American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Design Consideration of Electrical Earthing System for High-rise Building

Lai Lai Win[a]*, Khin Thuzar Soe[b]

[a,b]*Department of Electrical Power Engineering, Mandalay Technological University Mandalay, Myanmar*
[a]*Email: lailaiwinpku9@gmail.com*

Abstract

Electricity is dangerous and required proper grounding to prevent unwanted voltage from passing through personnel, critical equipment and other nearby metallic objects. Soil resistivity directly affects the design of a grounding system. When designing an extensive grounding system it is advisable to locate the area of lowest soil resistivity in order to achieve the economical grounding installation. Neither very low resistivity nor very high resistivity is safe for human safety under power system fault conditions. The earthing or grounding is mainly affected by soil resistivity. This study will briefly explain the earthing of Lightning Protection System for 11th storeyed building. The soil type of this building is loam and soil resitivity is 150 Ωm.

Keywords: Electrical earthing system; Soil resistivity; Safety; Earth electrode resistance; Effective grounding.

1. Introduction

Electrical installation in high rise building become important and it is necessary to use modern electrical installation methods. Power system earthing is very important, particularly since a large majority of faults involve ground or are caused by thunderstorm/lightning strikes. The terms earthing and grounding have the same meaning and it is a mean of making a connection between the equipment and the general mass of the earth. The principal purpose of earthing is to minimize potential transient overvoltage, in compliance with standards for personnel safety requirements and to assist in the rapid detection and isolation of the fault areas. Grounding connection is accomplished by driving ground electrode into several places of the earth. The installation of an earth electrode is an important factor in achieving a satisfactory earthing system.

2. Main electrical system

Electrical installations are to be provided essentially in high-rise buildings incorporating all by laws and codes etc. It is divided in the systems such as Power house, Power supply distribution system, Lighting system, Air conditioning system, Lift, Lightning Protection System, Fire protection system, Water supply system and Earthing system. Electrical design and installation professionals need to consider several different building grounding systems for any building or structure on which they may work. All earthing systems shall comply with Local Regulation. The object of protective earthing is to prevent excessive shock-hazard voltage from persisting on non-live accessible conductive parts of apparatus. It is achieved by connecting the non-live parts to earthed electrodes or earthed parts [3].

3. Earthing system

The earthing system consists of conductive material above ground, and metal electrodes within the soil and the surrounding soil itself. Each of these will contribute towards the overall resistance value. The contact resistance of joints must be kept to a minimum by using appropriate materials and installation practice. In a new installation, the most significant contact resistance is likely to be at the interface between electrodes and soil [1].

The soil immediately adjacent to the rod will influence its contact resistance, which will form an important part of the overall resistance. If the natural soil is of low resistivity, but the rod is surrounded by soil which has dried out and has a high resistivity.

The rod will have a high resistance dictated by the nearby high resistivity layer. A rod installed in a cavity in rock may be surrounded by low resistivity soil. It will still have a high resistance.

The main earthing system of an electrical installation must consist of:

a) An earth electrode;

b) A main earthing wire;

c) An earth bar for the connection of the main earthing wire, protective earthing wires and/or bonding wires within the installation

d) A removable link, which effectively disconnects the neutral bar from the earth bar.

The main earthing wire termination must be readily accessible at the earth electrode. The main earthing wire connection must be mechanically and electrically sound, be protected against damage, corrosion, and vibration, not place any strain on the various parts of the connection, not damage the wire or fittings and be secured at the earth electrode [2].

3.1. Earth electrode

An earth electrode is a metal plate, metal pipe or metal conductors electrically connected to the earth. The materials generally used for earth electrodes are made of copper, aluminum, mild steel and galvanized iron in order of preference. The factors that influence the earthing resistance of an electrode or group of electrodes includes the composition of the soil in the immediate neighbour, the temperature of the soil, the moisture content of the soil and the depth of the electrode. Earth electrode either in the form of pipe electrode or plate electrode should be provided at all premises for providing an earth system. Under ordinary conditions of soil, use of copper, iron or mild steel electrodes is recommended. To obtain low overall resistance the current density should be as low as possible in the medium adjacent to the electrodes [5].

3.2. Types of earth electrodes

Earth electrodes are made by a number of materials which include cast iron, steel, copper and stainless steel. They may be in the form of plates, tubes, rods or strips. The most common material is copper. It has good conductivity, is corrosion resistant to most of the chemicals that exist in soil and it is a material that is easily worked. The most versatile type of earth electrode is the driven rod. This may be of copper, copper clad steel, galvanized steel or austenitic iron. Standard sizes are 1.0–2.5 m in length and 16 mm in diameter. The rods are extensible and are joined together by either an internal stud or an external sleeve. Copper clad steel rods are more suitable for driving and will penetrate most types of soil to a depth of 10–15 m. When using copper clad steel rods to ensure that the copper is actually bonded to the steel.

3.3. Soil resistivity

Soil resistivity and earthing system plays a key role in generation, transmission and distribution for safe and proper operation of any electric power system. Soil resistivity directly affects the design of earthing system. When designing an extensive earthing system it is advisable to locate the area of lowest soil resistivity in order to achieve the economical grounding installation [6].

$$R = \frac{\rho \times L}{A} \qquad (1)$$

where,

ρ = Resistivity of the conductor material (Ω-m)

L = Length of the conductor (m)

A = Cross sectional Area (m^2)

When designing an earthing system to meet safety and reliability criteria, an accurate resistivity model of the soil is required.

Factors that affect resistivity may be summarized as

1) Type of earth (eg, clay, loam, sandstone, granite).

1) Stratification; layers of different types of soil (eg, loam backfill on a clay base)

2) Moisture content; resistivity may fall rapidly as the moisture content is increased, however, after a value of about 20% the rate of decrease is much less.
3) Temperature; above freezing point, the effect on earth resistivity is practically negligible.
4) Chemical composition and concentration of dissolved salt
5) Presence of metal and concrete pipes, tanks, large slabs, cable ducts, rail tracks, metal pipes

Table 1: Resistivity values for several types of soils and water [4]

Type of Soil or Water	Typical Resistivity (Ωm)	Usual Limit (Ωm)
Sea water	2	0.1 to 10
Clay	40	8 to 70
Ground well & spring water	50	10 to 150
Clay& sand mixtures	100	4 to 300
Shale, slates, sandstone	120	10 to 100
Peat, loam & mud	150	5 to 250
Lake & brook water	250	100 to 400
Sand	2000	200 to 3000
Moraine gravel	3000	40 to 10000
Ridge gravel	15000	3000 to 30000
Solid granite	25000	10000 to 50000
Ice	100000	10000 to 100000

It is important to know a little more about the electrical properties of soil because it is so critical to the eventual resistance value of the rod or electrode system. Some typical resistivity values of soils are shown in Table 1.

The two main factors which influence soil resistivity are the porosity of the material and the water content. Porosity is a term which describes the size and number of voids within the material, which is related to its particle size and the pore diameter. It varies between 80 and 90% in the silt of lakes, from 30 to 40% in sands and unconsolidated clay and by a few per cent in consolidated limestone.

3.4. Earth Resistance of an electrode

Soil exhibits a resistance to the flow an electrical current and is not an “ideal” conductor. There will always be some resistance (can never be zero) between the earth electrode and “true Earth”. The resistance between the earth electrode and “true Earth” is known as the Earth Resistance of an electrode and it will depend on the soil resistivity, the type and size of the electrode and the depth to which it is buried.

If the soil resistivity is known using the 4-point method, the Earth Resistance of an electrode configuration may be calculated for the various types and sizes of the earth electrode used [7].

3.5. Rods driven vertically into the ground

The Earth Resistance (Rg) of a single spike, of diameter (d) and driven length (L) driven vertically into the soil of resistivity (ρ), can be calculated as follows:

$$R = \frac{\rho}{2\pi L} \; \log e(\frac{8L}{d}) - 1 \qquad (2)$$

where,

ρ= Soil Resistivity in Ωm

L=Buried Length of the electrode in m

d=Diameter of the electrode in m

3.6. Low resistivity materials

Adding low resistivity materials to the soil in the immediate vicinity of the earthing system or rod will have a dramatic effect on reducing its resistance. This is not normally true. There is always a contact resistance between the electrode and the soil. The gap between the rod surface and the compressed soil to its side will introduce a large contact resistance which will be apparent when testing the resistance of the rod.

The resistance falls over time as the soil becomes consolidated around the rod due to rainfall. This is to add a low resistivity material, such as bentonite slurry, as the rod is driven in. Bentonite is a fine, naturally occurring clay powder. It is mixed with water to form slurry. As the earth electrode is driven into the soil the bentonite is drawn down by the rod. By continuously pouring the mixture into the hole as driving proceeds, a sufficient quantity is dragged down to fill most of the voids around the rod and lower its resistance. It has a low resistivity and does not dry out under normal conditions. Installing the rods a little deeper can achieve a better result than using low resistivity material [8]

3.7. Chemical treatment

Treating the soil surrounding the earth electrode with chemicals normally only provides a temporary improvement as the chemicals will usually be dispersed over time by rainwater. One must ensure that the chemicals used do not have any corrosive effect on the electrode material. Low resistivity material was then introduced into the cavity and fissures and the earth electrode installed within it.

This forms a relatively large electrode at a lower cost than drilling. Marconite, concrete or similar materials are also now increasingly used around structures where these are to be used as part of the earthing system [8].

4. Earthing of lightning protection system

The reliable performance of the entire lightning protection system is dependent upon an effective earthing system. Consideration must be given to:

1) Providing a low impedance network to dissipate the fast-rising lightning impulse
2) Minimization of touch and step potential hazards
3) Long term performance of the system

While the LPS earthing system is normally installed and tested as a dedicated system, it is required by most codes that the lightning protection earthing system be interconnected with other earthing systems.

Table 2: Earthing material requirements [6]

Material	Application	Requirements
Copper or tin plated copper	Conductor	50 mm^2 solid
	Conductor	50 mm^2 stranded conductor (minimum strand size 1.7 mm diameter)
	Conductor	50 mm^2 solid tape (minimum thickness 2 mm)
	Rod	25 mm solid copper rod
	Rod	20 mm pipe with 2 mm wall thickness
	Plate	Plate 500 x 500 mm, 2 mm minimum thickness
	Plate	4.8 m lattice grid – 600 x 600 mm lattice made from 25 x 2 mm minimum material
Copper bonded steel	Rod	14 mm with 250 µm minimum copper coating- intrinsically bonded

4.1. Earthing resistance requirement

The general requirement is that the lightning protection earthing system must have a resistance of less than 10 ohms. Design details are given by two methods:

1) Type A – vertical and/or horizontal electrodes installed outside the structure footprint

2) Type B – ring electrode installed outside the structure footprint (counterpoise), or natural earth electrode within footprint (e.g. footing reinforcing)

These methods have the advantage that if the total electrode length requirements are met, then the earthing is in accordance with the minimum requirements even if the measured resistance is not less than 10 ohms.

Type B is recommended for bare solid rock and for structures with extensive electronic systems or great risk of fire. Type B is preferential from the point of view of providing equipotential bonding between the down conductors and providing better potential control in the vicinity of conductive building walls. Note that the electrode applies to horizontal or vertical conductors, rods, plates, natural elements and combinations. An earth rod is just one form of possible electrode. Multiple parallel interconnected earth rods are also an electrode.

The earthing system should be located away from entrances and exits of the structure and places where people may congregate.

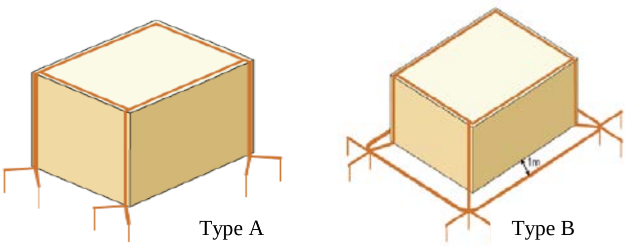

Figure 1: Type A& Type B earthing systems [4]

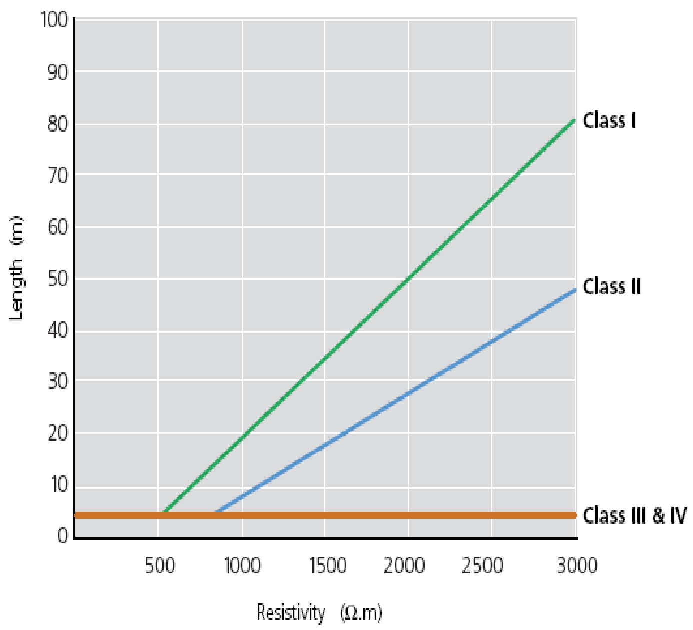

Figure 2: Minimum length of electrodes, $l1$, for Type A & Type B earthing systems [6]

4.2. Type A – vertical and horizontal electrodes

Vertical and/or horizontal electrodes are used. There must be earth electrodes installed at the base of each down-conductor. In minimum, two electrodes must be used. The minimum total length of electrode at each down-conductor is:

• *l*1 for horizontal electrodes

• 0.5 *l*1 for vertical (or inclined) electrodes

For combinations, the total combined length is considered. If less than 10 ohms resistance is measured, then these minimum requirements do not need to be followed.

The top of vertical electrodes must be buried at least 0.5 m below ground surface. This requirement is to reduce the risk of dangerous step potentials.

Frost and freezing soil will limit the effectiveness of any electrode and the presence of electrode in soil that may freeze should not be considered. In this case the length of any electrode in the top 1.0 m of soil should not be considered as contributing to the total length requirement

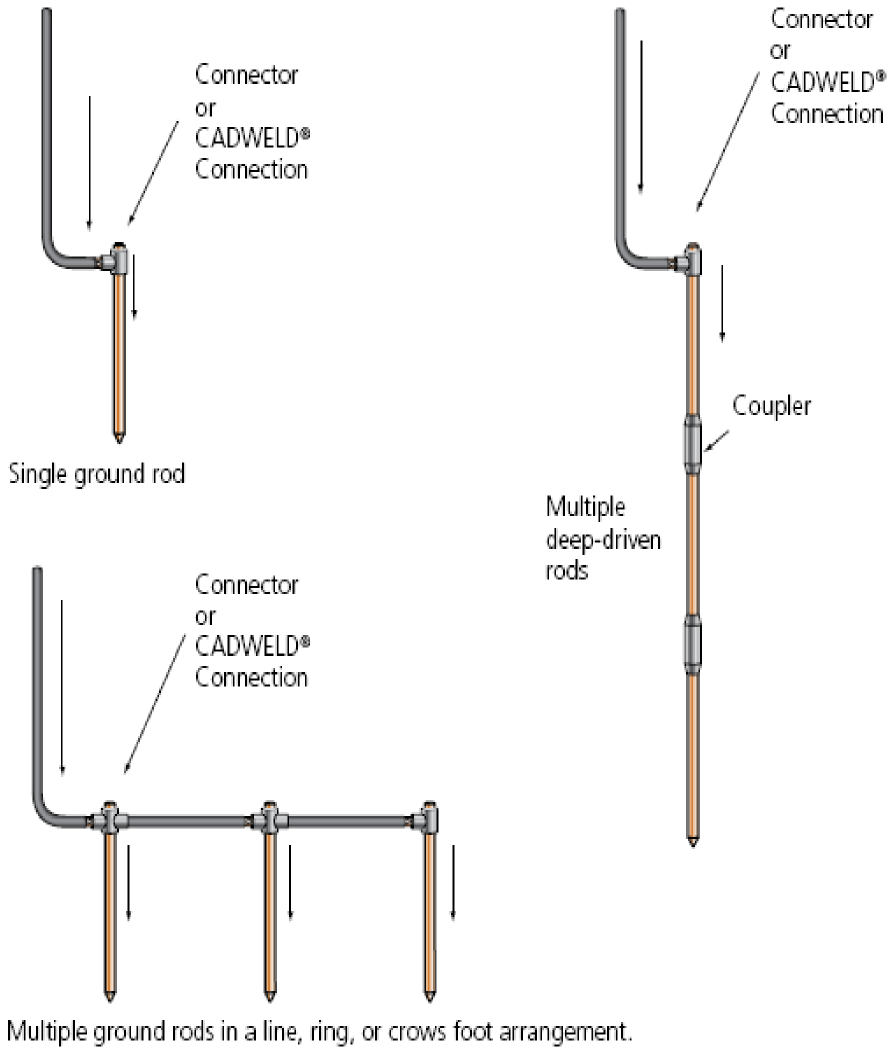

Figure 3: Example vertical electrode arrangements [6]

4.3. Type B – ring electrode

A ring electrode around the perimeter of the structure, or natural elements within the foundation is used. A ring conductor should have a mean radius of distance $re \geq l1$. It should be buried at a depth of at least 0.5 m. The length of any electrode not deeper than 0.5 m should not be considered as contributing to the total length requirement 1m or deeper for areas subject to permafrost.

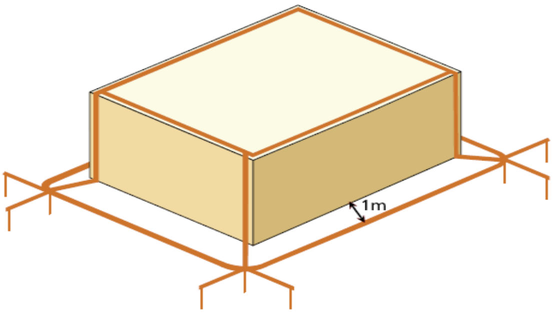

Figure 4: Type B earthing system with additional elements [6]

A ring conductor is installed at a distance of approximately 1 m from structure walls. It should be a closed ring, encircling the structure and in contact with the soil for at least 80% of its length. Note that the buried depth requirement, while helping to improve the electrode coupling to the soil, also reduces the step potential risk. For locations where ground freezing occurs, greater depth of electrodes should be considered.

Additional horizontal electrode length

at each down-conductor = $l_1 - re$

Additional vertical electrode length

at each down-conductor = $(l_1 - re) / 2$

For combined resistance R in parallel line,

$$Rn = R\left[\frac{1+\lambda a}{n}\right] \qquad (3)$$

$$a = \frac{\rho}{2\pi Rs} \qquad (4)$$

where, R_n= combined resistance, Ω

R=resistance on one rod in isolation, Ω

S=distance between adjacent rods, m

ρ=resistivity of the soil, Ω m

Table 3: Factors for parallel electrodes in line [7]

Number of Electrodes (n)	Factor λ
2	1.00
3	1.66
4	2.15
5	2.54
6	2.87
7	3.15
8	3.39
9	3.61
10	3.81

5. Calculation of Earthing System for 11th Storeyed Building

The earthing of Lightning Protection System (LPS) for 11th storeyed building is calculated as follow.

5.1. Structural Configuration of the Building

Type of structure : Eleven-storeyed RC building

Type of occupancy : Residential building

Height of building : Typical storey height = 10ft

Bottom storey height = 20ft

Overall height = 130ft

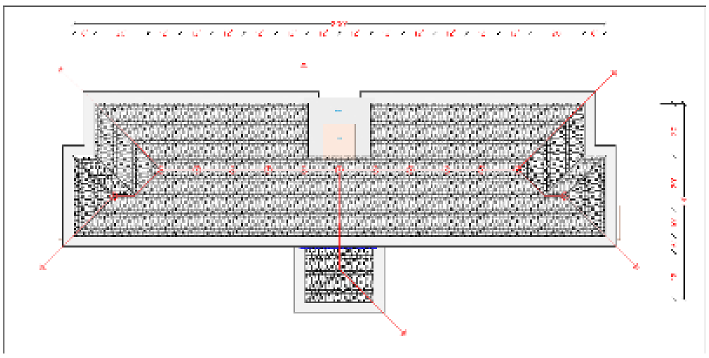

Figure 5: Layout plan of Earthing for LPS of the building

The electrical earthing of LPS of 11th storeyed building is shown in Figure 5. In the building, lightning protection level IV is safe for lightning strike. The building is installed 12 number of air termination rods. In earth termination system, (Loam) soil resistivity is 150Ωm. 50mm^2 copper down conductor is used for safety in building.

5.2. Calculation for Earthing of LPS by using Type A

Class IV lightning protection system is installed with 2 down conductors in 150 Ωm soil.

For horizontal conductors, l_1 = 5 m (from Figure. 2)

For Vertical electrodes, 0.5 l_1 = 2.5 m

In the use of single vertical electrode, minimum length of electrode (2.5 m) needs to be installed for each down conductor to achieve 10 ohms or less.

When 16 numbers earth rod are installed,

$$R = \frac{\rho}{2\pi\, L}\left(\log e(\frac{8L}{d}) \; - 1\right)$$

$$R = \frac{150}{2\pi \;\times 19.2}\left(\log e(\frac{8 \times 19.2}{0.025}) \; - 1\right) = 9.603\Omega < 10\Omega$$

Total requirements of earth termination for lightning protection system of the building are 16 earth rods (1.2m length), 15 numbers of couplers and 1 rod clamp for each down conductor to achieve 10 ohms or less.

For this building, Class IV lightning protection system is installed with 2 down conductors in 150 Ωm soil. 50 mm^2 copper down conductor needs 80 m. So, 32 earth rods (1.2m length), 30 numbers of couplers and 2 rod clamps are required to achieve 10 ohms or less for Type A earthing system.

5.3. Calculation for Earthing of LPS by using Type B

This building is installed with 6 down conductors. When earthing system for this building is installed by using Type B, to obtain less than 10 Ω resistance for the system, each down conductor will need to be connected to an electrode of 60 Ω or less.

When 3 numbers earth rod are installed,

$$R = \frac{150}{2\pi \times 3.6} \quad \log e(\frac{8 \times 3.6}{0.025}) - 1 = 40.12\ \Omega$$

For combined resistance R in parallel line,

$$a = \frac{150}{2\pi \times 40.12 \times 20} = 0.029$$

$$Rn = R\left[\frac{1 + \lambda a}{n}\right] = 40.12\left[\frac{1 + (2.87 \times 0.029)}{6}\right]$$

$$Rn = 7.243\ \Omega < 10\ \Omega$$

The building is installed with 6 down conductors. So 18 earth rods (1.2m length), 12 numbers of couplers and 6 rod clamps are required to achieve 10 ohms or less for Type B earthing system. 50 mm^2 copper down conductor needs 240 m.

6. Discussion and conclusion

Electrical installation is very important for daily life of residences and safety to be convenient. Electrical system of building is important to protect lightning. The buildings should be installed with good protection to protect damages caused lightning. In this paper, design consideration of earthing of lightning protection system for high-rise building is presented. The earthing design for lightning protection system is calculated by considerateness characteristics of the building, its environment and soil resistivity. For Type A earthing system of the building, 32 earth rods (1.2m length), 30 numbers of couplers and 2 rod clamps are required to achieve 10 ohms or less. In Type B, 12 earth rods (1.2m length), 6 numbers of couplers and 6 rod clamps are required. Type B is more convenient and economical than Type A. So, Type B earthing system should be used for the earthing of LPS in high- rise building.

Acknowledgments

The author is deeply gratitude to Dr. Myint Thein, rector, Mandalay Technological University, for his guidance and advice. The author would like to thank to Dr. Yan Aung Oo, Professor, Head of Department of Electrical Power Engineering, Mandalay Technological University, for his kind permission, providing encouragement and giving helpful advices and comments. The author is grateful to her paper supervisor, Dr. Khin thuzar Soe, Associated Professor, Department of Electrical Power Engineering, Mandalay Technological University, for her invaluable supervision, helpful suggestion and necessary assistance throughout the preparation of this paper.

References

[1] Dawalibi, F.P., Ma,J., and Southey, R, (1994), Behaviour of Grounding Systems in Multilayer Soils, a parametric Analysis, IEEE Transactions on Power Delivery, PWRD, No.1, pp. 334-341.

[2] C. Prévé, “Protection of Electrical Networks,” ISTE Ltd, London, 2006.

[3] Brian Scaddan, “Electrical Installation Work”, 5^{th} edition, 2005.

[4] B. Lacroix and R. Calvas, “Earthing Systems in LV,” Schneider Electric’s Cahier’s Technique no. 172, March 2002.

[5] Blatner, C.J., (1982), Study of Driven Ground Rods and Four Point pin soil Resistivty Tests, IEEE Transactions on Power Apparatus and Systems, Vol. PAP 101, No.8, pp. 2837- 2850.

[6] Nigel Johnson, .J, (2006), “Earthing Manual”, section E3 Soil Resistivity Measurement

[7] Wenner, F.C (1915), “A method of measuring Earth Resistivity”, U.S Bureau of standards, scientific paper 258,pp 469-478

[8] Dawalib F.P and, Ma, J (2002), “Extended Analysis of Ground Impendence Measurement using the Fall-of-Potential Method”, IEEE Transactions on PWRD, vol. 17, No.4, pp. 881-885