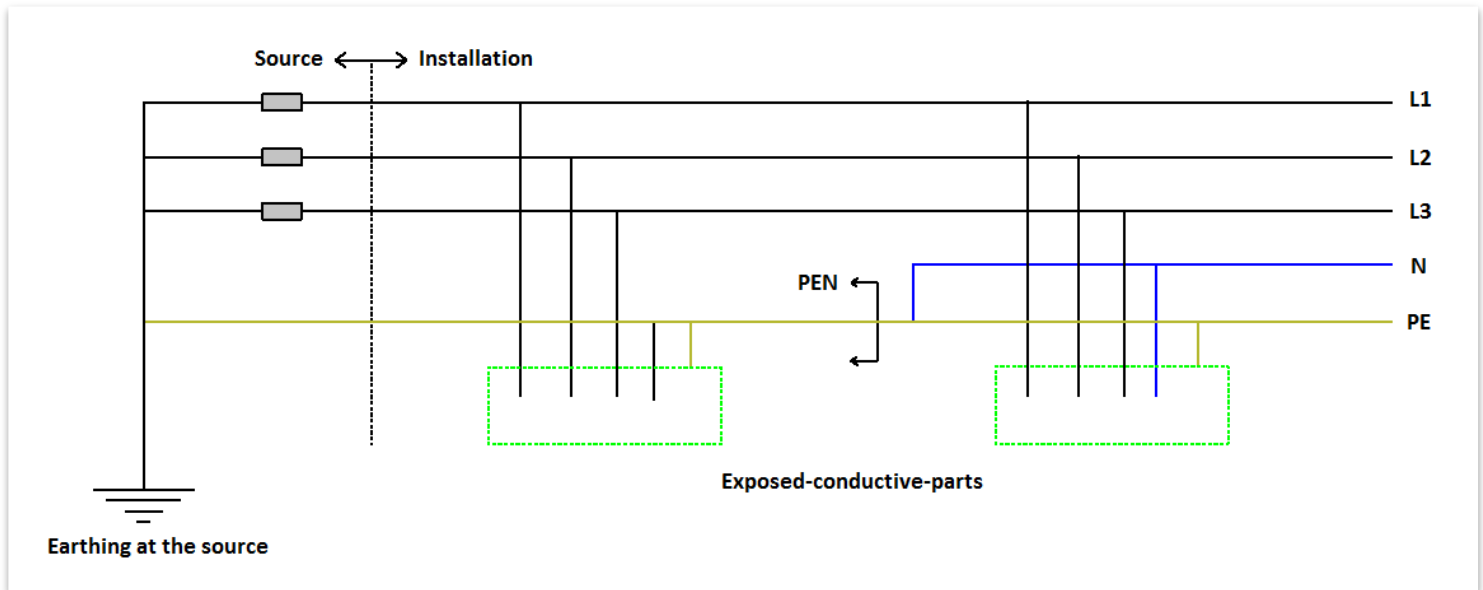
- TN-C system with neutral and protective conductor functions combined in the



same conductor throughout the system (Figure 16).

Figure 16. TN-C system.

- TN-C-S system in which neutral and protective conductor functions are



combined in a single conductor in a part of the system (Figure 17).

Figure 17. TN-C-S system.

In these types of grounding, TN systems any phase-exposed-conductive-part current fault is a short-circuit current. The fault loop consists exclusively on metallic conductors.

## 10.2 TT SYSTEM

The TT system has only one point directly earthed and the exposed-conductive-parts of the installation are connected to earth electrodes electrically independent of the earth electrode of the supply system (Figure 18).

In this type of system, the phase-exposed-conductive-parts current or the phase-ground current could have lower values than short-circuit values but they could be sufficient to cause the appearance of dangerous voltages.

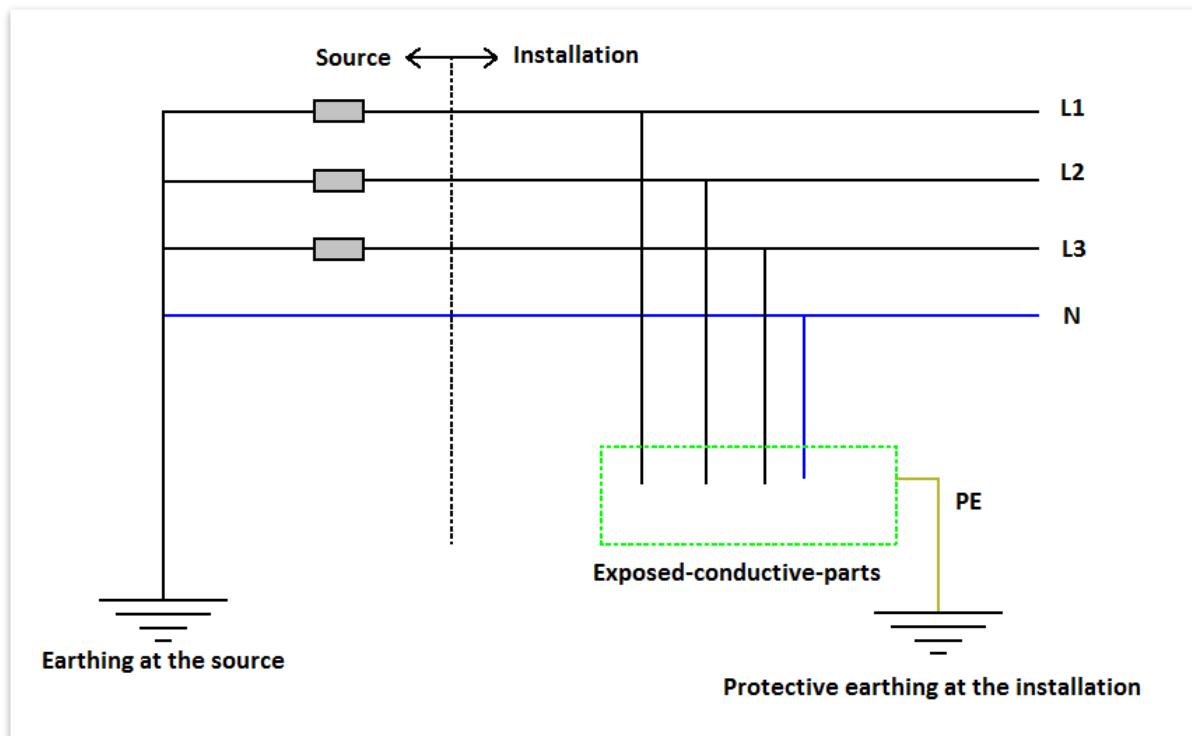


Figure 18. TT system.

### 10.3 IT SYSTEM

The IT system has all live parts isolated from earth or one point connected to earth through an impedance. The exposed-conductive-parts of the electrical installation are earthed independently or collectively or to the earthing of the system (Figure 19).

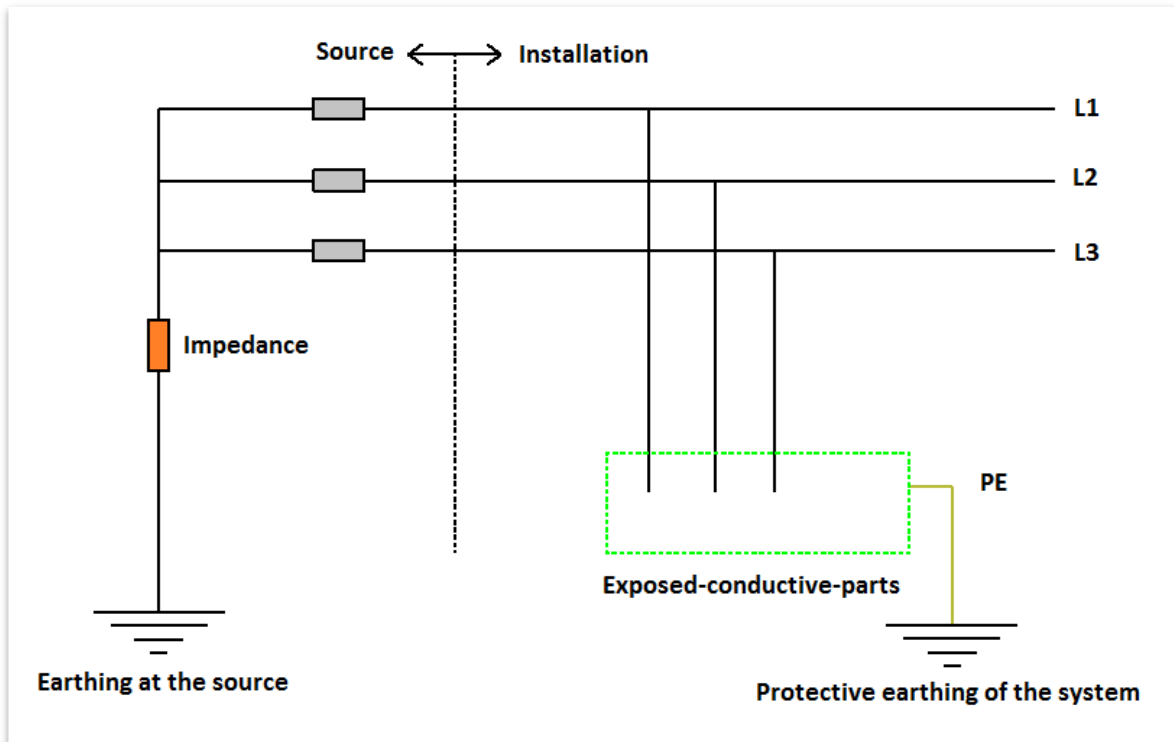


Figure 19. IT system.

In this type of system, the resulting current from a first phase-exposed-conductive-parts current fault or from a phase-ground current fault has a value which is not big enough to cause the appearance of dangerous touch voltage.

The limitation of the resulting current value from a first current fault is obtained either by a lack of earthing at the source or by adding an enough impedance from a source point (which is usually the neutral point) to earth. For this purpose, it may be necessary to limit the extension of the system to reduce the capacitive effect in the wires respect to ground. In this type of system it is recommended not to distribute the neutral conductor.

## 10.4 APPLICATION OF THESE SYSTEMS

The choice of one of the three types of systems has to be based on the technical and economic characteristics of each installation. However, the following principles should be taken into account:

- The electrical public power networks of low voltage have one point directly connected to earth due to the public standards. This point is the neutral of the electrical power network. The distribution for installations is supplied from a network of low voltage is TT system.
- Installations supplied at low voltage from a transformer can choose any system mentioned before.



- Notwithstanding, an IT system can be established some parts of an installation supplied from a public power network using appropriate transformers.

## **10.5 INSPECTION**

A good grounding system must receive periodic inspection and maintenance, if needed, to retain its effectiveness. Continued or periodic maintenance is aided through adequate design, choice of materials and proper installation techniques to ensure that the grounding system resists deterioration or inadvertent destruction. Therefore, minimal repair is needed to retain effectiveness throughout the life of the structure.



## 11. WIN-IGS PROGRAM TOOL

### 11.1 INTRODUCTION

A high number of electrical applications can be studied and can be performed with this software. The program Win-IGS supports from the design of generation substation grounding system, the stray current analysis and control or transmission line parameter computations to harmonic propagation computations and photovoltaic farm grounding design and analysis. Generally, the program Win-IGS is an analysis/design tool for grounding system design, multiphase power system analysis and so on. The software is based on the IEE Std 80 safety criteria as well as the IEC Standard for grounding system safety.

Specifically, we are going to use this useful tool to analyse the grounding system of a building with a particular dimensions and electrical parameters that we have chosen following the particular electrical characteristics of a building.

These parameters for the electrical simplified circuit of the grounding system are the source current with its resistance, the line impedance and the earthing components.

We are going to illustrate the computation of the characteristics exposed before and also some important data, such as the ground system resistance, the importance of the layer resistivity and the touch voltage and step voltage distribution for a given ground potential rise.

Depending on the study case, the electrical parameters will be different and we will discuss about the difference values obtained. On one hand, we consider the grounding system make up by a group of rods and a grid. On the other hand, we analyse only the grounding system form by the grid. We also consider the important parameter which is the soil resistivity. Thus, step by step we are attaching the data files viewing the system data running the analysis and inspecting the results.

In the next Figure 20, it is shown the Win-IGS interface in the Edit Mode. We observe the electrical components of the grounding circuit which are the above mentioned, such as the source and the grounding system. We can modify the values double-clicking on the electrical symbols. A new window is opened as shown in Figures 21 to 23.

Figure 21 shows the injected current which is the earth or grid current. This current is the fault current times the split factor. It is important to note that the split factor depends on many parameters of the system around the grounding system under design and it can be any value between zero and 1.0.

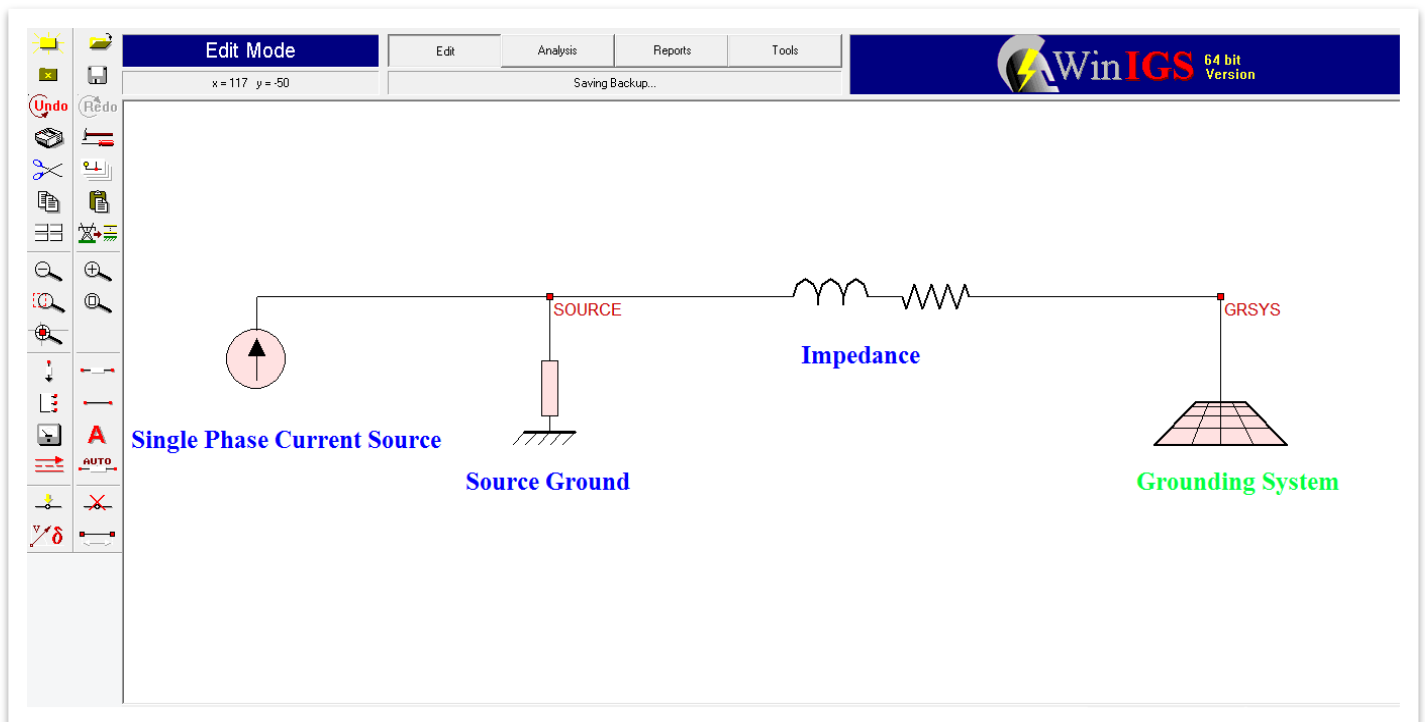
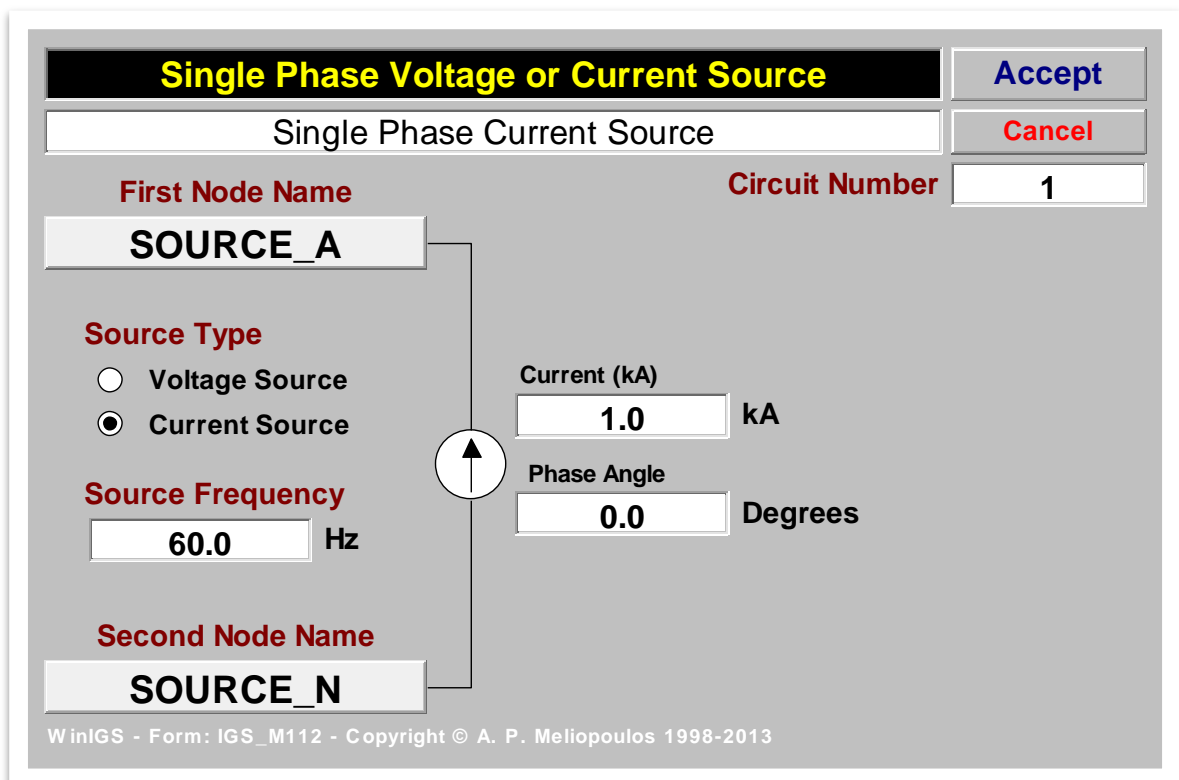


Figure 20. Win-IGS interface. Edit Mode. Electrical components.



The dialog box is titled 'Single Phase Voltage or Current Source'. It contains the following fields and controls:

- Single Phase Current Source** (selected in the dropdown)
- Accept** and **Cancel** buttons.
- First Node Name**: **SOURCE\_A**
- Circuit Number**: **1**
- Source Type**:
  - ☐ Voltage Source
  - ☒ Current Source
- Source Frequency**: **60.0** Hz
- Current (kA)**: **1.0** kA
- Phase Angle**: **0.0** Degrees
- Second Node Name**: **SOURCE\_N**

A diagram of a current source (circle with an upward arrow) is shown between the node names. The copyright notice at the bottom reads: 'WinIGS - Form: IGS\_M112 - Copyright © A. P. Meliopoulos 1998-2013'.

Figure 21. Single phase current source.

The value of the earth or grid current is 1.0 kA because we suppose we are next to a substation and the source frequency is 60.0 Hz.

RL or RC Ground Model

Cancel

Accept


Source Resistance

Node Name

SOURCE\_N

Circuit Number

2



Resistance

0.1

 Ohms

Reactance at Base Frequency

0.0

 Ohms

(Positive for Inductive, Negative for Capacitive Reactance)

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Figure 22. Source ground parameter form.

Series R-L or R-C Model

IF AGC

Cancel

Accept

Impedance

Resistance (Ohms)

2

Reactance (Ohms @ 60 Hz)

0.5

Circuit Number

1

Rated Line to Line Voltage

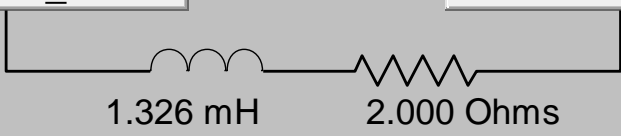
400

First Node Name

SOURCE\_A

Second Node Name

GRSYS\_N



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Figure 23. Impedance parameter form.

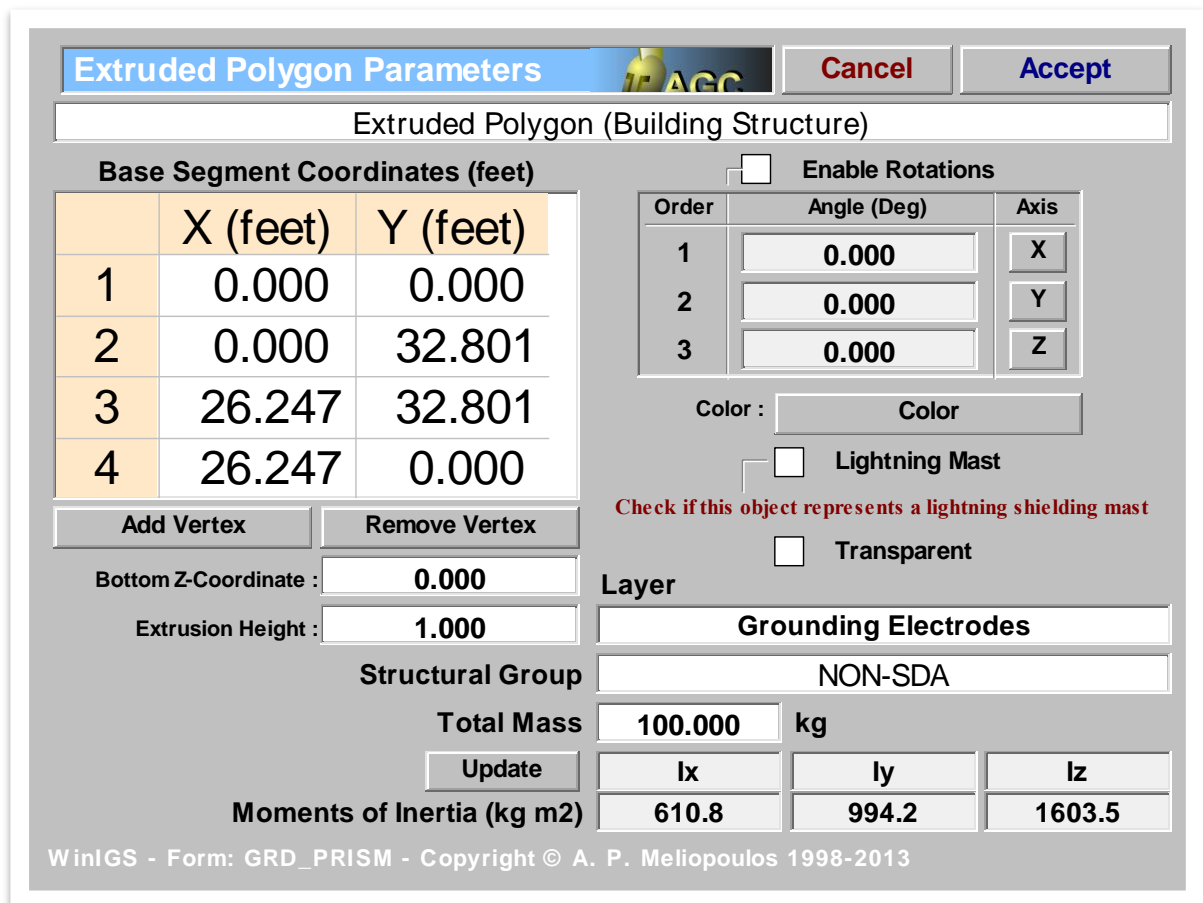


The value for the rated line to line voltage is equal to 400V due to the low voltage distribution for a three-phase circuit including three conductors plus the neutral conductor. Considering a factor 4 to divide the resistance of the line we obtain 0.5 Ohms for the inductive reactance.

## 11.2 INSPECTION OF THE GROUNDING SYSTEM

The first step is to consider the dimensions of the building in which we are going to design the grounding system. Considering 80 m<sup>2</sup> (8 meters large per 10 meters width) as a normal building size, we create the model as shown in Figure 24. We have created the civil structure.

Note: All the calculations are expressed in feet: 1 meter = 3.281 feet.



**Extruded Polygon Parameters** Cancel Accept

Extruded Polygon (Building Structure)

Base Segment Coordinates (feet)		
	X (feet)	Y (feet)
1	0.000	0.000
2	0.000	32.801
3	26.247	32.801
4	26.247	0.000

☐ Enable Rotations  

Order	Angle (Deg)	Axis
1	0.000	X
2	0.000	Y
3	0.000	Z

Color : Color

☐ Lightning Mast  
 Check if this object represents a lightning shielding mast  
☐ Transparent

Add Vertex Remove Vertex  
 Bottom Z-Coordinate : 0.000  
 Extrusion Height : 1.000

Structural Group Grounding Electrodes  
 Layer NON-SDA

Total Mass 100.000 kg  
 Update Ix Iy Iz


Moments of Inertia (kg m2) 610.8 994.2 1603.5

WinIGS - Form: GRD\_PRISM - Copyright © A. P. Meliopoulos 1998-2013

Figure 24. Using Extruded polygon lines we have created the Building structure.

The second step is to choose the type of rods and its placement. We select the copper clad rods with 4 meters for rod length and we place the rods in the ground level, thus 0 meters for depth. Note that the grounding system consists of 4 rods and a number of horizontal conductors. These horizontal conductors are placed in 0.80 meters for depth respect to the rods. We can see that condition in Burial depth in Figure 28.



Conductor Library							Accept
		Sort by Name	Sort by Size			Cancel	
11	ALU_PIPE		AWG	DCRes	Area	Dia	Strands\mpacity
12	ALU_PIPE	1	1/2	0.3380	250.0	0.5180	9
13	BARENEL	2	3/8	0.3380	250.0	0.5180	9
14	BOLTS	3	5/8	0.2780	390.6	0.6280	1
15	COPPER	4	3/4	0.2580	562.5	0.7580	1
16	COPPERV	5	1INCH	0.1450	1070.7	1.0348	1
17	COPPERV						
18	COP_CLA						
19	EHS						
20	HS						
21	OPGW						
22	OPTGW						
23	RAILROAI						
24	STEEL						
25	STL_PIPE						
26	ST_STEEI						

\* Resistance in ohms/mile, area in cmils, diameter in inches, ampacity in A

Program WinIGS - Form LBE\_001

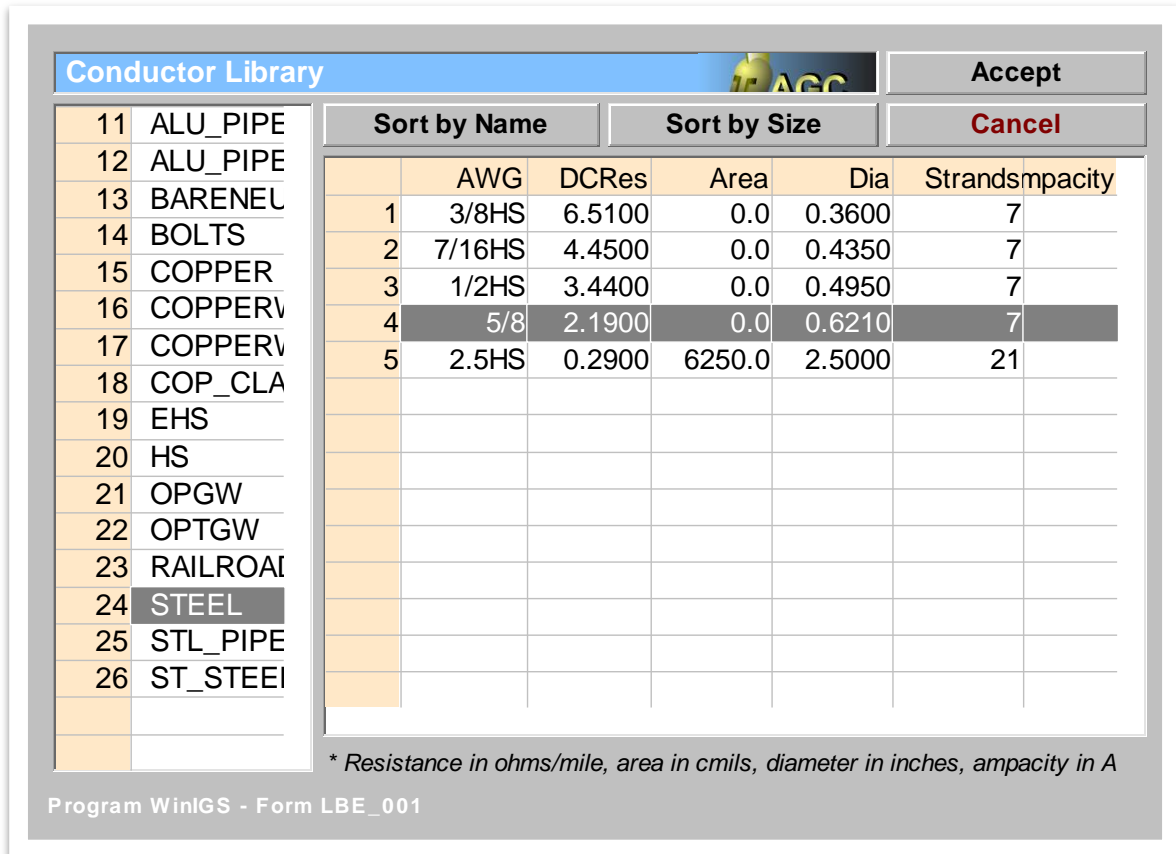
Figure 25. Selection of rods.

Ground Rod Parameters		IFAGC		Accept
Single Ground Rod				Cancel
X Coordinate (feet)	-3.281			
Y Coordinate (feet)	-3.281			
Rod Top End Depth (feet-positive)	0.000			
Rod Length (feet)	13.123			
Type	COP_CLAD	<b>Connector Type</b> <input type="radio"/> None <input checked="" type="radio"/> Exothermic <input type="radio"/> Compression <input type="radio"/> Screw <input type="radio"/> Other		
Size	3/4			
Group	MAIN-GND			
Layer	Grounding Electrodes			

WinIGS - Form: GRD\_GE03 - Copyright © A. P. Meliopoulos 1998-2013

Figure 26. Placement of rods and selection of depth and length.

We have considered 1 meter for the distance between the building and the grounding system. And finally we place the point for the input current and the steel underground conductors each one connected with their respective rod and each rod with the input current point.



Conductor Library		LBE_001						Accept
		Sort by Name		Sort by Size		Cancel		
11	ALU_PIPE							
12	ALU_PIPE							
13	BARENEL							
14	BOLTS							
15	COPPER							
16	COPPERV							
17	COPPERV							
18	COP_CLA							
19	EHS							
20	HS							
21	OPGW							
22	OPTGW							
23	RAILROAI							
24	STEEL							
25	STL_PIPE							
26	ST_STEEL							

	AWG	DCRes	Area	Dia	Strands	Ampacity
1	3/8HS	6.5100	0.0	0.3600	7	
2	7/16HS	4.4500	0.0	0.4350	7	
3	1/2HS	3.4400	0.0	0.4950	7	
4	5/8	2.1900	0.0	0.6210	7	
5	2.5HS	0.2900	6250.0	2.5000	21	

\* Resistance in ohms/mile, area in cmils, diameter in inches, ampacity in A

Program WinIGS - Form LBE\_001

Figure 27. Steel underground conductor characteristics.

The horizontal conductors are named as a Polyline ground conductor. And in the Figure 29 we can see the parameters of the input current point. We have placed that point in a hypothetical situation as follows.

**Horizontal Polygonal Conductor**

Accept

Cancel

**PolyLine Ground Conductor**

**Conductor Segment Coordinates (feet)**

	X (feet)	Y (feet)
1	-3.281	-3.281
2	29.528	-3.281

Add Vertex

Remove Vertex

Burial Depth (positive): 2.625

Update Diagram

**Conductor Specifications**

Type STEEL

Size 5/8

**Group** MAIN-GND

**Layer** Grounding Electrodes

Program WinIGS - Form GRD\_GE11

Figure 28. Placement of a steel underground conductor.

**Interface Node**

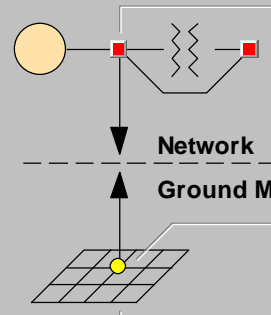
Cancel

Accept

**Node Interface Element**

**Layer** Grounding Electrodes

**Node** GRSYS\_N



Network

Ground Model

**Local Coordinates**

X Coordinate: 5.0 ft

Y Coordinate: 5.0 ft

Z Coordinate: 0.000 ft

Update from GPS Coordinates

**GPS Coordinates**

Latitude : N0 Deg 0.000000 Min

Longitude : E0 Deg 0.000000 Min

Update from Local Coordinates

WinIGS - Form: GRD\_GE00 - Copyright © A. P. Meliopoulos 1998-2013

Figure 29. Input current point.

In the figure above it is shown in 3D perspective the building grounding system created and it is also shown in X-Y view.

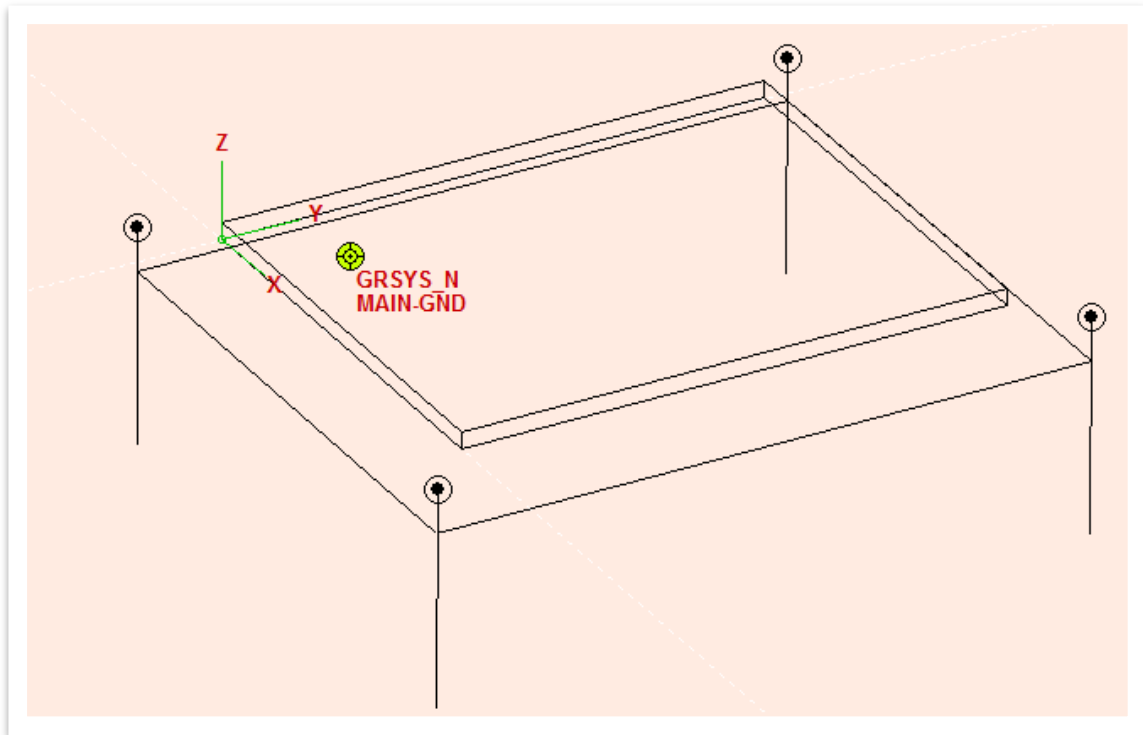


Figure 30. Grounding system with the 4 rods and the grid.

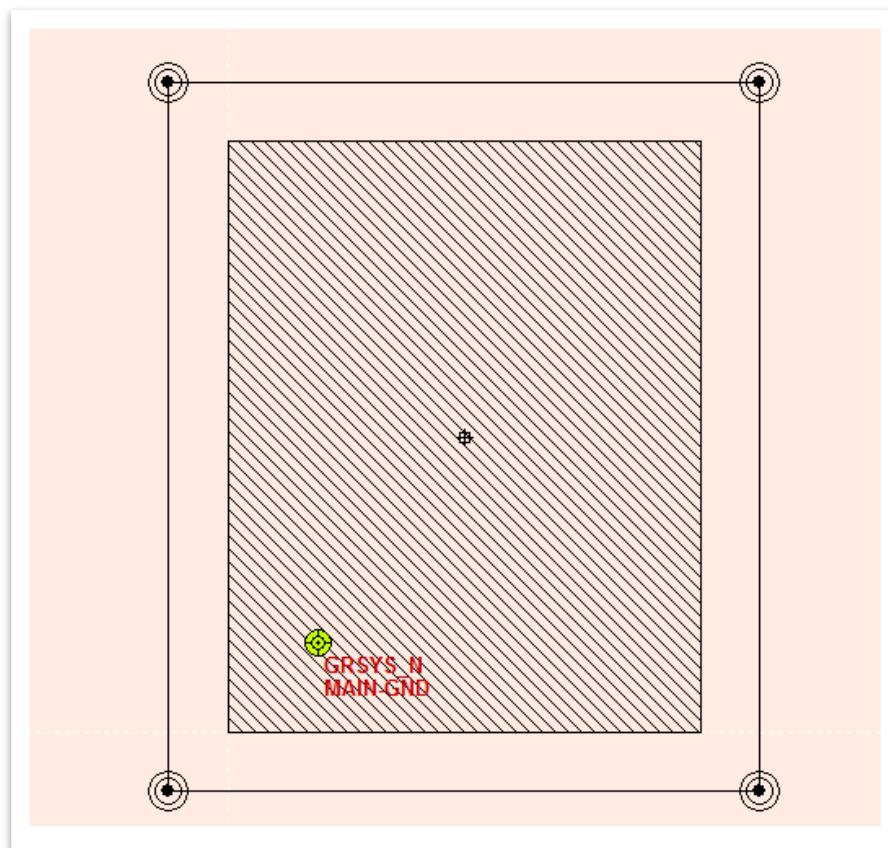
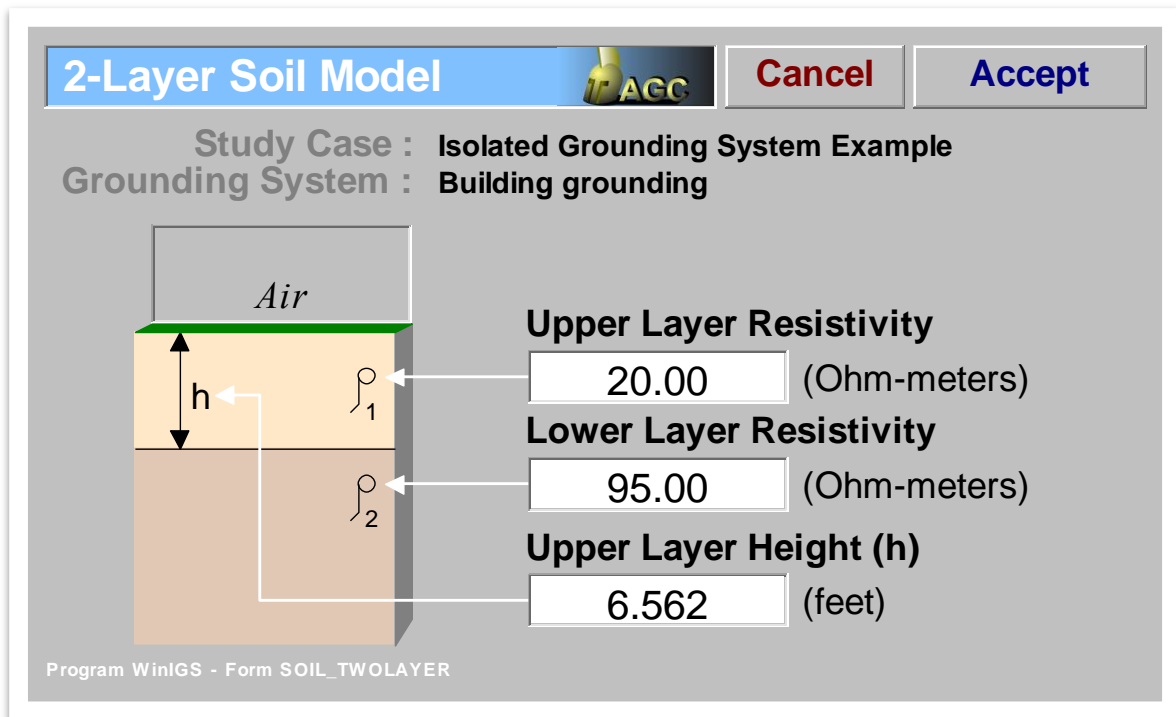



Figure 31. X-Y (Top) view of the grounding system.

### 11.3 SOIL MODEL

Another important set of grounding system parameters are the soil parameters. In this case, the soil model is derived from soil resistivity which is the upper layer is considered as grass, so the resistivity is equal to 20 Ohm-meters. The value for the lower layer is 95 Ohm-meters considering that we have rock. We consider a upper layer height about 2 meters.



**2-Layer Soil Model** 

**Study Case :** Isolated Grounding System Example  
**Grounding System :** Building grounding

**Upper Layer Resistivity**  
 20.00 (Ohm-meters)

**Lower Layer Resistivity**  
 95.00 (Ohm-meters)

**Upper Layer Height (h)**  
 6.562 (feet)

Program WinIGS - Form SOIL\_TWOLAYER

Figure 32. Layer soil model.

### 11.4 ANALYSIS OF THE SYSTEM

#### 11.4.1 CASE A: FOUR RODS AND GRID

In order to perform the analysis of the case we are studying click on Analysis button and select Base Case analysis mode from the pull-down list and click on the Run button. Once the analysis is completed we can click on the Reports.

In the next Figure 33 we can see that the ground current is 1.0 kA and the ground potential rise is 1.465 kV.

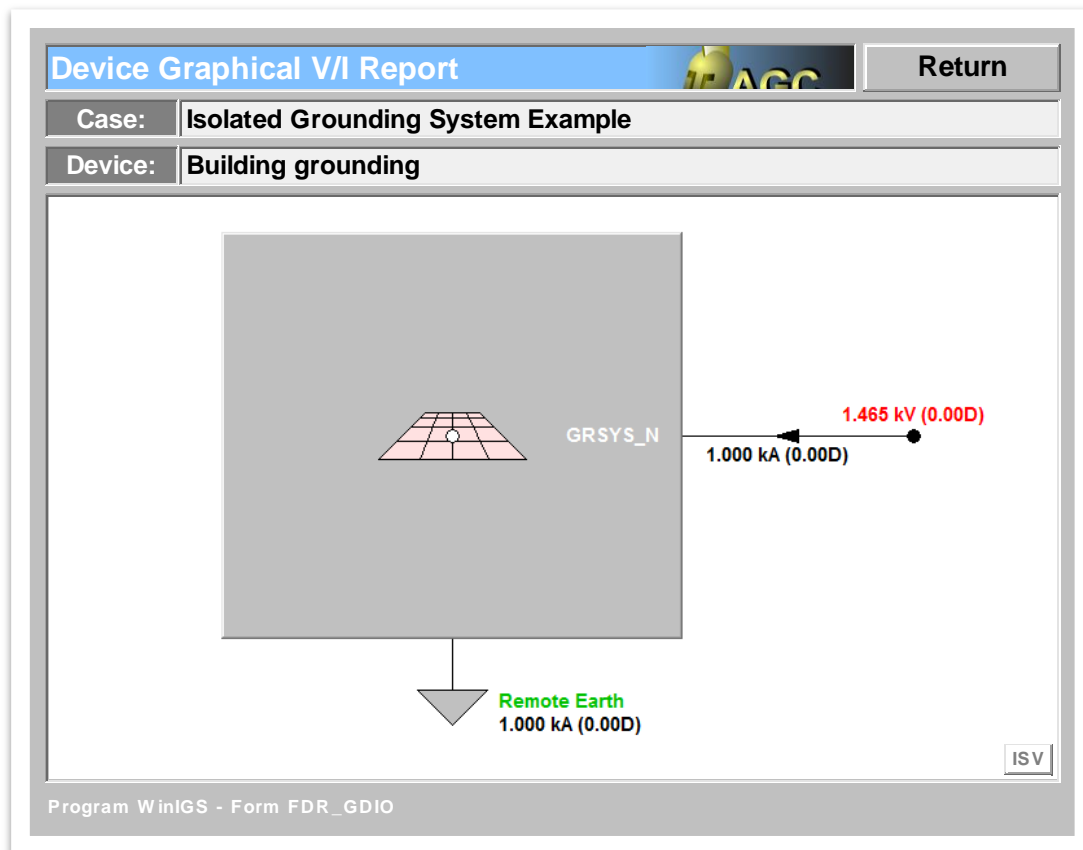


Figure 33. Graphical V/I Report.

Now, the most important data of this analysis which is the ground system resistance shown in Figure 34. The resistance is named as  $R_p$ . The importance of this measurement consists on its difficulty of being obtained using other numerical methods or software. We can also modify the value of the layer resistivity which is shown in Figure 35. In this case we are considering grass with the value of 20 Ohm-meters.

We can analyse using the tool Voltage/Current profiles and visualize if the touch and step voltages are allowed. It means that the values for these voltages are below the tolerance ones.

We are going to see in Figure 36 a black line which represents the profile of the earthing system and the building we have created and in Figure 37 a graphic which shows the “curve#1” below the allowable touch voltage. Thus, the touch voltage in that case is correct because the blue curve represent our touch voltage and in almost every moment is under the red one which is the limit. The dangerous zone is located about 47 feet away.

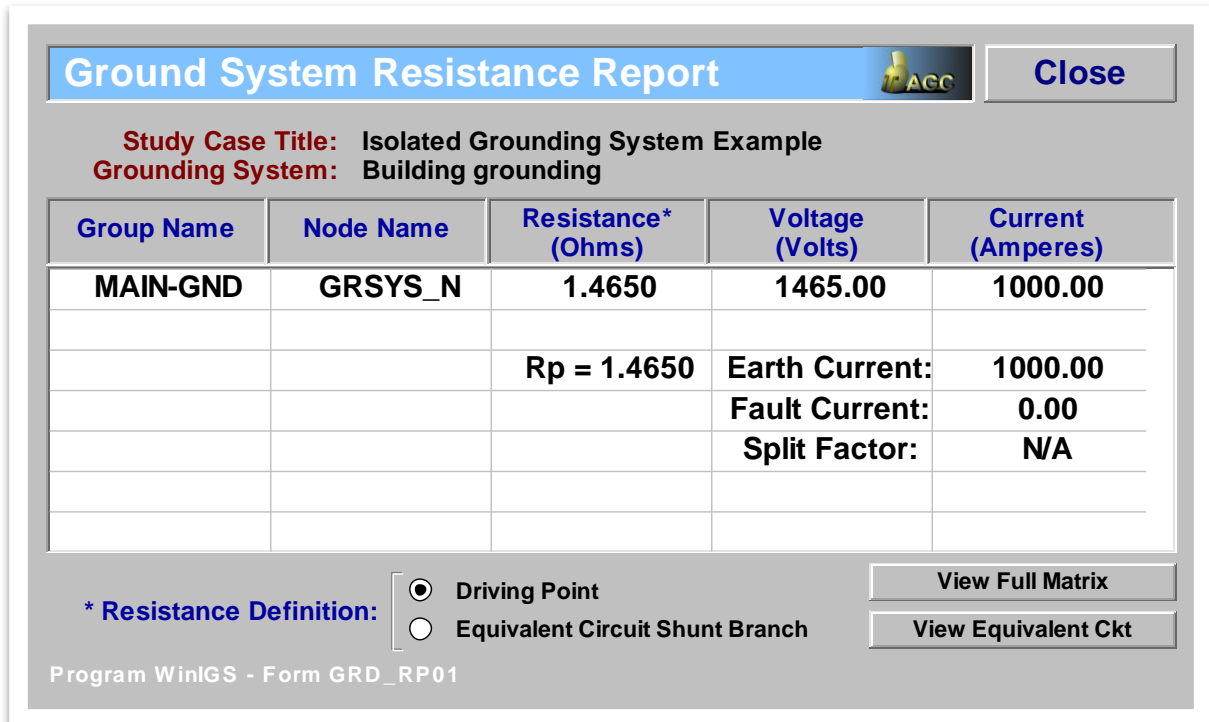


Figure 34. Ground system resistance report.

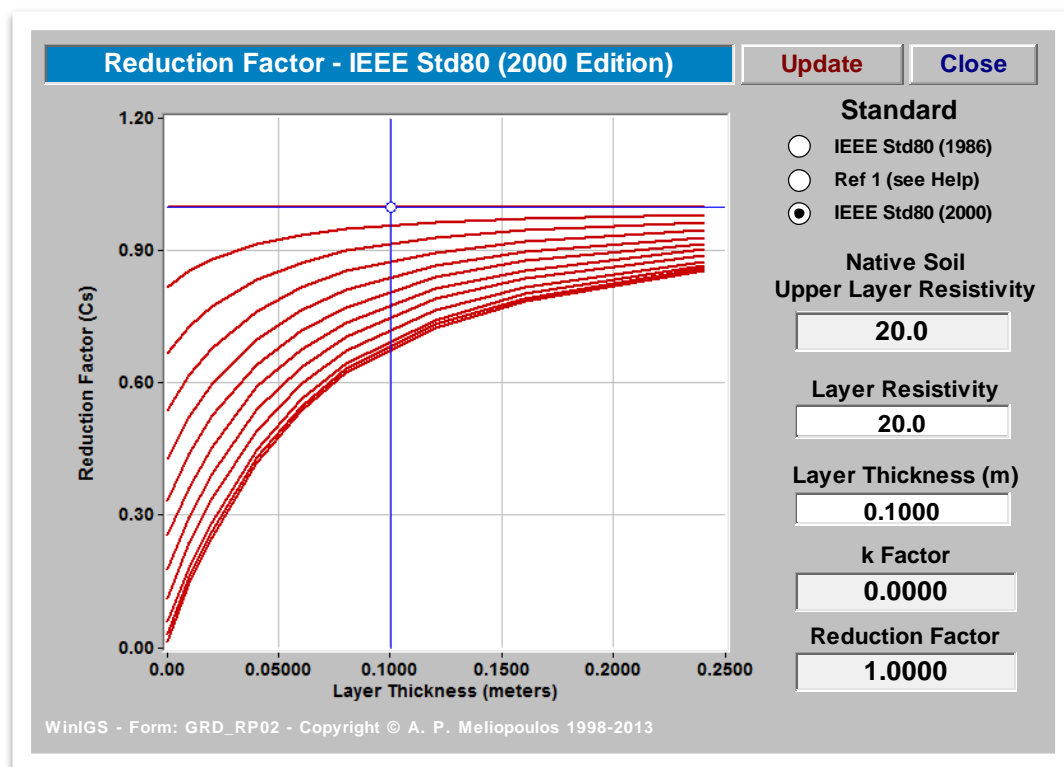


Figure 35. Resistive layer effect considering grass.



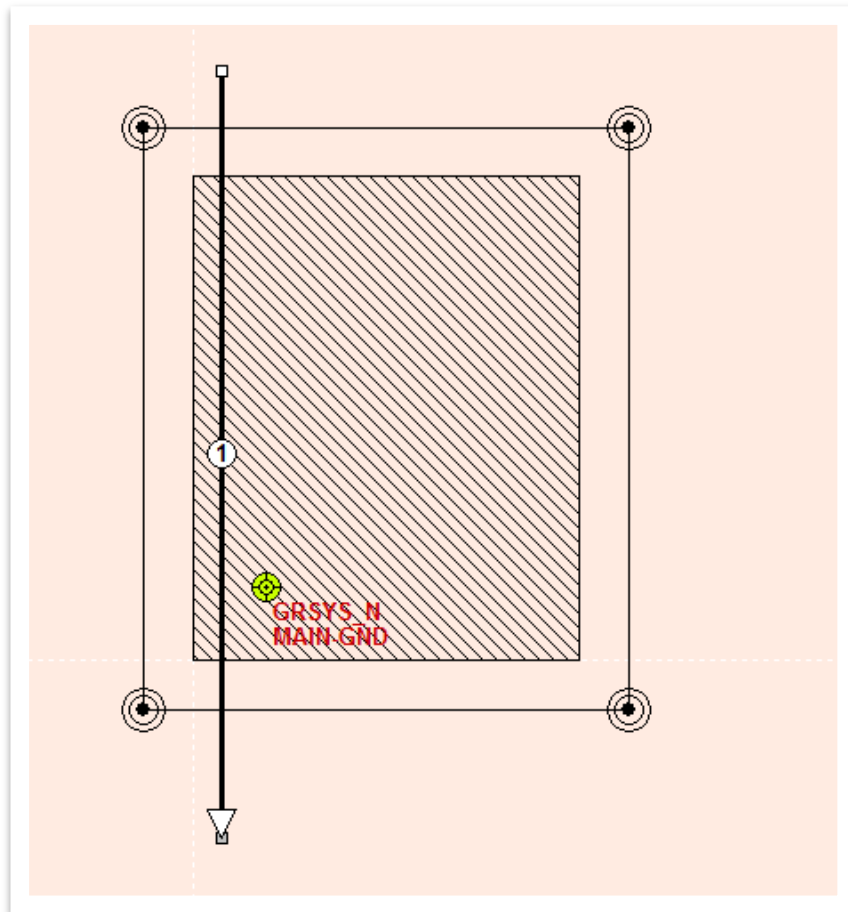


Figure 36. Profile of the building and earthing system.

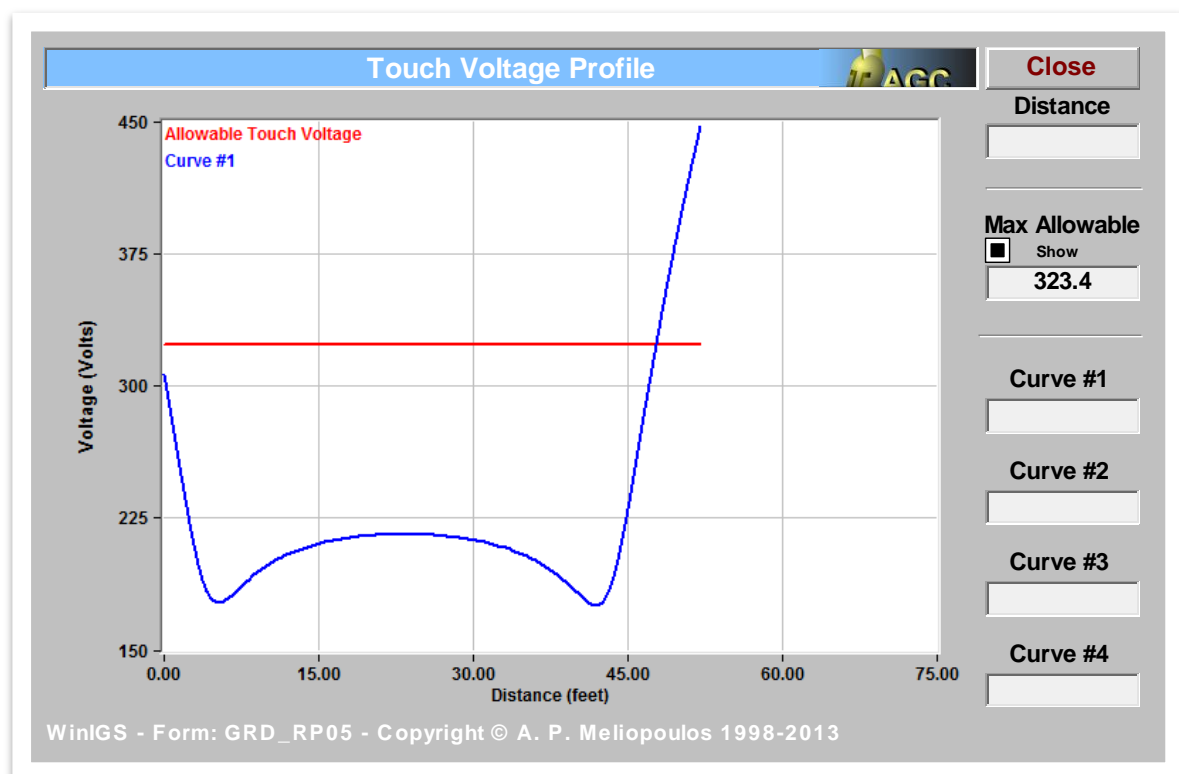


Figure 37. Reference of allowable touch voltage.

We can modify the layer resistivity to analyse the influence of this parameter to improve safety. If this time we consider crushed rock or gravel placed on top of the soil which a value of 2000 Ohm-meter:

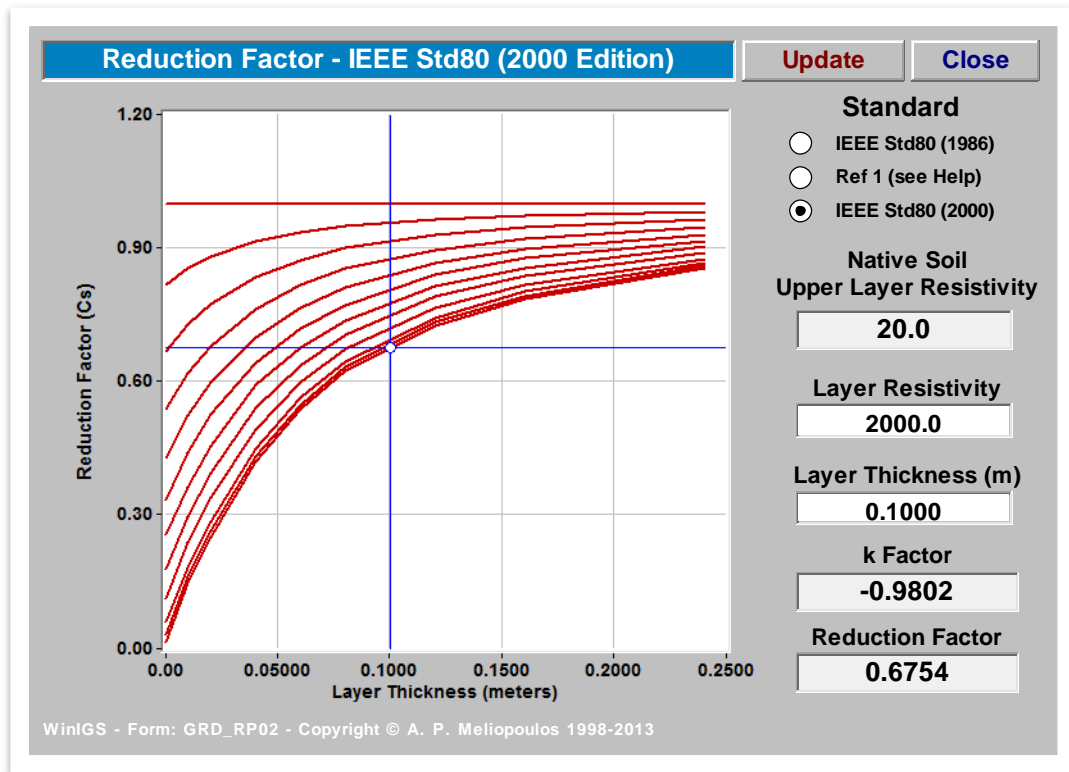


Figure 36. Layer resistivity of 2000 Ohm-meters.

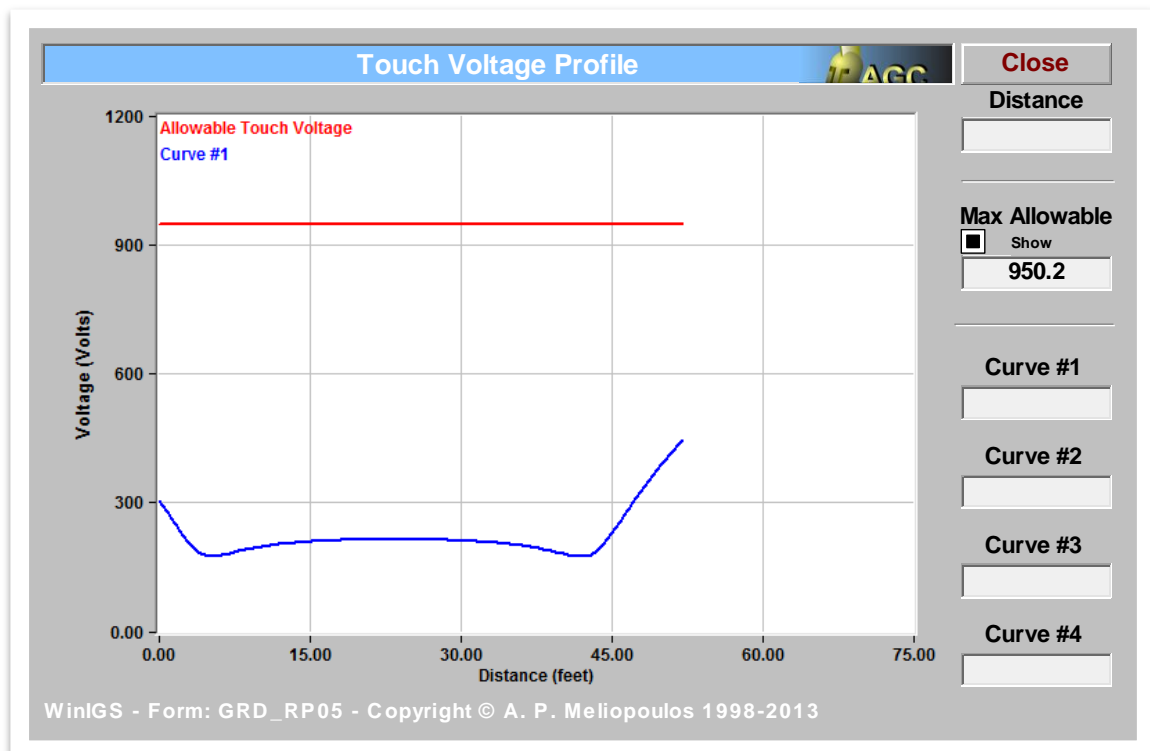


Figure 37. Touch voltage improve safety.

If we consider the same process for step voltage, considering grass for the first calculation which is shown in Figure 38:

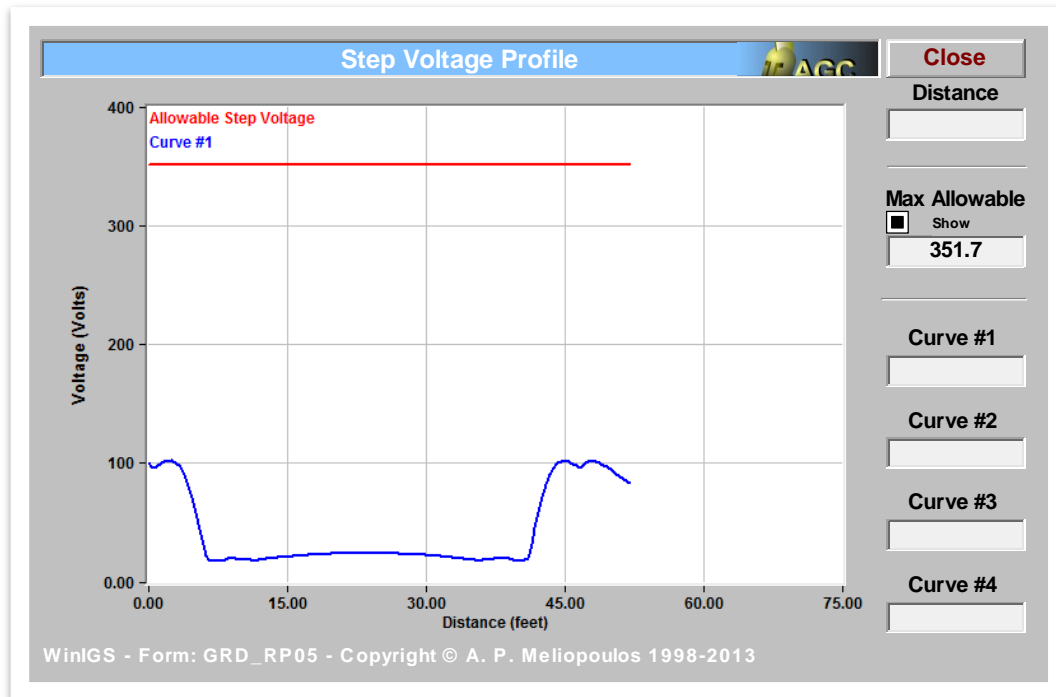


Figure 38. Step touch curve against allowable step voltage.

As we can see the step voltage is all the time under the level of allowable step voltage. Thus, we are always in a safety region. In case of increasing the layer resistivity as shown in previous Figure 36, the distance between these curves will be higher.

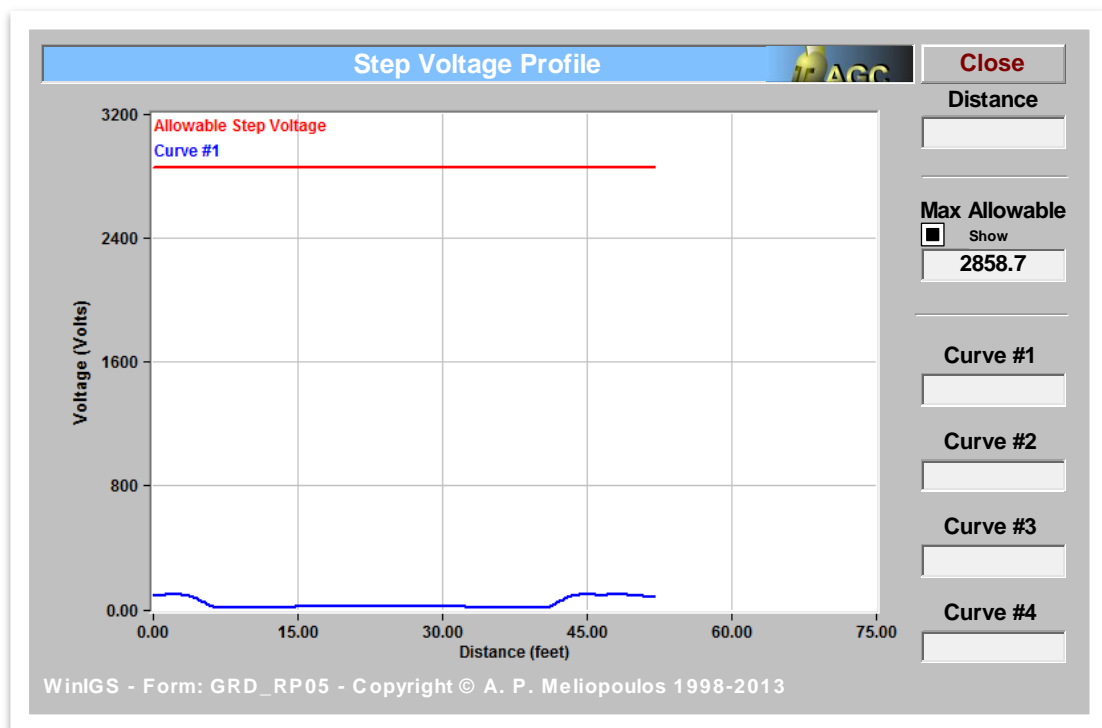


Figure 39. Step voltage improve safety.

### 11.4.2 CASE B: GRID

In this case, we are going to consider the grounding system formed only by the grid system. The analysis process is the same that the shown before.

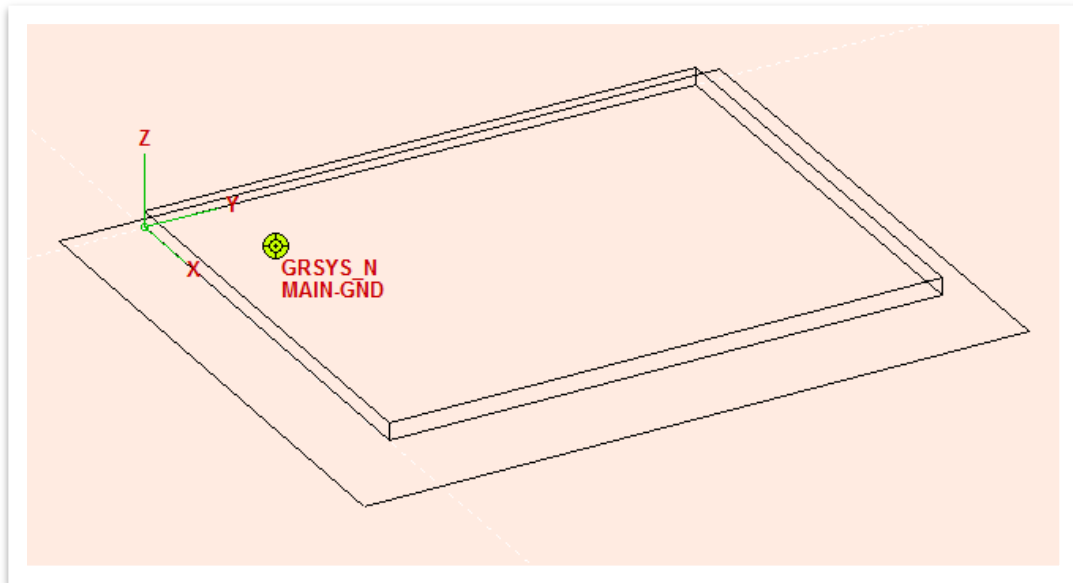


Figure 38. Case B grounding system.

The potential ground has increased to 1.535 kV and also has increased the system resistance,  $R_p$ .

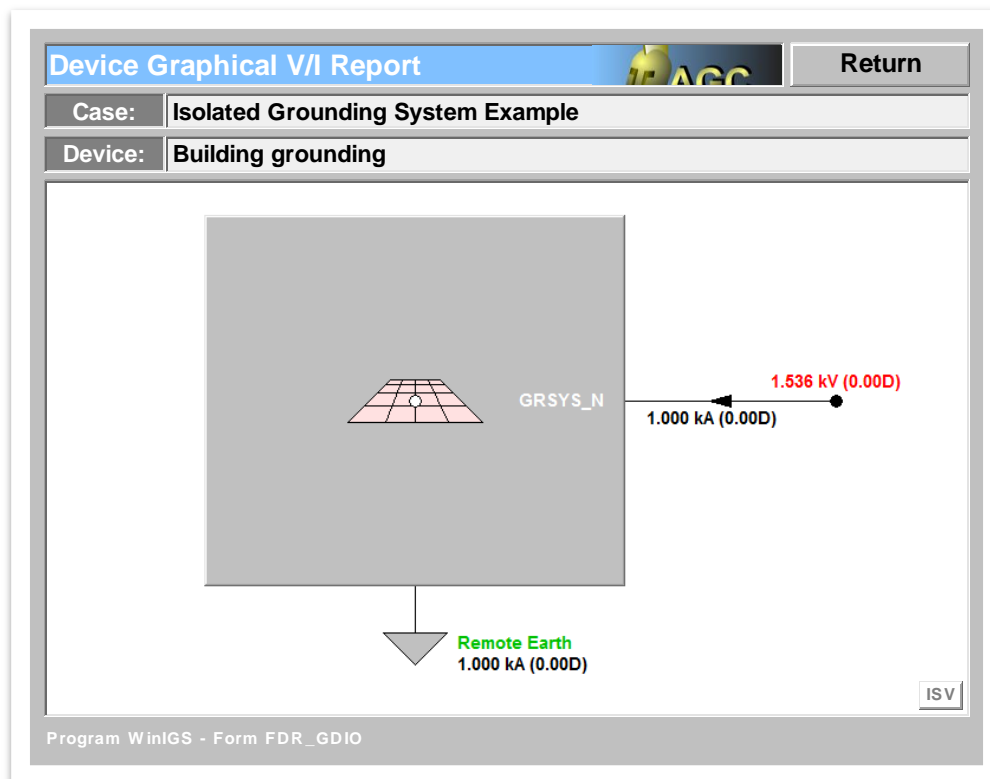


Figure 39. Graphical V/I Report.

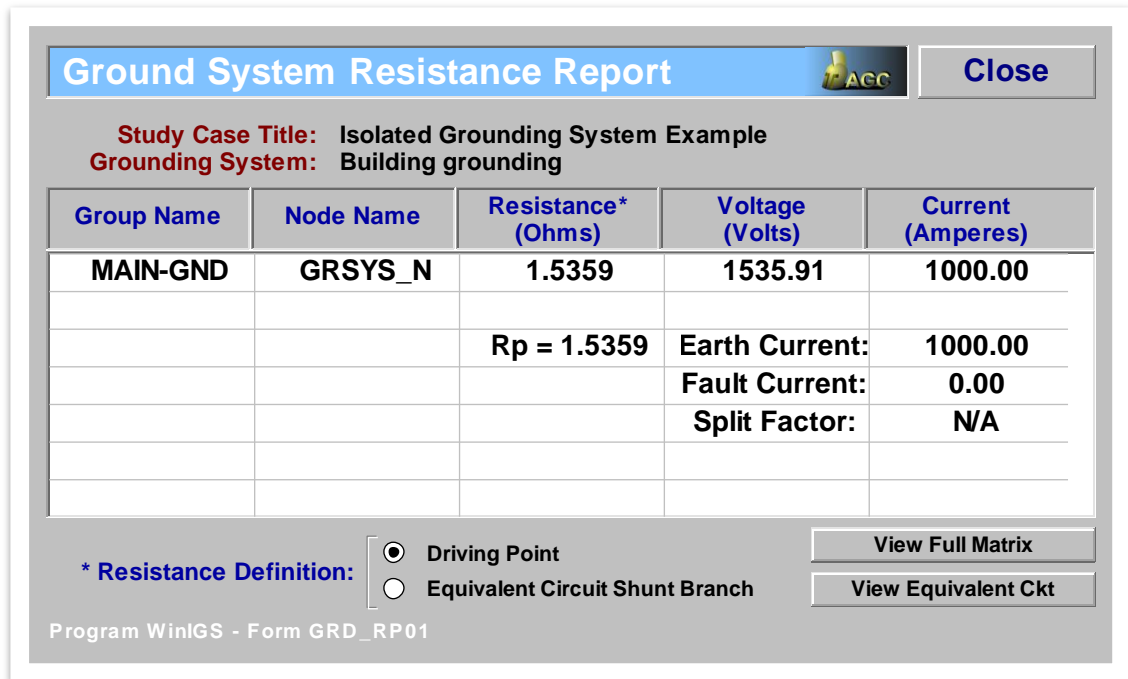


Figure 40. Case B, Ground system resistance report.

We also analyse the touch and step distribution in this case considering the resistive layer as grass and after that considering the resistive layer as crushed rock or gravel. It is the same process like in case A.

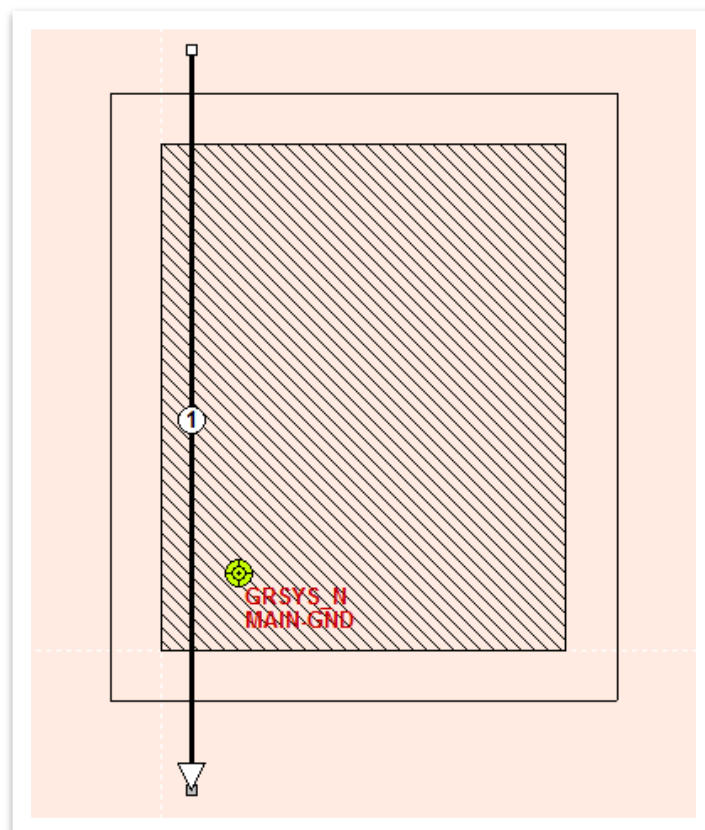


Figure 41. Case B, building and grounding system profile.

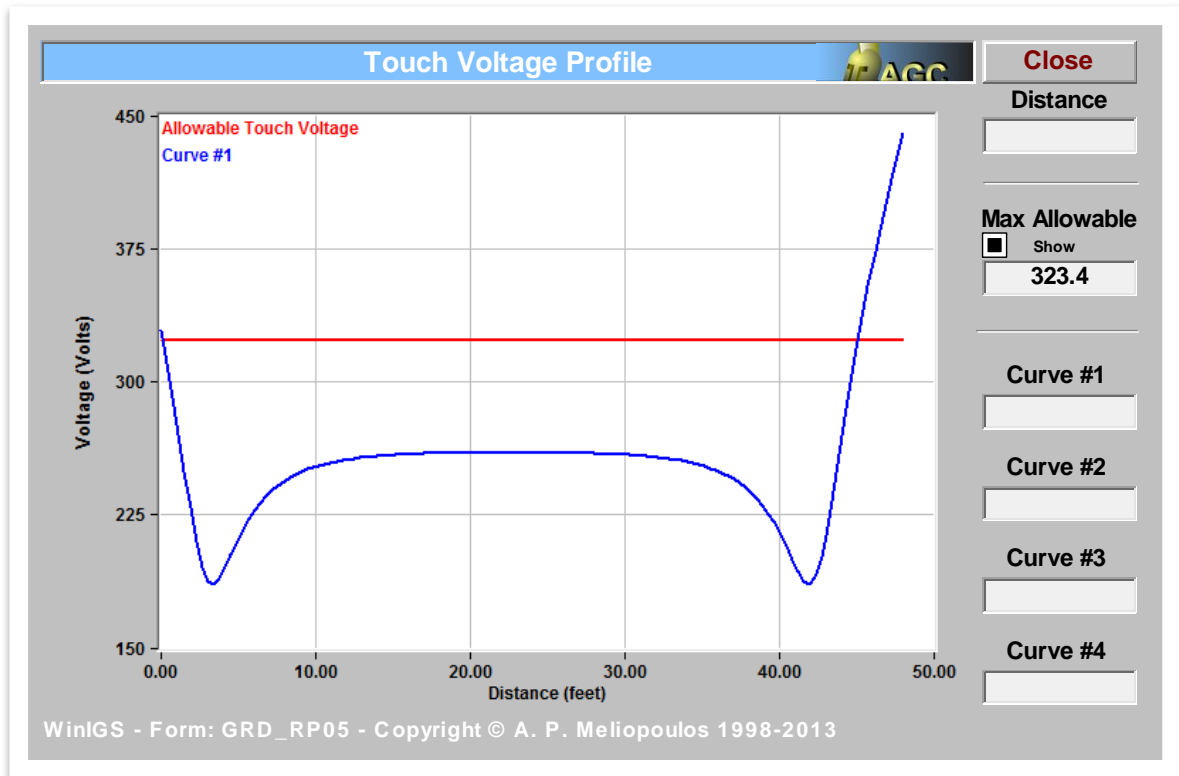


Figure 42. Touch voltage profile. Grass layer resistive.

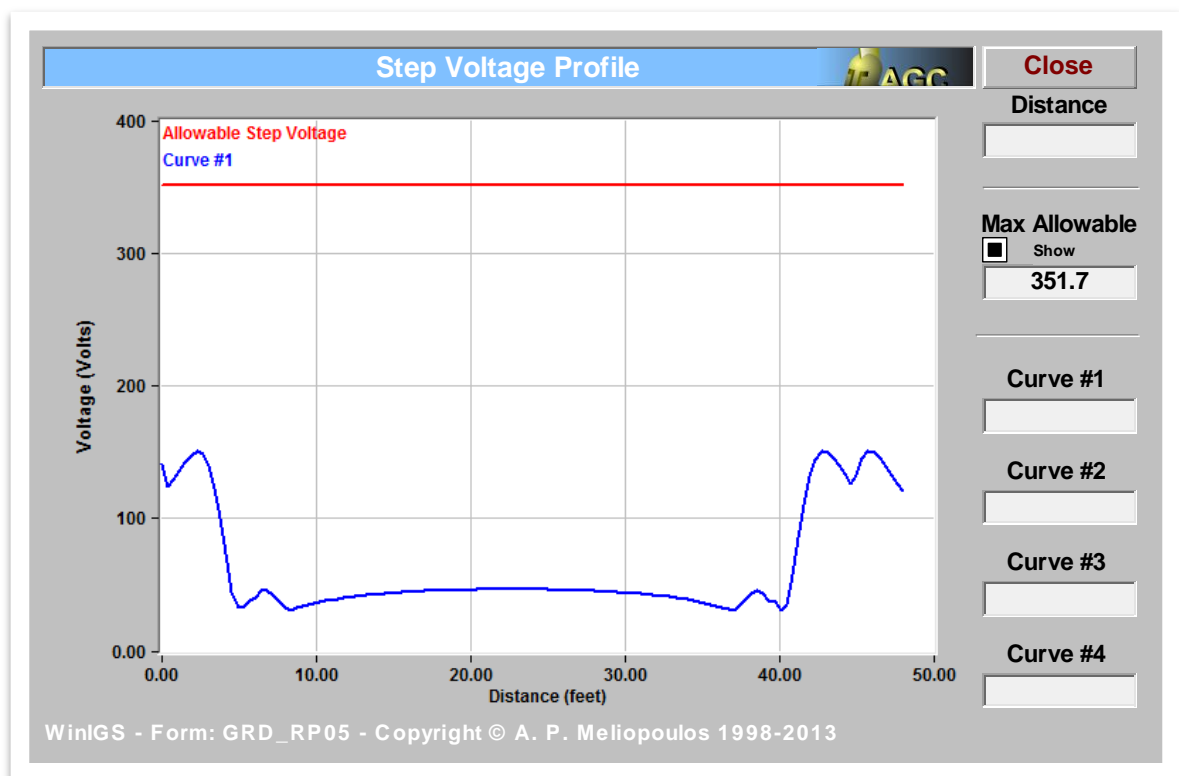


Figure 43. Step voltage profile. Grass layer resistive.

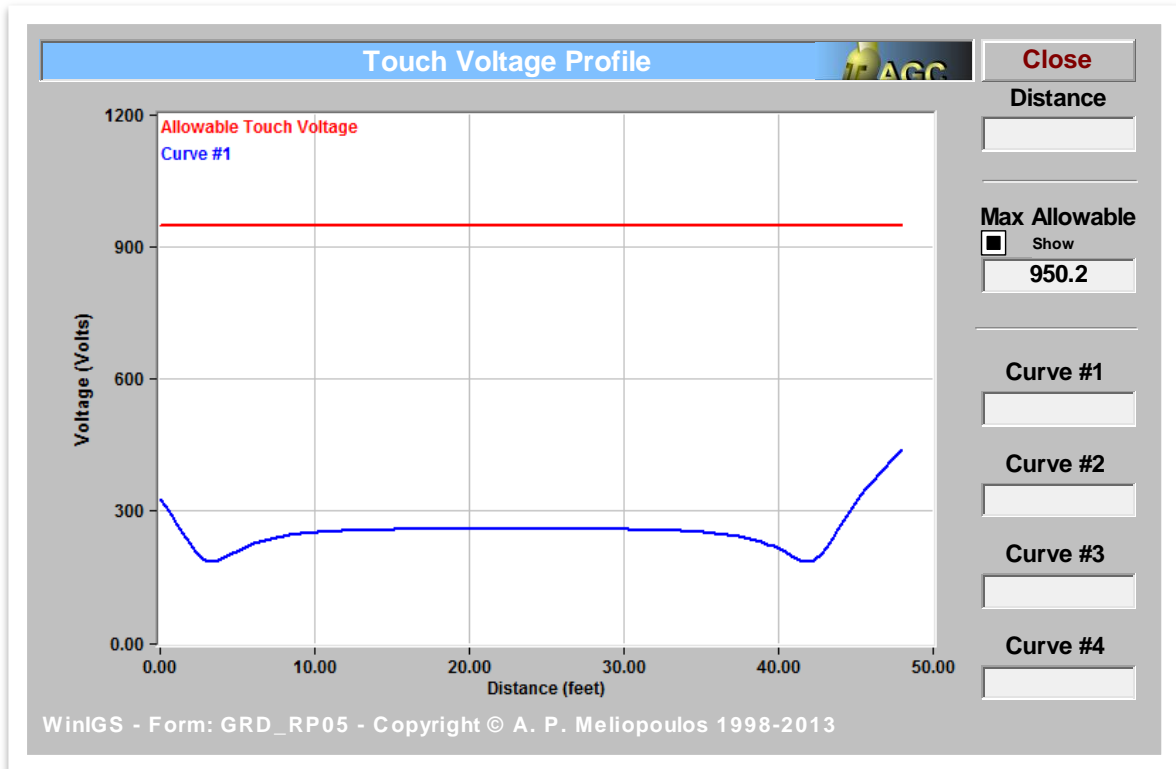


Figure 44. Touch voltage profile. Crushed rock or gravel layer resistive.

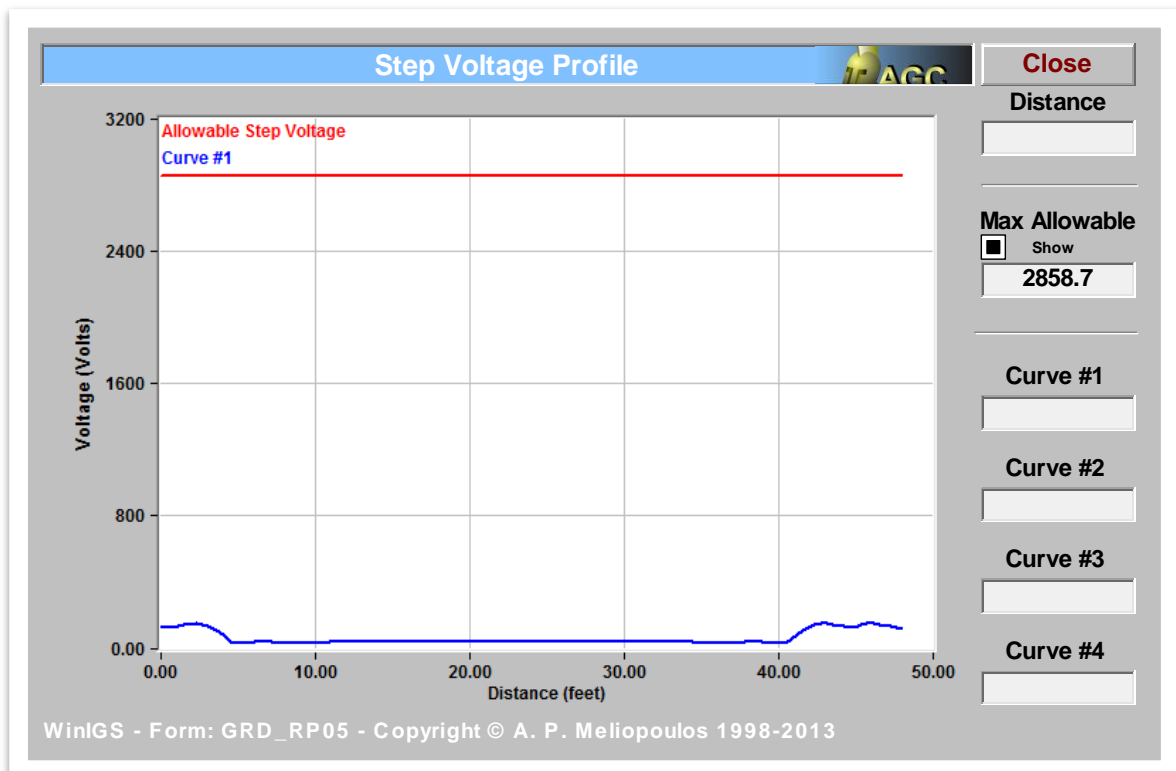


Figure 45. Step voltage profile. Crushed rock or gravel layer resistive.

In the profile of the distribution of the touch voltage shown in Figure 42 we can see that the blue curve which is crossing the allowable voltage in two points, one in the vicinity of the building and other far away. The nearest one is close to the value of the limit and the other, about 45 feet, is higher than the nearest one. In addition, when we change the value for the soil to 2000 Ohm-meters, Figure 44, which is the value for the crushed rock or gravel, the safety criteria, is in all points correct. In reference to the step voltage, Figure 43 and Figure 45, in both cases the safety criteria is achieve.

## 12. CALCULATIONS OF STEP AND TOUCH VOLTAGES. SHORT CIRCUIT CURRENTS

We have obtained the values for the touch and step voltage of our grounding systems. If we want to determine the electric current that will flow in a human body due to these voltages we are going to consider the next figures to understand the procedure.

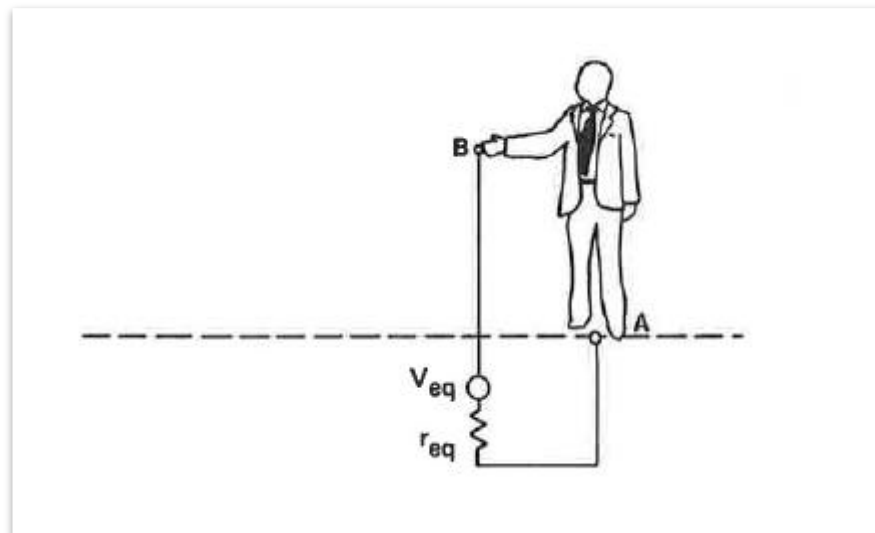


Figure 43. Touch voltage simplified circuit.

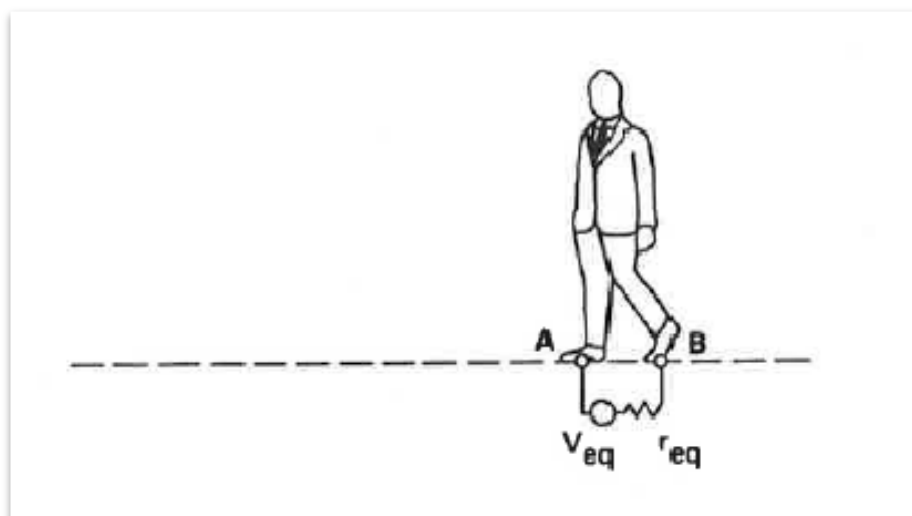


Figure 44. Step voltage simplified circuit.



The previous figures illustrate human beings in the vicinity of a building ground system subjected to touch and step voltages, respectively. We include the graphics obtained with the Win-IGS program tool of the touch voltage and step voltage in the vicinity of the building and grounding system considering grass and crushed rock or gravel as the soil layer.

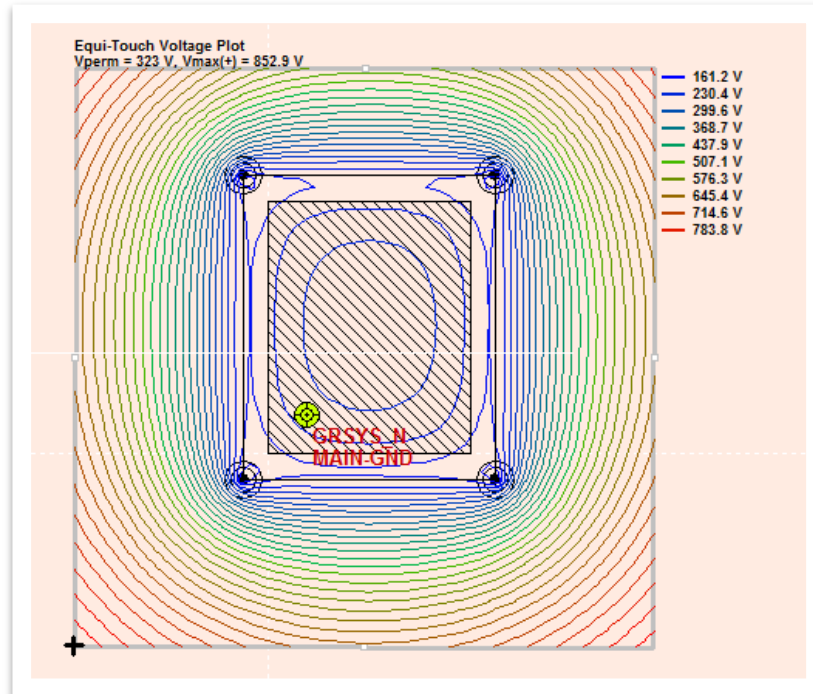


Figure 45. Touch voltage distribution. Grass layer resistive.

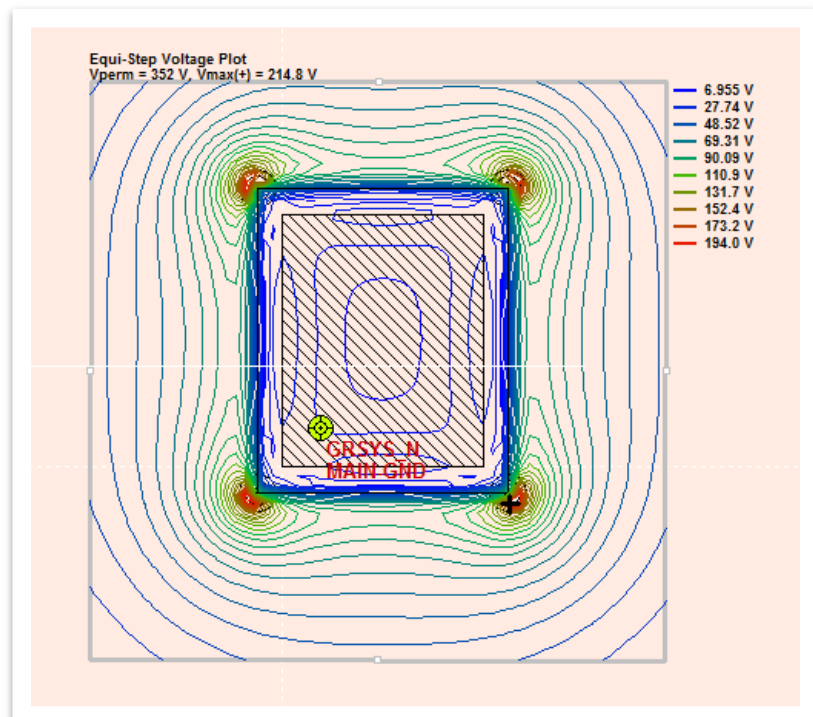


Figure 46. Step voltage distribution. Grass layer resistive.

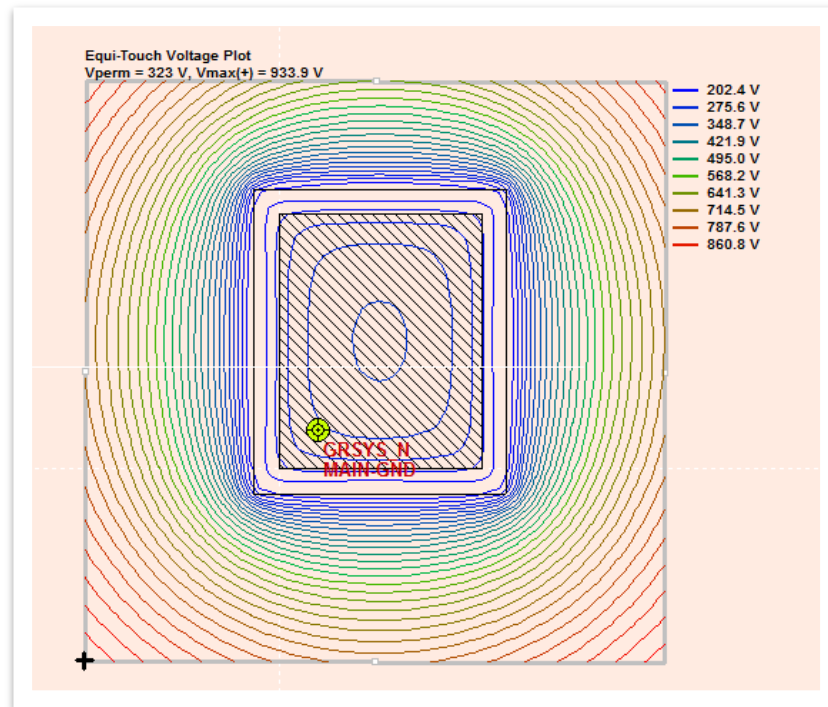


Figure 47. Touch voltage distribution. Crushed rock layer resistive.

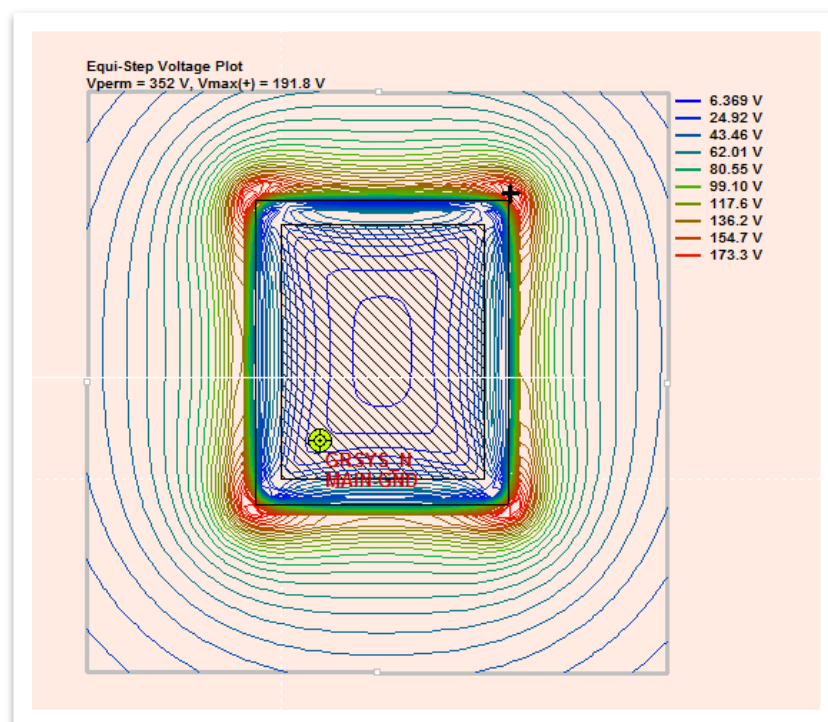


Figure 48. Step voltage distribution. Crushed rock layer resistive.



The equivalent voltage sources,  $V_{eq}$ , are suitable to the measurements we have before calculated. The equivalent resistance,  $r_{eq}$ , between the points of contact depends on the resistance of the two feet to soil and the resistance of the grounding system,  $R_p$ . According to the references we can write the following equation:

$$r_{eq} = 1.5 * \rho + R_p \quad (1)$$

Thus, for the case A, we consider the grass resistivity of 20  $\Omega$ -m,  $R_{pA} = 1.465 \Omega$  and replacing in Equation 1:

$$r_{eqA} = 1.5 * 20 + 1.465 = 31.4650 \Omega$$

We can calculate the electric current through the human body,  $i_b$ , as follows:

$$i_b = \frac{V_{eq}}{r_{eq} + r_b} \quad (2)$$

Where  $r_b$  is the resistance of the human body between the points of contact. That resistance depends on many factors, such as size, skin condition, pressure at the contact, and level of voltage  $V_{eq}$ , among others. Reasonable values are 1000  $\Omega$  for the resistance from foot to arm and 2000  $\Omega$  for the resistance from one foot to another foot. The pessimistic values are 500  $\Omega$  and 1000  $\Omega$  respectively. According IEEE Standard 80 suggests the value of 1000  $\Omega$ .

Therefore, for the touch voltage taking the value from Figure 45 of  $V_{eq} = 161.2$  V, the voltage coloured in blue, the electric current due to this voltage, substituting in Equation 2:

$$i_{bTV,A} = \frac{161.2}{31.465 + 1000} = 0.1563 A$$

For the step voltage we select the value from Figure 46,  $V_{eq} = 6.955$  V, the value which is also coloured in blue in reference to the inside building, substituting in Equation 2:

$$i_{bSV,A} = \frac{6.955}{31.465 + 1000} = 0.0067 A$$

Secondly, case B, the same resistivity,  $R_{pB} = 1.5359 \Omega$  and replacing in Equation 1:

$$r_{eqB} = 1.5 * 20 + 1.5359 = 31.5359 \Omega$$

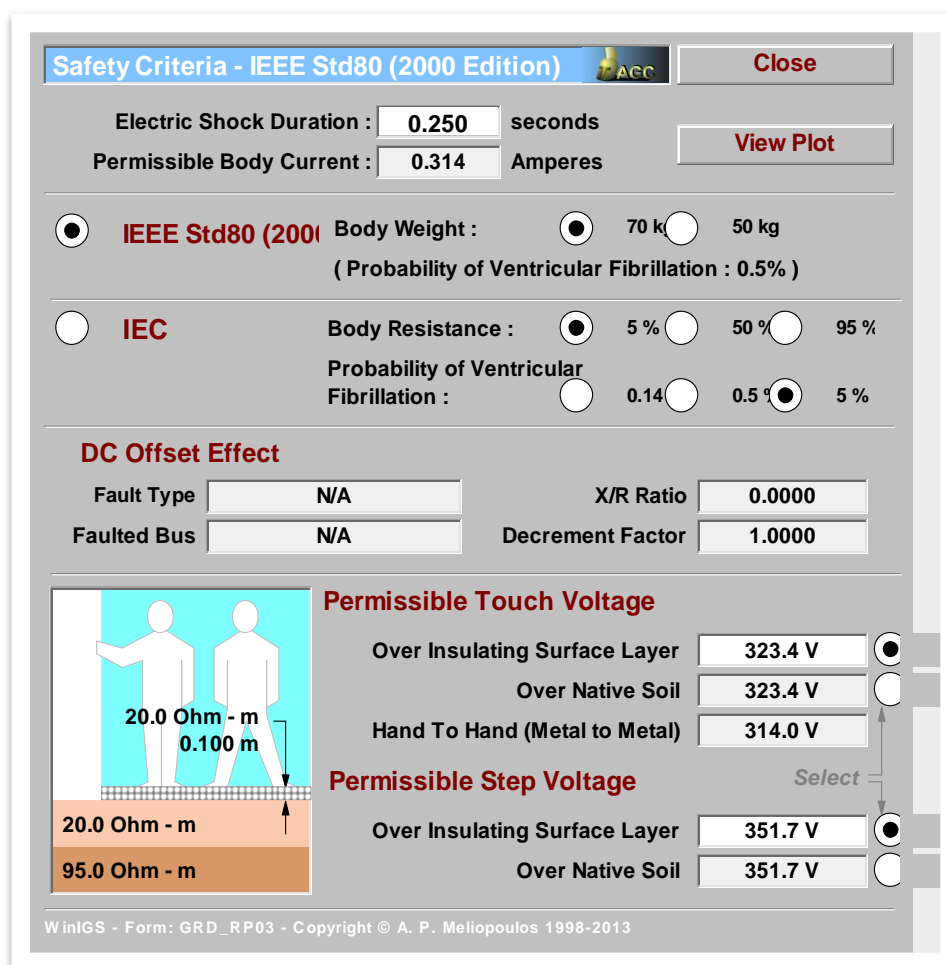
If we use the same operations as in Case A, taking the value from touch voltage from Figure 47,  $V_{eq} = 202.4$  V, replacing in Equation 2:

$$i_{bTV,B} = \frac{202.4}{31.5359 + 1000} = 0.1962 A$$

With step voltage from Figure 48,  $V_{eq} = 6.369$  V, replacing in Equation 2:

$$i_{bSV,B} = \frac{6.369}{31.5359 + 1000} = 0.0062 \text{ A}$$

Electric currents can cause effects on human bodies which depend on the individual, duration, and magnitude of current. These parameters refer to the case in which the heart beat stops irrecoverably what is known in medical jargon as ventricular fibrillation. The threshold of ventricular fibrillation for a typical adult subjected to 60-Hz ac current of 1-s duration is on the order of 200 to 300 mA. Thus, the preceding values for electric currents which are calculated for 0.25-s are below the limit values. If we consider instead of grass or crushed rock, as soil, concrete which has higher resistivity (100 – 50.000  $\Omega$ -m) the electric currents will be even smaller.



**Safety Criteria - IEEE Std80 (2000 Edition)** Close

Electric Shock Duration :  seconds View Plot

Permissible Body Current :  Amperes

☒ **IEEE Std80 (2000)** Body Weight : ☒ 70 kg ☐ 50 kg  
 ( Probability of Ventricular Fibrillation : 0.5% )

☐ **IEC** Body Resistance : ☒ 5 % ☐ 50 % ☐ 95 %  
 Probability of Ventricular Fibrillation : ☐ 0.14 ☐ 0.5 ☒ 5 %

**DC Offset Effect**

Fault Type  X/R Ratio   
 Faulted Bus  Decrement Factor

**Permissible Touch Voltage**

Over Insulating Surface Layer  ☒  
 Over Native Soil  ☐  
 Hand To Hand (Metal to Metal)  ☐

**Permissible Step Voltage**

Over Insulating Surface Layer  ☒  
 Over Native Soil  ☐

Diagram: Two people standing on a surface with a 20.0 Ohm-m layer and a 95.0 Ohm-m layer, with a 0.100 m distance between them.

WinIGS - Form: GRD\_RP03 - Copyright © A. P. Meliopoulos 1998-2013

Figure 49. Safety criteria and permissible touch and step voltage.

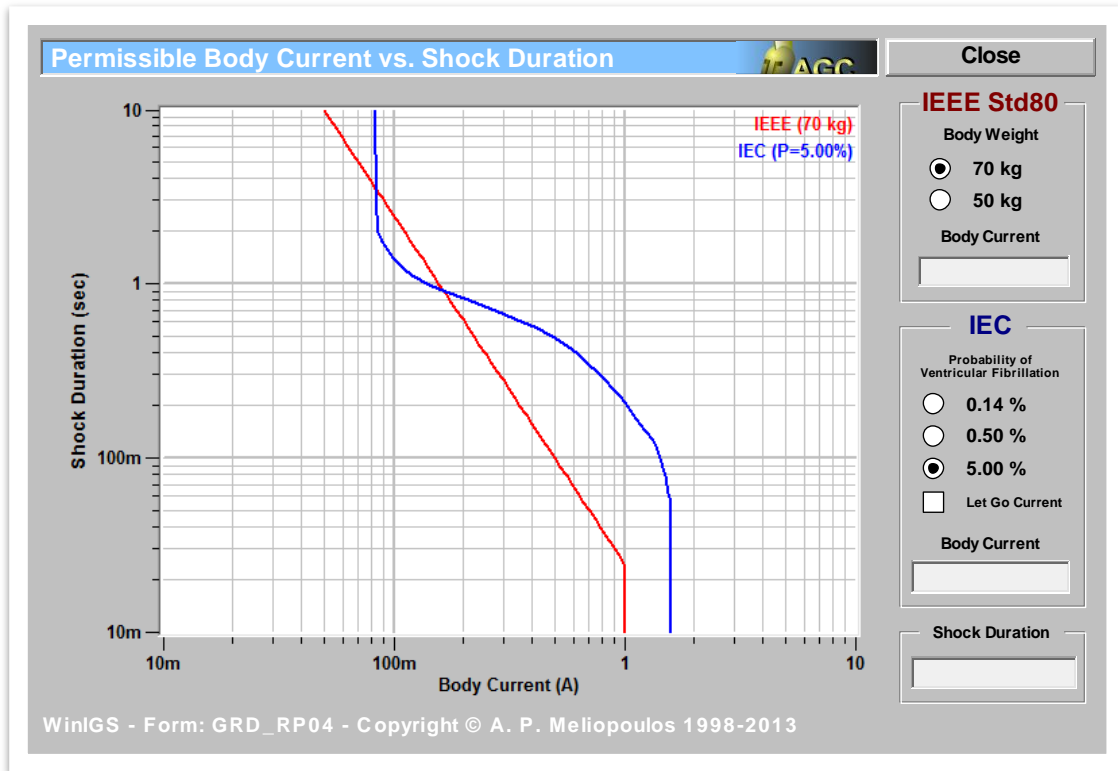


Figure 50. Comparative graphic for different standards.

An interesting point is to compare the different guidelines to compute the body allowable current using IEEE Std 80 or IEC standard. As we can see in the previous Figure 50, the American one gives specific values depending on the conditions of weight instead of the European one which is based on probabilities and it is more complicated to understand and to calculate.



### **13. CONCLUSIONS**

The most important factor that we can easily compute using Win-IGS program tool is the resistance of the grounding system. In fact, this parameter is very difficult to measure but using this software it is not a problem. In our case, the creation and design of the building grounding system is simple and easy because of the interface of the Win-IGS program. It is also easy to modify the dimensions and the electric parameters of the earthing system and the new grounding resistance is recalculated easily. Another fundamental parameter is the soil resistivity. The Win-IGS program allows varying the soil resistivity. Thus, we can calculate for very different types of soil the grounding resistance of our earthing system. The software provides wide variations of soil measurements. Therefore, the needed accuracy depending on the user expectations or requirements can be satisfied. We can choose between lots of materials for our earthing system design which is also an advantage. Other parameters like touch and step voltages can be measured too. One advantage more of the Win-IGS program tool is that it provides several electrical Standards to be followed by the user.

In summary, for the design of the earthing systems in buildings, the Win-IGS program tool calculates the resistance value of the grounding system, among others electrical parameters, taking into consideration the earthing system structure and the soil resistivity, being this last parameter one of the most important element to consider in grounding systems.



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