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IMPORTANCE CUM UNDERSTANDING EARTHING, GROUNDING AND NEUTRAL SYSTEMS IN ELECTRICAL TRANSMISSION NETWORK

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***Abstract*—**In this paper effort has been made to understand technical requirement, Design considerations understanding basic difference between neutral and grounding, also to understand practical applicability of earthing systems. Expanding transmission network, adding new generating stations, increasing load requirement with the development of any society or system are the symptoms of development. With increase in load demand, spreading network complexities also have impact on number and type of faults. Not only this with addition of transformers in spreader network there is increase in fault levels and accordingly it has become a great challenge for designers/manufacturers to design the equipment of high fault bearing capacity during faults. Outdoor ac substations, either conventional or gas-insulated, are covered in this paper. Distribution, transmission, and generating plant substations are also included. With proper caution, the methods described herein are also applicable to indoor portions of such substations, or to sub-stations that are wholly indoors. No attempt is made to cover the grounding problems peculiar to dc substations. A quantitative analysis of the effects of lightning surges is also beyond the scope of this paper.

***Keywords*—** Ground grids, grounding, substation earthing design, substation grounding, Earth Mat Design

I. INTRODUCTION

Expanding transmission network, adding new generating stations, increasing load requirement with the development of any society or system are the symptoms of development. With increase in load demand, spreading network complexities also have impact on number and type of faults. Not only this with addition of transformers in spreader network there is increase in fault levels and accordingly it has become a great challenge for designers/manufacturers to design the equipment of high fault bearing capacity during faults. In this paper effort has been made to understand technical requirement, Design considerations understanding basic difference between neutral and grounding, also to understand practical applicability of earth systems, in view of ROW and public awareness at a large.

II. STANDARDS APPLICABLE

1. Indian standards IS -3043-1987 – Reaffirmed in 2006.
2. Earthing (grounding) system according to IEC, BS-EN and IEEE standards

IEC Standard for Earthing: IEC Standard 60364 specifies a two letter codes to identify type of earthing. It also defines three families of earthing arrangements.

- The two letter code is based on source side – Device side earthing.
- The First Letter indicates how the earthing is done on source side (Generator / Transformer).
- The Second Letter indicates how the earthing is done on device side (place where electricity is consumed at customer premises).

The Letters used are as follows:

- TN-C-S
- TN-S: In this, separate conductors for Protective Earth (PE) and Neutral run from Consumer's electrical installation till the source. They are connected together only at the power source.

T – (French word "Terre" meaning Earth) – It means direct connection of a point to earth

I – It means that either no point is connected to Earth or it is connected via high impedance

N – It means that there is direct connection to neutral at the source of installation which is in turn connected to the ground.

Based on a combination of these three letters, there are three families of Earthing arrangements proposed by IEC as below:

- TN Network
- TT Network
- IT Network

TN Network: In TN type of earthing system, one of the points of the source side (Generator or Transformer) is connected to earth. This point is usually the star point in a three phase system. The body of the connected electrical device is

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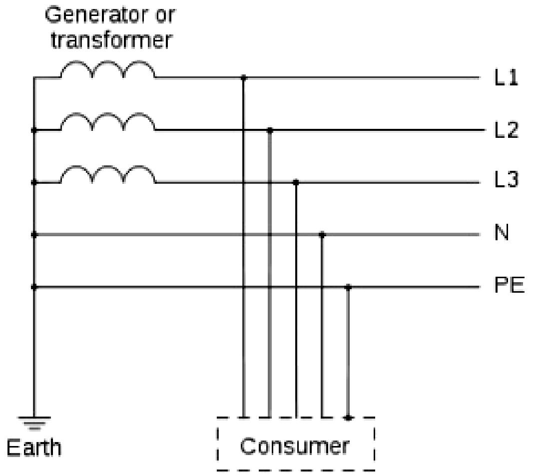


connected to earth via this earth point on the source side. See fig. below which depicts this:

PE – Acronym for "Protective Earth" – is the conductor that connects the exposed metallic parts of the consumer's electrical installation to the ground.

N –Also called Neutral. It is the conductor that connects Star point in a 3 phase system to the earth.

There are two types of TN networks as below:

TN-S In this a earth protective conductor with no distributed throughout the system.

TN-C In this neutral and protective conductor functions combine throughout system.

TN-C-S is various combinations in Single and three phase systems.

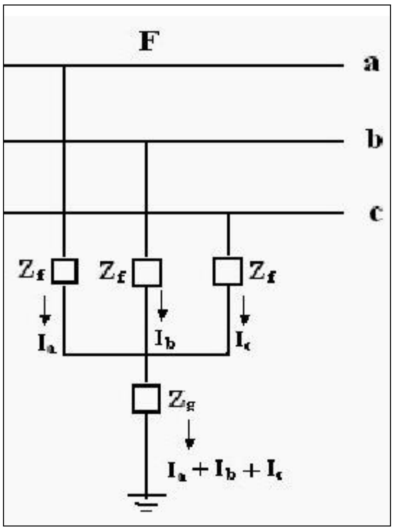
III. Understanding Earthing, Grounding and Neutral

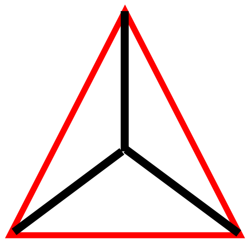
Grounding is connecting body of live equipment to allow leakage/spill current to flow to be absorbed by earth. This spill current is due to following reasons

1. Leakage due to improper insulation.
2. Eddy currents in body
3. Poor quality of Insulating media
4. Over Voltages
5. Ageing of insulating material
6. Moisture in Insulating material
7. Over heating in long run
8. Basic aim is to provide grounding is the safety of operating personnel/Human lives i.e. save human life from danger of electrical shock or death. Thus provide low resistance path for the leakage/spill current to flow so that it will not endanger the user

Earthing is allowing return path to leakage/spill current by earth or soil. This point or return flow of current is of same capacity as of main wire/conductor, however potential is zero.

Neutral; Neutral is the star point of a 3 phase system and is earthed to make it earth point of star point to zero. When it is earthed it allows unbalanced/unwanted current to flow or absorbed by earth. This makes the system stable. If it is kept open or away from earth or not earthed, then voltage between the phases remains unbalance or unequal, hence load sharing





is abnormal on primary source. It may result into tripping from source due to unbalance load. In case of single phase system, it is a wire or conductor carrying normal cum return current to source or earth and It also completes the circuit. From the figures below let us understand earthed and unearthed neutral. Under idle conditions Current through Neutral should be zero, but due to load unbalancing and leakage due to weak insulation etc current through neutral wire exists and when it crosses the limits, protective equipment is either to make a alarm or trip or isolate the load from system to avoid disturbance in the system.

IV. Purpose of Earthing

A. Safety for Human life / Building /Equipment

- To save human life from danger of electrical shock or death by blowing a fuse i.e. to provide an alternative path for the fault current to flow so that it will not endanger the user
- To protect buildings, machinery & appliances under fault conditions.
- To ensure that all exposed conductive parts do not achieve a dangerous potential.
- To provide safe path to dissipate lightning and short circuit currents.
- To provide stable platform for operation of sensitive electronic equipment i.e. to maintain the voltage at any part of an electrical system at a known value so as to prevent over current or excessive voltage on the appliances or equipment.

B. Over voltage protection

Lightning, line surges or unintentional contact with higher voltage lines can cause dangerously high voltage surges in the electrical distribution system. Earthing provides an alternative path around the electrical system to minimize damages in the System.

C. Voltage stabilization

There are many sources of electricity. Every transformer can be considered a separate source. If there were not a common

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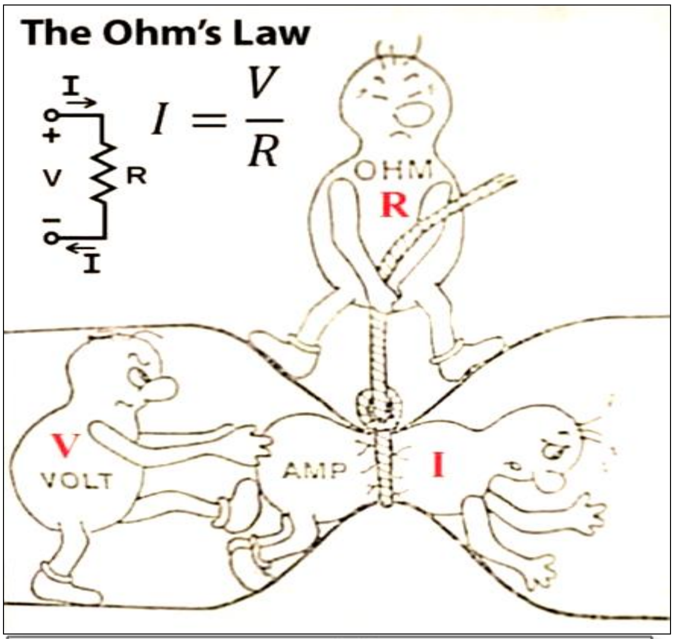
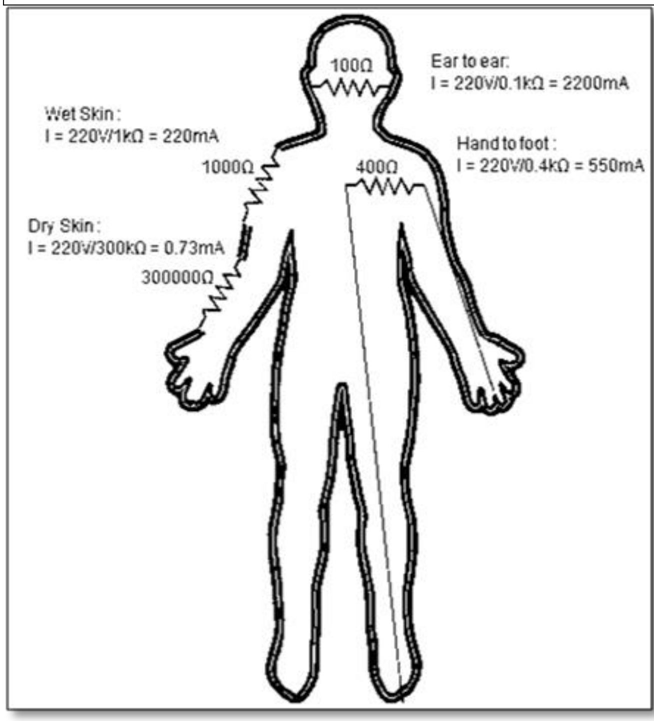


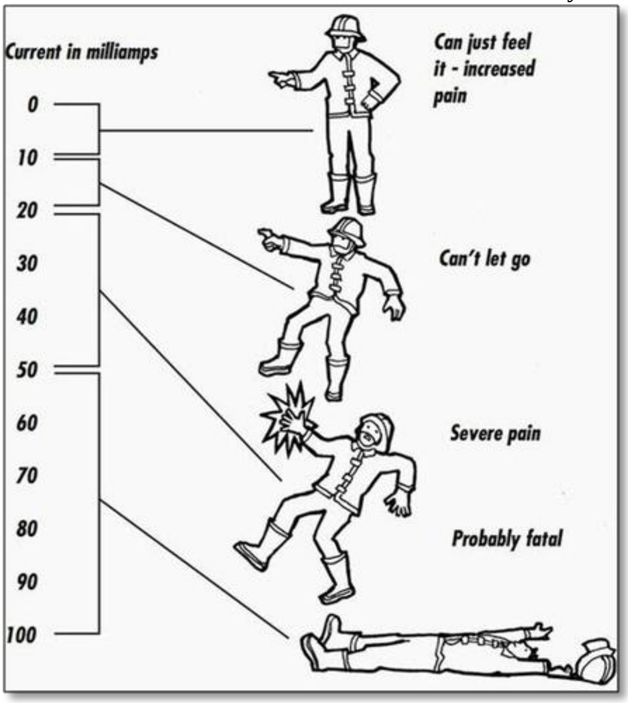


reference point for all these voltage sources, also known as floating neutral, it would be extremely difficult to calculate their relationships to each other.

The earth is the most omnipresent conductive surface, and so it was adopted in the very beginning of electrical distribution systems as a nearly universal standard for all electric systems.

Safe limit of leakage/spill current through human body

- The Physiological Effects of Electric Shock: It is the voltage to make current flow, Effects of an electric current passing through the vital parts of a human body depend on the duration, magnitude, and frequency of this current. The most dangerous consequence of such an exposure is a heart condition known as ventricular fibrillation, resulting in immediate arrest of blood circulation. It can be very well



expressed or understood by the exhibit below Electric shock is relatively more severe as the current rises, as shown in figure above.
- Effect of frequency: Humans are very vulnerable to the effects current at frequencies of 50 Hz or 60 Hz. Currents of approximately 0.1 A can be lethal. Research indicates that the human body can tolerate a slightly higher 25 Hz current and approximately five times higher direct current. At frequencies of 3000–10 000 Hz, even higher currents can be tolerated. In some cases the human body is able to tolerate very high currents due to lightning surges. The International Electro technical Commission provides curves for the tolerable body current as a function of frequency and for capacitive discharge currents [IEC 60479-2 (1987-03)].
- Effect of magnitude and duration: The most common physiological effects of electric current on the body, stated in order of increasing current magnitude, are threshold perception, muscular contraction, unconsciousness, fibrillation of the heart, respiratory nerve blockage, and burning. Current of 1 mAmp is generally recognized as the threshold of perception; that is, the current magnitude at which a person is just able to detect a slight tingling sensation in his hands or fingertips caused by the passing current. Currents of 1–6 mA, often termed let-go currents, though unpleasant to sustain, generally do not impair the ability of a person holding an energized object to control his muscles and release it. In the 9–25 mA range, currents may be painful and can make it difficult or impossible to release energized objects grasped by the hand. For still higher currents muscular contractions could make breathing difficult. These effects are not permanent and disappear when the current is interrupted, unless the

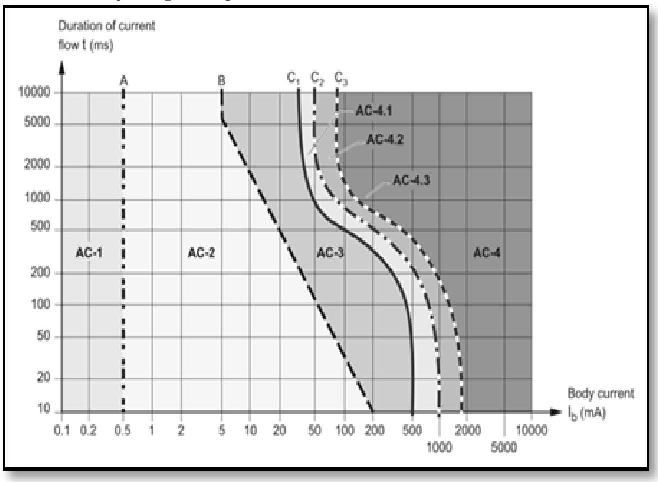
contraction is very severe and breathing is stopped for minutes rather than seconds. It is not until current magnitudes in the range of 60–100 mA are reached that ventricular fibrillation, stoppage of the heart, or inhibition of respiration might occur and cause injury or death. A person trained in cardiopulmonary resuscitation (CPR) should administer CPR until the victim can be treated at a medical facility.

Hence, this guide emphasizes the importance of the fibrillation threshold. If shock currents can be kept below this value by a carefully designed grounding system, injury or death may be avoided.

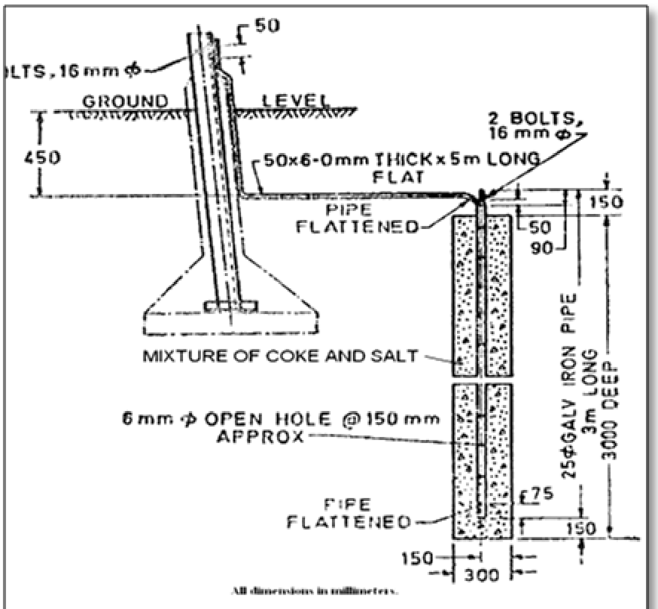
Above 200 milliamps, the muscular contractions are so severe that the heart is forcibly clamped during the shock. This clamping protects the heart from going into ventricular fibrillation and the victim's chances for survival are good.

Resistance of the human body: For dc and 50 Hz or 60 Hz ac currents, the human body can be approximated by a resistance. The current path typically considered is from one hand to both feet, or from one foot to the other one. The internal resistance of the body is approximately 300 Ω, whereas values of body resistance including skin range from 500 Ω to 3000 Ω. The human body resistance is decreased by damage or puncture of the skin at the point of contact. It is stated that “Low Voltage is more dangerous than high voltage” which is explained as -It is common knowledge that victims of high-voltage shock usually respond to artificial respiration more readily that the victims of low-voltage shock. The reason may be the merciful clamping of the heart, owing to the high current densities associated with high voltages. However, lest these details be misinterpreted, the only reasonable conclusion that can be drawn is that 75 volts are just as lethal as 750 volts.

IEC – 60345 and further related standards like 61140, 61008, 61009. 60947 and in particular 60479-1-2016 define four zones of current magnitudes/time path physical effects on human body as per fig. below



AC-1 is imperceptible AC-2 is Perceptible
AC-3 is Reversible Muscular Contraction
AC-4 is Irreversible Muscular Contraction
AC-1,2,3,4 further describes possibilities of Heart fibrillation.



TYPICAL EXAMPLE OF PIPE TYPE EARTHING

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V. Type of Earthing

A. *Pipe/ Plate type earthing*

In pipe type earthing each leg of transmission tower is connected to earthing electrode through a galvanised flat strip. One leg is connected to a pipe away from tower around 3500 mm to 5000 mm towards farmer/open field. Pipe is perforated by around 5 mm holes and grouted by mix of Charcoal and salt. Very purpose of salt is to absorb moisture from soil and charcoal keeps/retains moisture. This attains resistance of soil to a value as low as possible.

In this type GI or Copper Plate is buried in ground to a depth around 3000mm. Connected to tower leg by 50x6mm GI flat or 3.14mm GI wire. The excavated pit is back filled with a mixture of salt and charcoal. Alternatively it may be in layers also. Size of plate may be like 600mmx 600mm x 12mm (Cast iron), 600mm x 600mm x 6mm (GI) or 600mmx 600mm x 3mm (Copper).

Use of Common Salt (NaCl) in Earthing: Although Indian Standard of earthing advises for mixing od common salt with charcoal in earthing. But in the opinion of authors it should be avoided as common salt eats away IRON/GI/COPPER with passage of time as a result very purpose is defeated.

NaCl + H2O + C = NaOh +HCl + COh

HCL along with other chemicals present in soil eats away.

Instead Bentonite clay may be used, which does not react and absorbs/retains moisture for long run.

B. *Counter Poise Earthing*

Counter poise earthing is implied on the locations where soil resistivity is quite high ie hard cum soft rocks, hilly terrains and to obtain required value GI Wire/ Flats are connected cum taken in all directions diagonally away from each other at least

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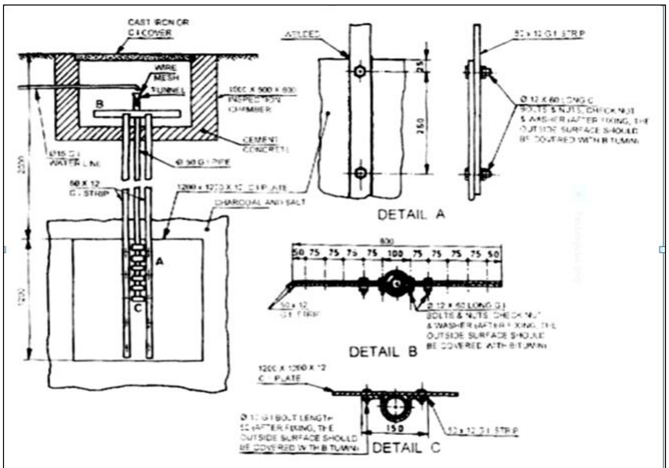
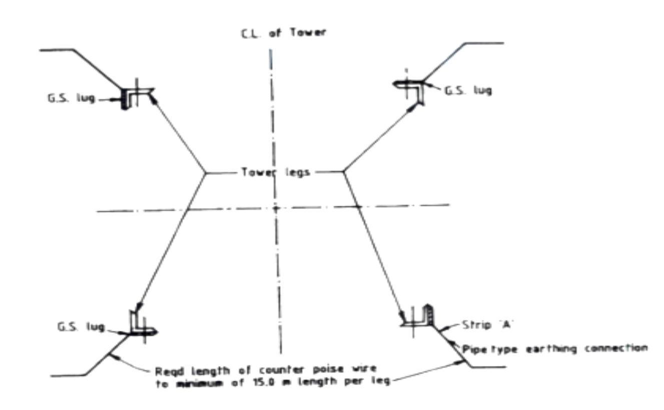


15A Earthing with G1 Plate
All dimensions in millimetres

Typical Sketch of Counter Poise Type Earthing



50 meters in length each, all the four legs are also connected to each other, this also makes more comfortable to reduce Earth value. It is buried in ground 300mm x 300 to 500 mm as per sketch below. It is back filled with soft borrowed earth. Since it GI wire/Flat is buried around 300 to 500mm below existing ground level, it is practically seen that with passage of time and due to regular rains, habitants take away wire/flat for their own use to handle cattle's. Hence to avoid theft, Back filling should be covered with Soft PCC up to 75mm thick.

C. Hard/Dry Fissured Rock Conditions

Locations where low resistance value is not achievable, there counter poise earthing is adopted. In this type of earthing, GI wire of min. 50 meters length of 7/3.14mm is laid across corners. It is buried in ground to min. Depth of 300mm, back filled by borrowed soft earth. GI wire is soldierly connected to tower leg by suitable size of lug. Also it is preferable to connect all the four legs at ground level with each other. More number of parallel paths, low resistance is achieved.

VI. Concept of Earth Mat:

Special earthing requirements for Grid stations where voltage levels are high, Earth mats are provided for user safety and are discussed as under:

Basic aspects of grid design: Conceptual analysis of a grid system usually starts with inspection of the substation layout plan, showing all major equipment and structures. To establish the basic ideas and concepts, the following points may serve as guidelines for starting a typical grounding grid design:

a) A continuous conductor loop should surround the perimeter to enclose as much area as practical. This measure helps to avoid high current concentration and, hence, high gradients both in the grid area and near the projecting cable ends. Enclosing more area also reduces the resistance of the grounding grid.

b) Within the loop, conductors are typically laid in parallel lines and, where practical, along the structures or rows of equipment to provide for short ground connections.

c) A typical grid system for a substation may include 4/0 bare conductors buried 0.3–0.5 m (12–18 in) below, spaced 3–7 m (10–20 ft) apart, in a grid pattern. At cross-connections, the conductors would be securely bonded together. Ground rods may be at the grid corners and at junction points along the perimeter. Ground rods may also be installed at major equipment, especially near surge arresters. In multilayer or high resistivity soils, it might be useful to use longer rods or rods installed at additional junction points.

d) This grid system would be extended over the entire substation switchyard and often beyond the fence line. Multiple ground leads or larger sized conductors would be used where high concentrations of current may occur, such as at a neutral-to-ground connection of generators, capacitor banks, or transformers.

e) The ratio of the sides of the grid meshes usually is from 1:1 to 1:3, unless a precise (computer-aided) analysis warrants more extreme values. Frequent cross-connections have a relatively small effect on lowering the resistance of a grid. Their primary role is to assure adequate control of the surface potentials. The cross-connections are also useful in securing multiple paths for the fault current, minimizing the voltage drop in the grid itself, and providing a certain measure of redundancy in the case of a conductor failure.

Tolerable Step and Touch Potential

The tolerable touch and step potential gives us a fare idea of maximum rise of potential at any point within station up to which the current levels through body of user / operator are below danger of any fatal accident and is given by following formulas

$$E_{step\,70} = (1000 + 6C_S\,\rho_S)\frac{0.157}{\sqrt{t_S}} \qquad (1)$$

$$E_{touch\,70} = (1000 + 1.5C_S\,\rho_S \qquad (2)$$

In all the above situations for step, touch, and transferred voltage, the actual voltage potential encountered by the person involved is related to the ground potential rise of the grounding system above remote earth. This fact stresses the importance of keeping that value as low as possible. Ground potential rise is the maximum electrical potential that a substation grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. This voltage, GPR, is equal to the maximum grid current times the grid resistance:

$$V_{GPR} = I_G\,Rg \qquad (3)$$

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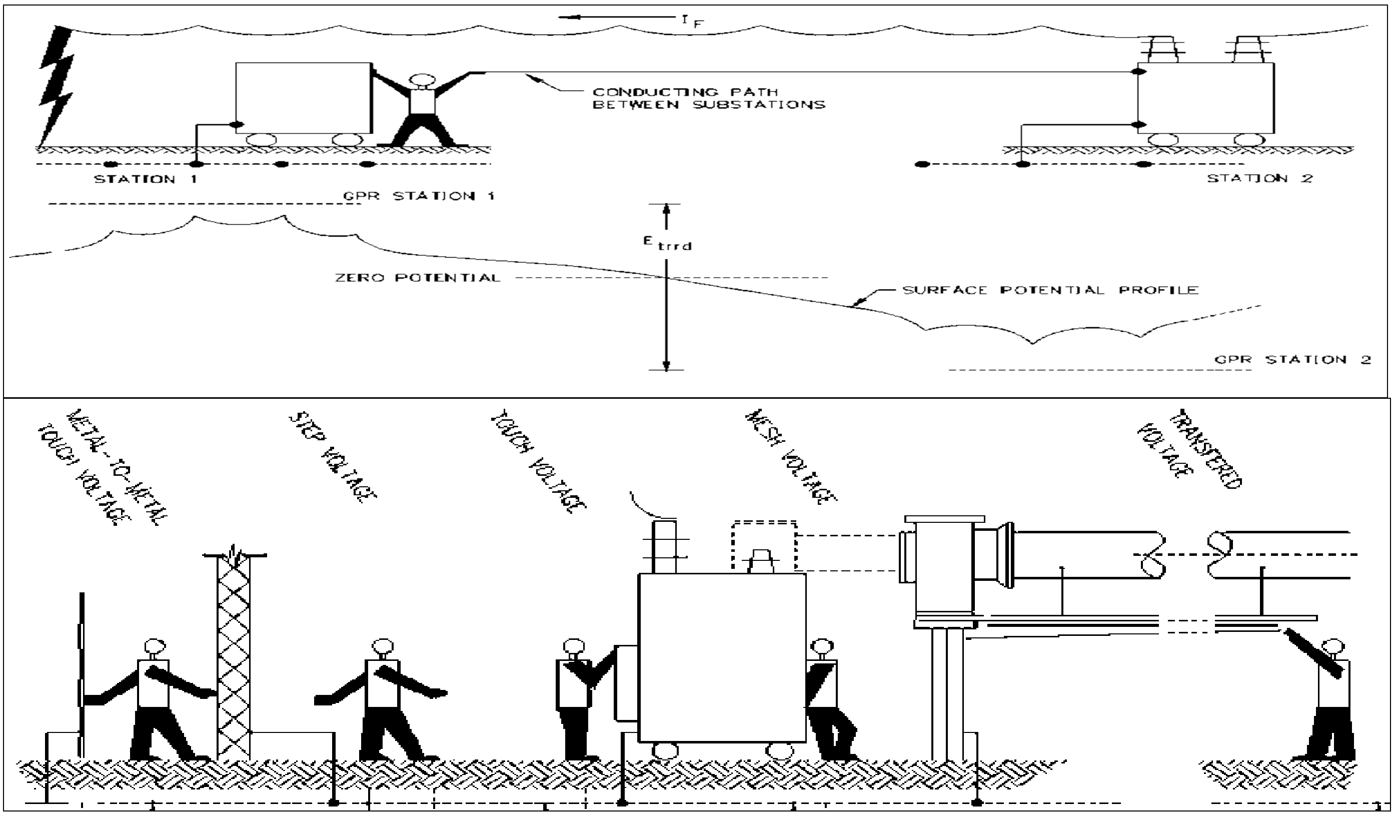


VII. Special Danger Points

A. Substation Fence Grounding

The grounding of the substation fence is critical because the fence is generally accessible to the public. The substation grounding design should be such that the touch potential on both sides of the fence is within the calculated tolerable limit of touch potential. The substation fence should be connected to the main ground grid by means of an outer grid conductor installed a minimum of 0.91 meter (3 feet) (approximately one arm's length) outside the substation fence. The gateposts should be securely bonded to the adjacent fence. It is recommended that all gates swing inward and be designed and installed to prevent an outward swing. If gates are installed with an outward swing, then the ground grid should extend a minimum of 0.91 meter (3 feet) past the maximum swing of the gate. The reasons to extend the ground grid to cover the swing of the gate are the same as the reason to install a ground conductor 0.91 meter (3 feet) outside the fence. The voltage above remote earth decreases rapidly as one leaves the substation grounding area. For example, if a person standing outside the substation grounding grid touches a fence or outward-swung gate under substation fault conditions, the resulting potential difference could be large enough to pose a serious danger.

B. Operating Handles

Equipment operating handles are a special circumstance because of the higher probability for coincidence of adverse factors, namely, the presence of a person contacting grounded equipment and performing an operation that can lead to electrical breakdown. If the grounding system is designed conservatively for safe mesh potentials, then the operator should not be exposed to unsafe voltages. However, because of the uncertainty inherent in substation grounding design, a metal grounding platform (mat), connected to the operating handle should be placed where the operator should stand on it to operate the device regardless of whether the operating handle is insulated. Considerations involved in the switch grounding platform ground conductor include the following:

1. Proper grounding calculations and grid design should result in acceptable touch and step potential voltages without the additional grounding platform grounding. However, since the operation of the switch places the operator directly at risk when a substation fault occurs, additional precautions are needed. This includes adding switch grounding platforms and a 3-to 6-inch layer of clean crushed rock that covers the entire area inside the substation fence and extends 3 to 4 feet outside the substation fence to reduce the risk of electric shock.
2. Switch grounding platform grounding is added to minimize the voltage between the switch operator's hands and feet in the event of a fault at the switch during manual operation.
3. The basic methods to minimize the hand-to-foot voltage at the switch handle include the:
   a. Minimize the current that flows in the conductor that connects the equipment grasped by the hand and the surface that is stood on.
   b. Minimize the resistance of the electrical connection between the hands and feet. The grounding platform should be connected to the operating handle by a copper cable that connects to the operating handle and the grounding platform as shown in Figure

C. Metallic Cable Sheaths

Metallic cable sheaths in power cable have to be effectively grounded to prevent dangerous voltages resulting from insulation failure, electrostatic and electromagnetic induction, and flow of fault current in the sheath, and voltage rise during fault current flow in the substation ground system to which the sheaths are connected. Cable sheaths should be grounded at two or more locations: at cable terminations and at splices and taps. Control cable shields are not intended to carry significant current and thus should only be grounded at one end. Where any cable sheath may be exposed to excessive ground current flow, a parallel ground cable should be run and connected to both ends.

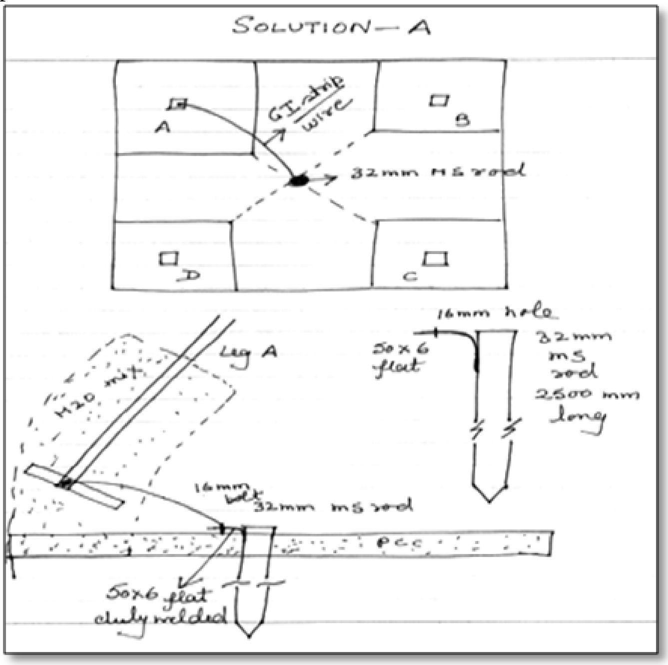
D. Surge Arrester Grounding

Surge arresters are designed to pass surge energy from lightning and switching transients to ground and so are frequently subjected to abnormal current flow to ground. They have to be reliably grounded to ensure protection of the equipment they are protecting and to minimize high potential gradients during operation. The surge arrester grounds should be connected as close as possible to the ground terminals of the apparatus to be protected and have as short and direct a path to earth as practical. Arrester leads should be as free from sharp bends as practical. The tanks of transformers and steel or aluminium structures may be considered as the path for grounding arresters, provided effective connections can be made and secure multiple paths are available. Where there can be any question regarding the adequacy of these paths, it is recommended that a separate copper conductor(s) be used between the arrester ground terminal and the substation grounding grid.

VIII. Earthing as Found in Field due to ROW and Public Awareness

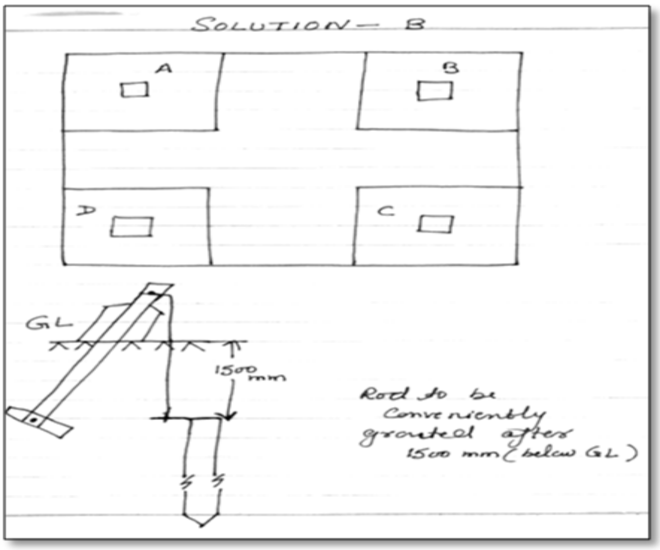
In the current years it is seen that due to urbanisation there is huge increase in land cost and public at large don't allow transmission companies to lay or pass transmission line through their fields as it drastically reduces cost of land by virtue of corridor occupied by the transmission companies and due to IS guidelines. For example – a) 400kv D/C occupies 23 meters corridor on both sides, b) 765/800kv D/C occupies 75 meters corridor on both sides. This does not allow land owners to construct high rise structure to be constructed along the line, thus results in limitations of land utilisation. Transmission utilities compensates to the owner for tower foundation/ location and not for corridor in spite of Supreme Court ruling. Still it is not sufficient as amount paid is one time at the instant.

Besides refer diagram, earthing flat is laid away from tower around 3.5 mtrs away for which it is not compensated. Farmers dig out the earthing flat and remove it as it is in convenient to him for ploughing in field and using hi-tech equipments. It is removed without understanding its complicacy towards threat to its life. However it is the prime responsibility of Transmission Company to look after it. Below are the exhibits which are self explanatory. Earthing as per normal standards is as below:



IX. Earthing for Other Structures like Telecom Towers, High Rise Buildings and Domestic and Industrial Installations

Installations which are subject to frequent lightening strikes also require additional protection. In this type of earthing a GI strip/copper strip is laid from top of building and connected to earth. A sharp edge spike is erected on top. Basically sharp edges attract electrical lightening strikes and discharges to



earth. Latest in practise is use of Domestic lightening arrestors having following characteristics (Branded as IONIFLASH MACH by Parc Ester Tehnopole, France)

- Double security due to spark gaps having operating range from 0 to 10 MHZ.
- Low carbon impact 33 kg eq. CO2/unit
- Reliable in extreme climatic conditions
- Confirming to International standards.
- Life time 25 years
- Made up of stainless steel of 316L, protective fairing.
- Arrestor provided with lightening counter for record of strikes.
- Attracts strikes to avert faults and continuous to monitor atmosphere.

This type of arrestors is recommended for use on buildings of very high importance like EIFFEL tower, Paris, Qutab Minar, NewDelhi etc. Depending upon intensity different versions has been developed.

Spike type earthing is totally free from carbon component and recommended for installations on telecom towers, structures of low height etc.However counter can be installed to monitor frequency cum number of strikes. In case strikes are frequent, decision can taken to install other versions of arrestors (as above) for more to be on safer side.

ABBREVIATIONS

MIET –Model Institute of Engg. And Technology.
D/C – Double Circuit
IS – Indian Standards
BS – British Standards
ROW – Right of way
IEC – International electricity Code

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