Earthing System

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Content:

Earthing Systems – Fundamentals of Calculation and Design

Introduction:-

The earthing system, sometimes simply called ‘earthing’, is the total set of measures used to connect an electrically conductive part to earth. The earthing system is an essential part of power networks at both
high- and low-voltage levels. A good earthing system is required for:

- protection of buildings and installations against lightning
- safety of human and animal life by limiting touch and step voltages to safe values
- electromagnetic compatibility (EMC) i.e. limitation of electromagnetic disturbances
- correct operation of the electricity supply network and to ensure good power quality.

All these functions are provided by a single earthing system that has to be designed to fulfil all therequirements. Some elements of an earthing system may be provided to fulfil a specific purpose, but arenevertheless part of one single earthing system. Standards require all earthing measures within aninstallation to be bonded together, forming one system.

What is earthing?

The whole of the world may be considered as a vast conductor which is at reference (zero) potential. In the UK we refer to this as 'earth' whilst in the USA it is called 'ground'. People are usually more or less in contact with earth, so if other parts which are open to touch become charged at a different voltage from earth a shock hazard exists. The process of earthing is to connect all these parts which could become charged to the general mass of earth, to provide a path for fault currents and to hold the parts as close as possible to earth potential. In simple theory this will prevent a potential difference between earth and earthed parts, as well as permitting the flow of fault current which will cause the operation of the protective systems.

The standard method of tying the electrical supply system to earth is to make a direct connection between the two. This is usually carried out at the supply transformer, where the neutral conductor (often the star point of a three-phase supply) is connected to earth using an earth electrode or the metal sheath and armouring of a buried cable. {Figure 5.1} shows such a connection. Lightning conductor systems must be bonded to the installation earth with a conductor no larger in cross-sectional area than that of the earthing conductor.

The advantages of earthing

The practice of earthing is widespread, but not all countries in the world use it.

There is certainly a high cost involved, so there must be some advantages. In fact there are two. They are:

1. - The whole electrical system is tied to the potential of the general mass of earth and cannot 'float' at another potential. For example, we can be fairly certain that the neutral of our supply is at, or near, zero volts (earth potential) and that the phase conductors of our standard supply differ from earth by 240 volts.

2. - By connecting earth to metalwork not intended to carry current (an extraneous conductive part or a an exposed conductive part) by using a protective conductor, a path is provided for fault current which can be detected and, if necessary, broken. The path for this fault current is shown in {Fig 5.2}.

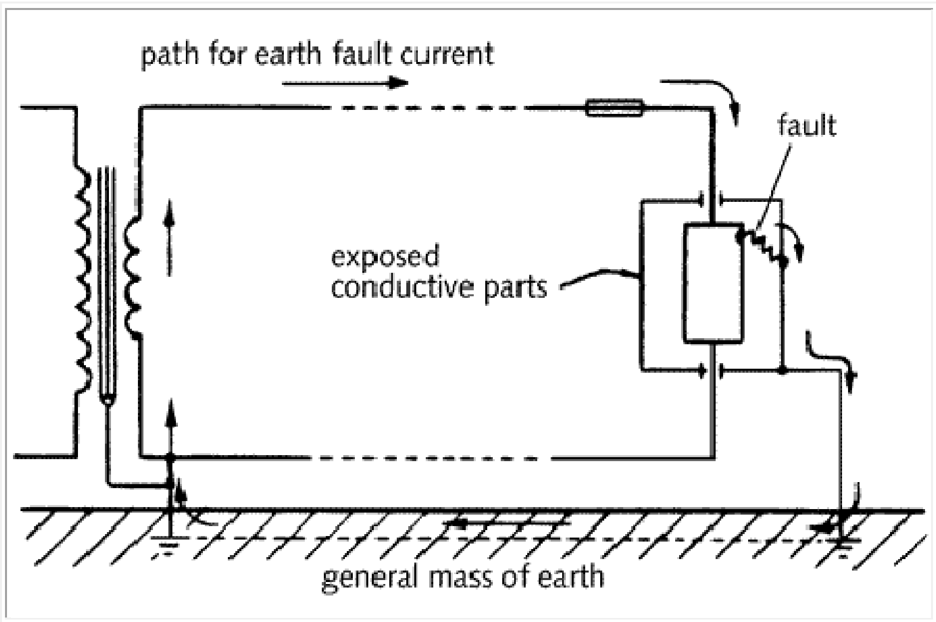


Fig 5.2 Path for earth fault current (shown by arrows)

The disadvantages of earthing

The two important disadvantages are:

1. - Cost: the provision of a complete system of protective conductors, earth electrodes, etc. is very expensive.

2. - Possible safety hazard: It has been argued that complete isolation from earth will prevent shock due to indirect contact because there is no path for the shock current to return to the circuit if the supply earth connection is not made (see {Fig 5.3(a)}). This approach, however, ignores the presence of earth leakage resistance (due to imperfect insulation) and phase-to-earth capacitance (the insulation behaves as a dielectric). In many situations the combined impedance due to insulation resistance and earth capacitive reactance is low enough to allow a significant shock current (see {Fig 5.3(b)}).

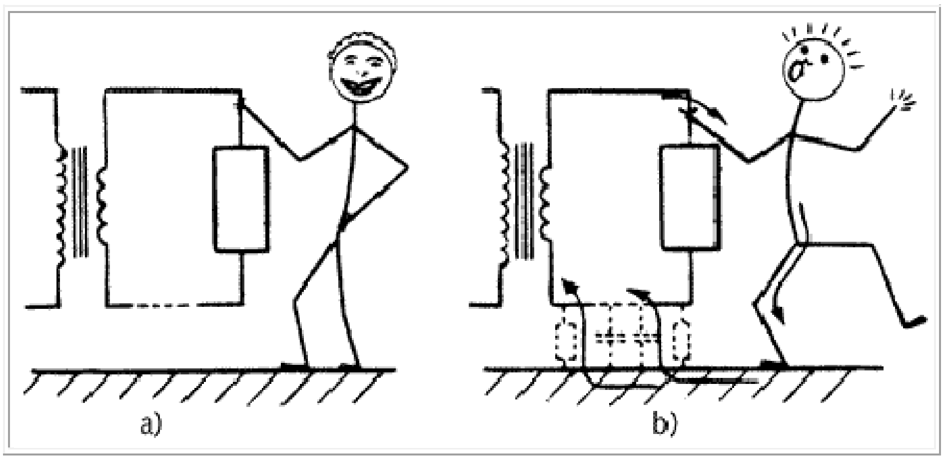


Fig 5.3 - Danger in an unearthed system

a) apparent safety: no obvious path for shock current
b) actual danger: shock current via stray resistance and capacitance

Basic definitions :

Earthing or earthing system is the total of all means and measures by which part of an electrical circuit,accessible conductive parts of electrical equipment (exposed conductive parts) or conductive parts in thevicinity of an electrical installation (extraneous conductive parts) are connected to earth.
Earth electrode is a metal conductor, or a system of interconnected metal conductors, or other metal partsacting in the same manner, embedded in the ground and electrically connected to it, or e.g. foundation embedded in the which is in contact with the earth over a large area (of a building).

Earthing conductor: is a conductor which connects a part of an electrical installation, exposed conductive parts or extraneous conductive parts to an earth electrode or which interconnects earth electrodes. The arthing conductor is laid above the soil or, if it is buried in the soil, is insulated from it.

Reference earth: is that part of the ground, particularly on the earth surface, located outside the sphere ofinfluence of the considered earth electrode, i.e. between two random points at which there is no perceptible voltages resulting from the earthing current flow through this electrode. The potential of reference earth is always assumed to be zero.

Earthing voltage (earthing potential) ***VE:*** is the voltage occurring between the earthing system and reference earth at a given value of the earth current flowing through this earthing system.

Earth resistivity ρ **(specific earth resistance):** is the resistance, measured between two opposite faces, of a one-metre cube of earth (Figure 1). The
earth resistivity is expressed in Ωm.

Earth surface potential ***Vx :*** is the voltage between a point *x* on the earth's surface and reference earth.

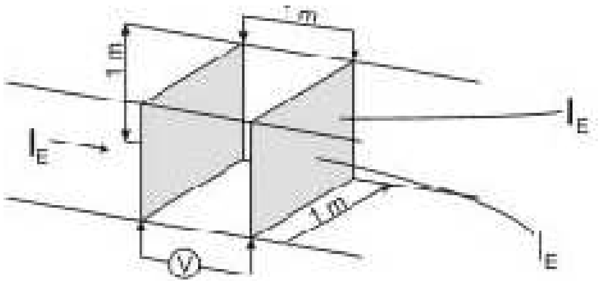


Figure 1 - Diagram illustrating the physical sense of earth resistivity ρ

System classification

1 - TT systems

2 - TN-S system

3 - TN-C-S system

4 - TN-C system

5 - IT system

The electrical installation does not exist on its own; the supply is part of the overall system. Although Electricity Supply Companies will often provide an earth terminal, they are under no legal obligation to do so. As far as earthing types are concerned, letter classifications are used.

The *first letter* indicates the type of supply earthing.
T -indicates that one or more points of the Supply are directly earthed (for example, the earthed neutral at the transformer).
I -indicates either that the supply system is not earthed at all, or that the earthing includes a deliberately-inserted impedance, the purpose of which is to limit fault current. This method is not used for public supplies in the UK.

The *second letter* indicates the earthing arrangement in the installation.
T - all exposed conductive metalwork is connected directly to earth.
N - all exposed conductive metalwork is connected directly to an earthed supply conductor provided by the Electricity Supply Company.

The *third and fourth letters* indicate the arrangement of the earthed supply conductor system.
S - neutral and earth conductor systems are quite separate.
C - neutral and earth are combined into a single conductor.

A number of possible combinations of earthing systems in common use is indicated in the following subsections.

Protective conductor systems against lightning need to be connected to the installation earthing system to prevent dangerous potential differences. Where a functional earthing system is in use, the protective requirements of the earthing will take precedence over the functional requirements.

1 - TT systems

In a **TT** earthing system, the protective earth connection of the consumer is provided by a local connection to earth, independent of any earth connection at the generator.

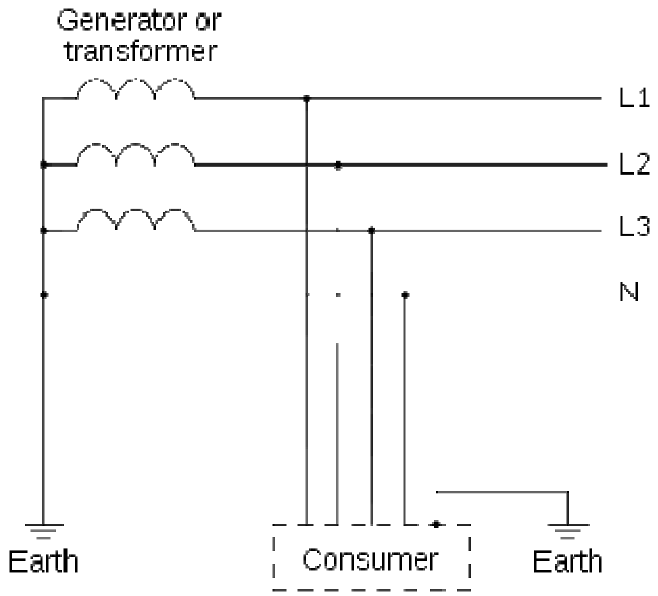
The big advantage of the TT earthing system is the fact that it is clear of high and low frequency noises that come through the neutral wire from various electrical equipment connected to it. This is why TT has always been preferable for special applications like telecommunication sites that benefit from the interference-free earthing. Also, TT does not have the risk of a broken neutral.

In locations where power is distributed overhead and TT is used, installation earth conductors are not at risk should any overhead distribution conductor be fractured by, say, a fallen tree or branch.

In pre-RCD era, the TT earthing system was unattractive for general use because of its worse capability of accepting high currents in case of a live-to-

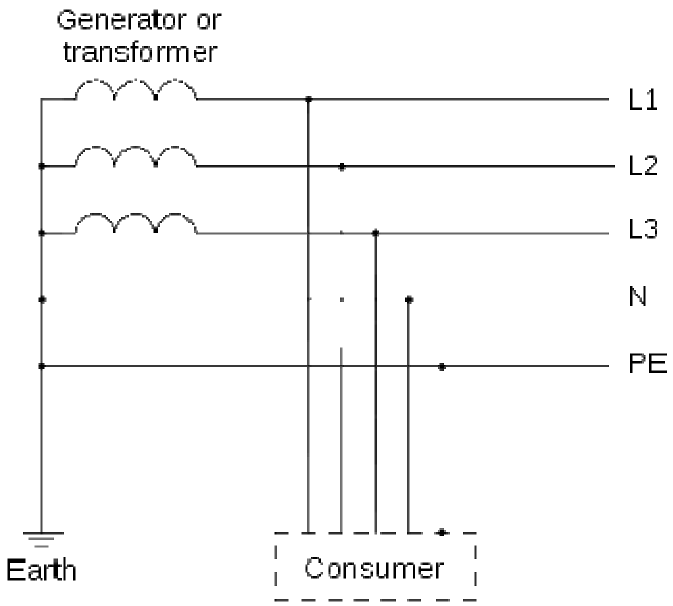
PE short circuit (in comparison with TN systems). But as residual current devices mitigate this disadvantage, the TT earthing system becomes attractive for premises where all AC power circuits are RCD-protected.

The TT earthing system is used throughout Japan, with RCD units in most industrial settings. This can impose added requirements on variable frequency drives and switched-mode power supplies which often have substantial filters passing high frequency noise to the ground conductor.



2-TN networks

In a **TN** earthing system, one of the points in the generator or transformer is connected with earth, usually the star point in a three-phase system. The body of the electrical device is connected with earth via this earth connection at the transformer.



The conductor that connects the exposed metallic parts of the consumer is called *protective earth* (*PE*). The conductor that connects to the star point in a three-phase system, or that carries the return current in a single-phase system, is called *neutral* (*N*). Three variants of TN systems are distinguished:

TN−S

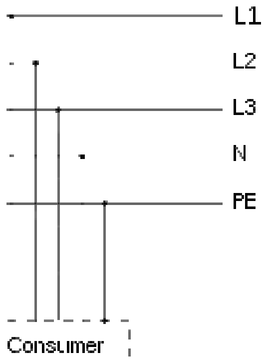
PE and N are separate conductors that are connected together only near the power source. This arrangement is the current standard for most residential and industrial electric systems in North America and Europe.

3-TN−C

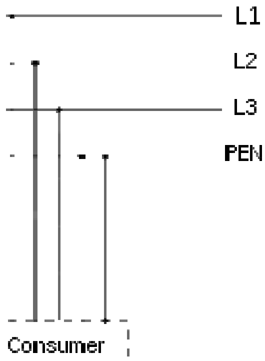
A combined PEN conductor fulfills the functions of both a PE and an N conductor. Rarely used.

4-TN−C−S

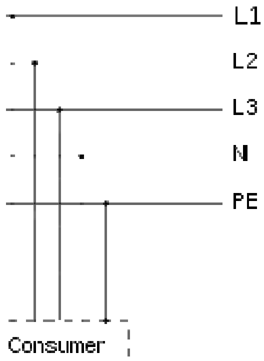
Part of the system uses a combined PEN conductor, which is at some point split up into separate PE and N lines. The combined PEN conductor typically occurs between the substation and the entry point into the building, and separated in the service head. In the UK, this system is also known as *protective multiple earthing (PME)*, because of the practice of connecting the combined neutral-and-earth conductor to real earth at many locations, to reduce the risk of broken neutrals - with a similar system in Australia being designated as *multiple earthed neutral (MEN)*.



TN-S: separate protective earth (PE) and neutral (N) conductors from transformer to consuming device, which are not connected together at any point after the building distribution point.



TN-C: combined PE and N conductor all the way from the transformer to the consuming device.

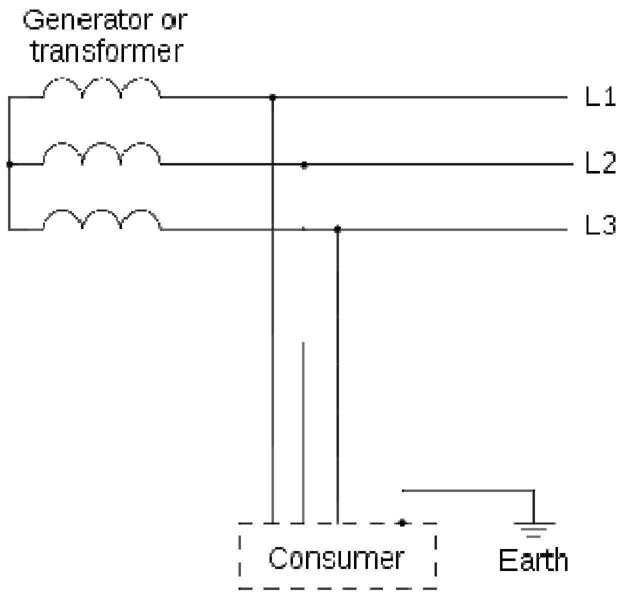


TN-C-S earthing system: combined PEN conductor from transformer to building distribution point, but separate PE and N conductors in fixed indoor wiring and flexible power cords.

It is possible to have both TN-S and TN-C-S supplies from the same transformer. For example, the sheaths on some underground cables corrode and stop providing good earth connections, and so homes where "bad earths" are found get converted to TN-C-S.

5-IT network

In an **IT** network, the distribution system has no connection to earth at all, or it has only a high impedance connection. In such systems, an insulation monitoring device is used to monitor the impedance.



Electrical properties of the ground:

The electrical properties of the ground are characterised by the earth resistivity ρ. In spite of the relatively simple definition of ρ given above, the determination of its value is often a complicated task for two main reasons:

- the ground does not have a homogenous structure, but is formed of layers of different materials
- the resistivity of a given type of ground varies widely (Table 1) and is very dependent on moisture content.

The calculation of the earthing resistance requires a good knowledge of the soil properties, particularly of its resistivity ρ. Thus, the large variation in the value of ρ is a problem. In many practical situations, a homogenous ground structure will be assumed with an average value of ρ, which must be estimated on the basis of soil analysis or by measurement. There are established techniques for measuring earth resistivity.

One important point is that the current distribution in the soil layers used during measurement should

simulate that for the final installation. Consequently, measurements must always be interpreted carefully.

Where no information is available about the value of ρ it is usually assumed ρ = 100 Ωm. However, as Table 1 indicates, the real value can be very different, so acceptance testing of the final installation, together with an assessment of likely variations due to weather conditions and over lifetime, must be undertaken.

Type of ground	Ground resistivity ρ [Ωm]	
	Range of values	Average value
Boggy ground	2 – 50	30
Adobe clay	2-200	40
Silt and sand-clay ground, humus	20-260	100
Sand and sandy ground	50-3,000	200(moist)
Peat	>1,200	2,000
Gravel (moist)	50-3,000	1,000(moist)
Stony and rocky ground	100-8,000	2,000
Concrete: 1 part cement + 3 parts sand	50-300	150
1 part cement + 5 parts gravel	100-8,000	400

Table 1 - Ground resistivity ρ *for various kinds of the soil and concrete [2, 3]*

Electrical properties of the earthling system:

The electrical properties of earthing depend essentially on two parameters:

- earthing resistance
- configuration of the earth electrode.

Earthing resistance determines the relation between earth voltage *VE* and the earth current value. The configuration of the earth electrode determines the potential distribution on the earth surface, which
occurs as a result of current flow in the earth. The potential distribution on the earth surface is an important consideration in assessing the degree of protection against electric shock because it determines the touch and step potentials. These questions are discussed briefly below.

The earthing resistance has two components:

- dissipation resistance *RD*, which is the resistance of the earth between the earth electrode and the reference earth
- resistance *RL* of the metal parts of the earth electrode and of the earthing conductor.

The resistance *RL* is usually much smaller than the dissipation resistance *RD*. Thus, usually the earthing resistance is estimated to be equal to the dissipation resistance *RD*. In the literature, ‘earthing resistance’usually refers to the dissipation resistance.

Any earth connection made available by the supplier appears in parallel with the locally provided earth and may well be expected to have a lower impedance at fundamental and harmonic frequencies. However, the availability and characteristics of this path are beyond the designer's control and hence should not be considered in the design of the earthing system which should be adequate for the required purpose in its own right.

Earthing resistance and potential distribution:

In AC circuits one must consider essentially the impedance of an earthing *ZE*, which is the impedance between the earthing system and the reference earth at a given operating frequency. The reactance of the earthing system is the reactance of the earthing conductor and of metal parts of the earth electrode. At low
frequencies - the supply frequency and associated harmonics - reactance is usually negligible in comparison to earthing resistance, but must be taken into account for high frequencies such as lightning
transients. Thus, for low frequencies, it is assumed that the earthing impedance *ZE* is equal the dissipation resistance *RD*, which is in t::urn assumed to be approximately equal to the earthing resistance, *R*:
$ZE \approx RD \approx R$ (1)
The earthing resistance *R* of an earth electrode depends on the earth resistivity ρ as well as the electrode geometry. In order to achieve low values of *R* the current density flowing from the electrode metal to earth should be low, i.e. the volume of earth through which the current flows is as large as possible. Once the current flows from metal to earth it spreads out, reducing current density. If the electrode is physically small, e.g. a point, this effect is large, but is very much reduced for a plate where spreading is only effective
at the edges,there are four value for earthing resistance:

1. Earthing resistance for the lightning protection system shall not exceed 5 OHM.
2. Earthing resistance for the power system earthing in power station and power plants shall not exceed 5 OHM.
3. Earthing resistance for the electrical earthing (equipment earthing) shall not exceed 4 OHM.
4. Earthing resistance for the electronic devices instrumentations shall not exceed 1 OHM.

9. TYPES OF EARTHING SYSTEM:

In industrial installations, where both electrical and instrumentation equipment are incorporated and installed, three types of earthing system is generally introduced, designed and erected to provide safety and protective measures.

- **Electrical Earthing Systems**

The earthing system, which is designed, installed and connected to all electrical machineries and equipment as well as the plant's bulk equipment is called the "Electrical earthing system" or "Electrical earthing network"

1. The overall earthing resistance of the electrical earthing system should not be greater than 4 OHM, no matter which point of the grid is put under measurement.

2. In earthing systems, where bare conductors of the earthing grid is buried directly underground, each section of the underground grid actually acts as an individual earth

well, parallel to the existing earth wells, thus contributing in reduction and improvement of the overall earthing resistance. **3.** Earthing connections made to the marshaling earth buses, equipment's earth bosses etc. should be carried out with such skill and workmanship to prevent any possible misconnections, which could lead to added earth resistance other than established and required.

- **Instrument Earthing Systems**

In an industrial installation with sophisticated power and electronic equipment, protective measures should be taken to safeguard the instrumentation and the relevant control panels

against the sudden high voltages which might hit the earthing system in the event of a fault (short-circuit) in the power circuit of the installation. To achieve this, as a standard design practice, a separate earthing system is defined, designed and installed in such plants.

Technical specification, particularly, the installation of instrument earthing system is quite the same as that of electrical system, described in detailed in earlier sections, except for that the earthing resistance should not be greater than 1 OHM throughout the instrument earthing network. Details on instrument earthing system, particularly the different types of instrument earthing shall be offered during the specific course. In this document several concept of instrument earthing is introduced to the trainees of common course period.

1. Sufficient distance should be maintained between the instrument earth wells and the electrical earth wells. Standard distance is at least twice that of the greatest length of the earth rod driven in either the instrument or the electrical well.

2. Separate earthing marshalling points (Marshalling buses) is defined and installed to be used for independent connections to instrument devices.

3. Instrument earth buses are generally installed inside the control building where the instrumentation control are installed and centralized.

4. The metal clad body of the instrument panels, particularly those which accommodate the power supply line, should be connected to the electrical earth system.

5. Instrumentations installed inside the plant, shall be connected to the instrument earthing system via the shield wires of the corresponding instrument cables.

6. Instrument earth wells are installed adjacent to the control building.

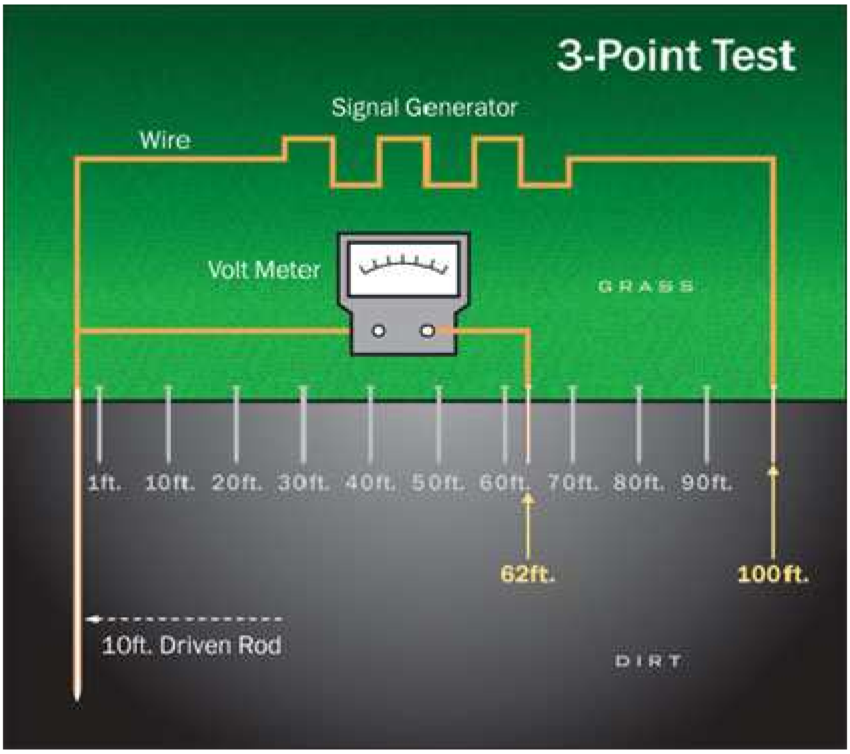
- **lightning earthing system**

How to do grounding system testing:

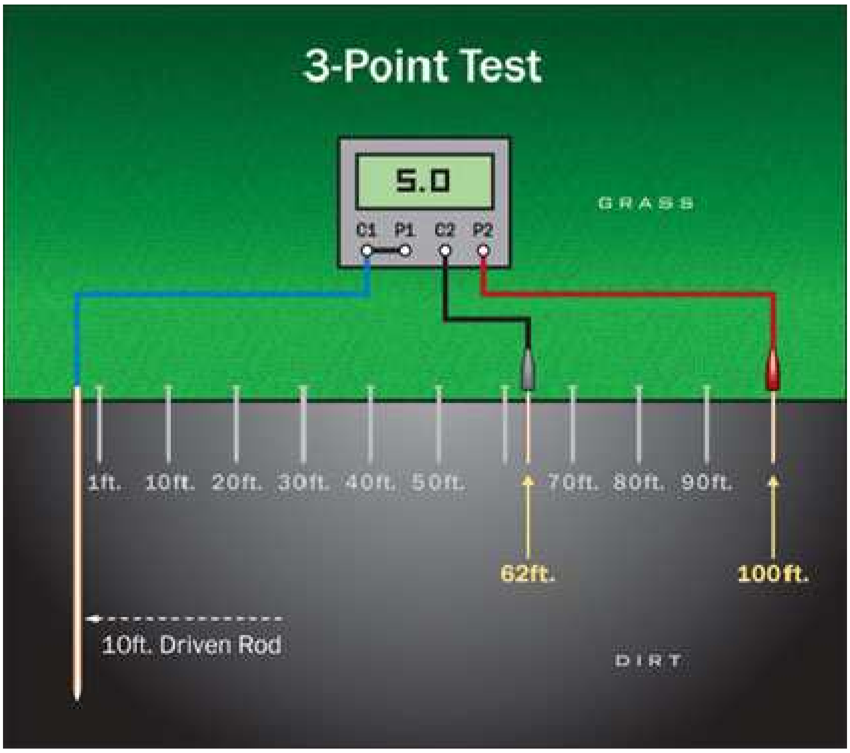
The measurement of ground resistance for an earth electrode system is very important. It should be done when the electrode is first installed, and then at periodic intervals thereafter. This ensures that the resistance-to-ground does not increase over time. There are two (2) methods for testing an existing earth-electrode system. The first is the 3-point or Fall-of- Potential method and the second is the Induced Frequency test or clamp-on method. The 3-point test requires complete isolation from the power utility. Not just power isolation, but also removal of any neutral or other such ground connections extending outside the grounding system. This test is the most suitable test for large grounding systems and is also suitable for small electrodes. The induced frequency test can be performed while power is on and actually requires the utility to be connected to the grounding system under test. This test is accurate only for small electrodes, as it uses frequencies in the kilo Hertz range, which see long conductors as inductive chokes and therefore do not reflect the 60 Hz resistance of the entire grounding system.

Fall-of-Potential Method or 3-Point Test

The 3-point or fall-of-potential method is used to measure the resistance-to-ground of existing grounding systems. The two primary requirements to successfully complete this test are the ability to isolate the grounding system from the utility neutral and knowledge of the diagonal length of the grounding system (i.e. a 10’ x 10’ grounding ring would have a 14’ diagonal length). In this test, a short probe, referred to as probe Z, is driven into the earth at a distance of ten times (10X) the diagonal length of the grounding system (rod X). A second probe (Y) is placed in-line at a distance from rod X equal to the diagonal length of the grounding system.



At this point, a known current is applied across X & Z, while the resulting voltage is measured across X & Y. Ohm's Law can then be applied (R=V/I) to calculate the measured resistance. Probe Y is then moved out to a distance of 2X the diagonal length of the grounding system, in-line with X & Z, to repeat the resistance measurement at the new interval. This will continue, moving probe Y out to 3X, 4X, ... 9X the diagonal length to complete the 3–point test with a total of nine (9) resistance measurements.

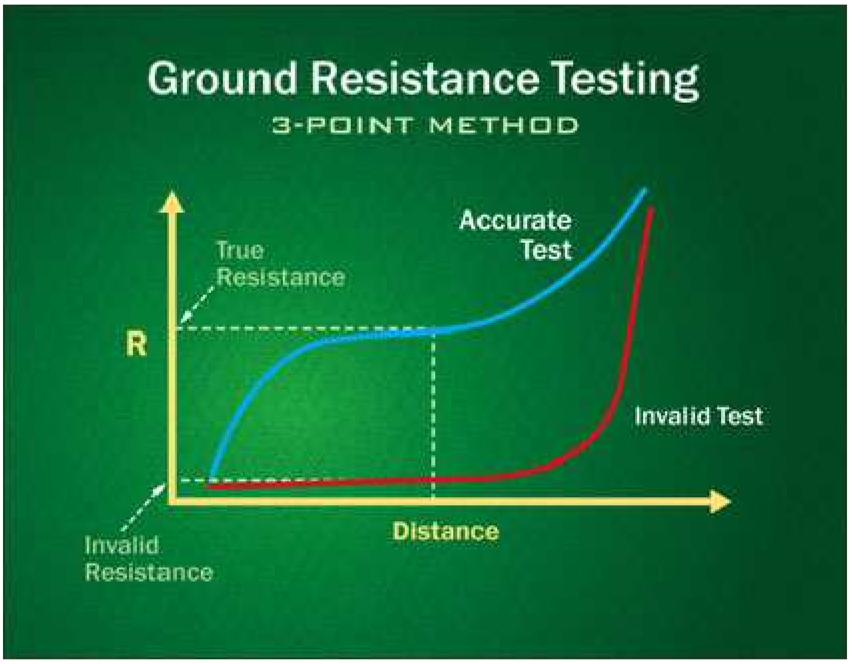


Graphing & Evaluation

The 3-point test is evaluated by plotting the results as data points with the distance from rod X along the X-axis and the resistance measurements along the Y-axis to develop a curve. Roughly midway between the center of the electrode under test and the probe Z, a plateau or "flat spot" should be found, as shown in the graph. The resistance of this plateau (actually, the resistance measured at the location 62% from the center of the electrode under test, if the soil is perfectly homogeneous) is the resistance-to-ground of the tested grounding system.

Invalid Tests

If no semblance of a plateau is found and the graph is observed to rise steadily the test is considered invalid. This can be due to the fact that probe Z was not placed far enough away from rod X, and can usually indicate that the diagonal length of the grounding system was not determined correctly. If the graph is observed to have a low plateau that extends the entire length and only rises at the last test point, then this also may be also considered invalid. This is because the utility or telecom neutral connection remains on the grounding system.



Induced Frequency Testing or Clamp-On Testing

The Induced Frequency testing or commonly called the "Clamp-On" test is one of the newest test methods for measuring the resistance-to-ground of a grounding system or electrode. This test uses a special transformer to induce an oscillating voltage (often 1.7 kHz) into the grounding system. Unlike the 3-

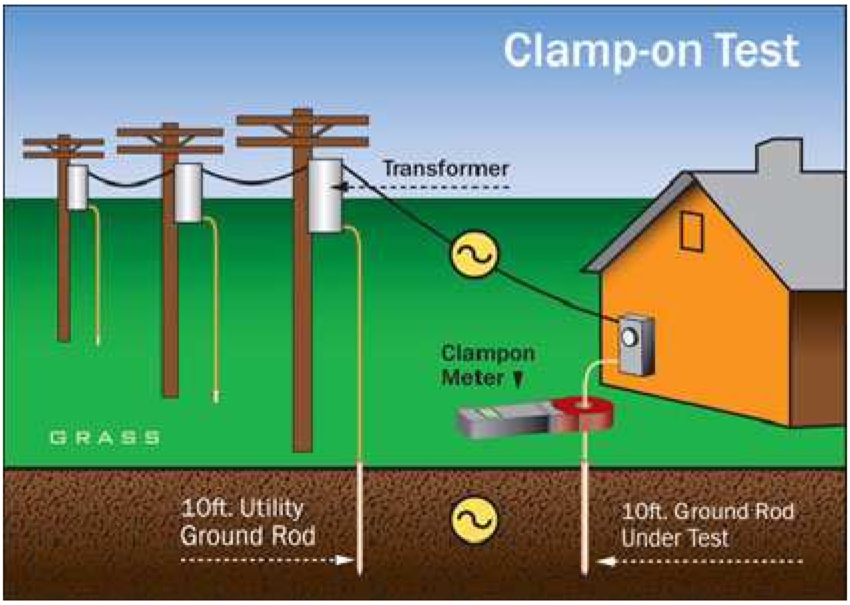
point Test which requires the grounding system to be completely disconnected and isolated before testing, this method requires that the grounding system under test be connected to the electric utilities (or other large grounding system such as from the telephone company) grounding system (typically via the neutral return wire) to provide the return path for the signal. This test is the only test that can be used on live or 'hot" systems. However, there are some limitations, primarily being:

1. The amount of amperage running through the tested system must be below the equipment manufacturer's limits.
2. The test signal must be injected at the proper location, so that the signal is forced through the grounding system and into the earth.
3. This instrument actually measures the sum of the resistance of the grounding system under test and the impedance of the utility neutral grounding, including the neutral wiring. Due to the high frequency used, the impedance of the neutral wiring is non-negligible and can be greater than the ground resistance of a very low resistance grounding system, which can therefore not be measured accurately.
4. The ground resistance of a large grounding system at 60 Hz can be significantly lower than at 1.7 kHz.

Many erroneous tests have been conducted where the technician only measured metallic loops and not the true resistance-to-ground of the grounding system. The veracity of the Induced Frequency Test has been questioned due to testing errors, however when properly applied to a small to medium sized, self-standing grounding system, this test is rapid and reasonably accurate.

Test Application

The proper use of this test method requires the utility neutral to be connected to a wye-type transformer. The oscillating voltage is induced into the grounding system at a point where it will be forced into the soil and return through the utility neutral. Extreme caution must be taken at this point as erroneous readings and mistakes are often made. The most common of these occur when clamping on or inducing the oscillating voltage into the grounding system at a point where a continuous metallic path exists back to the point of the test. This can result in a continuity test being performed rather than a ground resistance test.



Understanding the proper field application of this test is vital to obtaining accurate results. The induced frequency test can test grounding systems that are in use and does not require the interruption of service to take measurements.

Ground Resistance Monitoring

Ground resistance monitoring is the process of automated timed and/or continuous resistance-to ground measurement. These dedicated systems use the induced frequency test method to continuously monitor the performance of critical grounding systems. Some models may also provide automated data reporting. These new meters can measure resistance-to-ground and the current that flows on the grounding systems that are in use. Another benefit is that it does not require interruption of the electrical service to take these measurements.

Conclusions:

Earthing resistance and earth surface potential distribution are the main parameters characterizing electrical properties of the earthing system.

Electrical parameters of the earthing system depend on both soil properties and earth electrode geometry.

Soil properties are characterised by earth resistivity, which changes over a wide range from a few Wm up to few thousand Wm, depending on the type of ground and its structure, as well as its humidity. As a result, it is difficult to calculate an exact value of earthing resistance. All relationships describing earthing resistance

are derived with the assumption that the ground has a homogenous structure and constant resistivity.

Ideally, the earth surface potential should be flat in the area around the earth electrode. This is important for protection against electric shock, and is characterized by touch and step voltages. Rod electrodes have a most unfavourable surface potential distribution, while meshed electrodes have a much flatter distribution.

The behaviour of the earthing system for high transient currents should be considered. Very high current values diminish earthing resistance due to the strong electric field between the earth electrode and the soil, while fast current changes increase earthing impedance due to earth electrode inductance. The earthing impedance is, in this case, a superposition of both these events.

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