Improvement of Earthing and Lightning System using Effective Electrode Resistance Reduction Method

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***Abstract-* In this study, Earthing and Lightning Protection system(ELPS) for effective protection against over voltage was investigated. Specific location within the Niger Delta region of Nigeria was used to evaluate the status of earth electrode resistance. Field electrode resistance measurement of 8 electrodes was conducted and the result of investigation showed that 5 out of 8 Electrodes investigated had high resistance above the maximum set standard of 10 ohms within the organization. The resistance results of 8 was used as base case resistance.at the beginning. Single vertical electrode deeper driven method of electrode resistance reduction was used to reduce high electrode resistance. The resistance values of the single vertical deeper driven electrodes were measured, the resistance was compared with the initial base case resistance values in descending order. The results of the deeper driven single vertical electrode were observed to have decreased after the deeper driven exercise. The resistance values of the deeper driven electrodes showed resistance of up to 98% resistance reduction. The achieved result affects the over all Earthing and Lightning protection system network profile positively for effective performance when bonded.**

Index Term: Effective, Electrode, Resistance, Reduction, Method, Protection, and system

1. INTRODUCTION

In Electrical safety, earthing and lighting system protection is a mechanism that is employed to dispose undesirable electrical charge to the earth mass or send back the electrical charge to the generator via earth mass. The transfer of electrical charge may be due to the earth faults at low frequency or high frequency noise or transients (e.g., Lightning or switching impulses). To be qualified as an overall earthing protection system the designed earthing and lightning protection system should be able to handle the currents at all frequencies [3].

Effective performance of earthing and lightning protection system is governed fully by the condition of soil concerned which is considered as a pathological case if it poses a typical opposition to the realization of high-performance electrical earthing and protection system. These conditions of concern are soil resistivity, soil stability and other Environmental factors which influence the performance of electrical earthing system,[3].

The need for conscious program designed for periodic earth resistance testing cannot be over emphasized as gradual reduction of water table in some locations change the minimum earth resistance. This shows that earth resistance checking just at the time of installation is not enough, but conscious effort to always keep the resistance as low as possible, and the ideal long-term remedy is effective electrode resistance reduction (EERR). With this changes that brings about the gradual reduction of water table in some locations which in turn change the minimum resistance for performance, the situation calls for reduction of high electrode resistance to keep the system performance optimally in and out of the season. The purpose of earthing and lightning protection system (ELPS) is to provide a path to general mass of the earth for the fault current at power frequency of either DC or 50Hz/60Hz AC to generator or Transformer even in the event of transient lightning and thunder strike where sub cycle current has risen times in order of nano seconds to microseconds [11].

2. FACTORS THAT AFFECT ELECTRODE RESISTANCE

2.1 Effect of Material conductivity on Electrode Resistance.

Material conductivity is the measure of the simplicity at which an electric charge is transferred through a material. A conductor is a material which gives little resistance to the flow of an electric or thermal energy. Generally, metals are classified as conductors, semiconductors, and insulators. Material conductivity is one of the most significant factors that cannot be underscored when designing an earthing and lightning protection system to reduce the resistance of electrode. Low conductive materials cannot guarantee the effective flow of charge needed in the event of thunder and lightning strike. Material conductivity shows how well a material will allow electricity charge to travel through [5].

Thermal limits have to do with the amount of heat generated by electric current that a transmission line can accommodate. The amount of heat individual part can sustain limits the amount of power that it can transmit, usually, the flow of current through the transmission lines (I^2R) or real power losses in the form of heat leading to increase in temperature which may then stretch the conductor to sag point. Semiconductors materials are materials whose conductor is between conducting (metals) and non-conductors or insulating (such as ceramics). Semiconductors are pure elements, such as silicon or germanium compounds of gallium arsenide or cadmium selenide. In a process of doping, small number of impurities are added to pure semiconductors causing substantial changes in the conductivity of material. While an insulator is any material or object that keeps electrical energy, heat energy, or cold from easily being transferred through it. Designing of any effective earthing system must take into consideration key and major elements such as earth electrode materials to be used, and its properties. Earth electrode being the conductive part which are buried in the soil or specific medium to improve the system earthing, can be of metallic plate, copper cable, copper rod, galvanized pipe with properties such as high conductivity, low resistivity, and low temperature ability

2.2 Effect of Depth on Electrode Resistance

The depth of buried Electrode has considerable influence on both the resistance and conductivity of material as the water of soil is in abundance at the sub soil which in turn help temperature reduction at that point. Water content of soil decreases the soil resistivity, reduction in soil resistivity decreases electrode resistance which in turn increase electrode conductivity.

The water content at the sub soil apart from decreasing the soil resistivity perform another significant role of reducing the acidity concentration of salt content of soil which is capable of initiating corrosion against the earth electrode. Inflection point for resistivity is reached at the depth of 47m because the rate of decline of resistivity decreases with depth at the 47m point in subsoil[6].

2.3 Effect of Electrode Spacing on Electrode Resistance

Earth Electrode is buried in the soil within a few meters from the soil surface. The electrode resistance area should be as large as possible. It is worthy to note that when several electrodes are connected in parallel, electrode resistance is decreased. However, the decrease in resistance was not significant. Pipes or rod used as electrode, where possible should be evenly spaced apart in other that their resistance areas do not overlap. Plates and strips should be similarly treated. To consider the installation cost, it is desirable to install small number of electrodes instead of larger electrode. [10]

2.4 Effect of Cross-Sectional Area on Electrode Resistance

Earth electrode Resistance is inversely proportional to the increase in electrode cross sectional area. The implication of this is that the larger the larger the cross-sectional area of the electrode, the lower the resistance of the electrode. This is achieved as the cross-sectional area is increased, more electrons flow through the electrode as voltage is injected across the electrode. The electrode does not change in length, so, the drift in electron speed did not get faster. The result of this is that reduction of the electrode resistance is insignificant. Movement of more electrons shows movement of more current which results in reduction of resistance as result high electrode conductivity. However, the reduction in electrode resistance experienced electrode- cross sectional area was not as remarkable as the reduction of electrode resistance when electrode length was increased.

3. METHODS OF ELECTRODE RESISTANCE REDUCTION

In general, electrode resistance reduction can be achieved in several ways [4]. Electrode resistance reduction can be achieved through the following ways: - Soil treatment, Electrode spacing, Increase electrode cross-sectional area, Electrode vertical deeper driven.

3.1. Soil treatment

In high resistivity spots or rocky sites where long-term effective earthing protection system performance is required, it may be considered necessary to employ a conductive concrete material to improve earth mass contact resistance around an earth electrode or strip (tape) where important. There are commercially accessible materials which can be used to achieve effective performance creditably. Care should be taken to understand how the materials work during design and installation to make sure that the materials remain in contact with the electrode or strip and the materials do not cave in or swell away after drying out [2].

Earth electrode resistance reduction is not the method of soil resistivity reduction, rather, reducing the resistivity of the soil around electrodes can help achieve adequate electrode resistance reduction. The elements that mostly affect the soil resistivity are soil moisture content, ionizable salts, and porosity. When soil water content and ionizable salts combine, they form an electrolyte, which is a conductor of electricity. Absorbency is an indicator of the ability of the soil to retain the electrolyte. Soil treatment on the other hand can be achieved in several other methods as elucidated below.

3.1.1 . Water Retention

Most soil lose water moisture when it receives direct sunlight. When sun heats the ground, it causes the water content in the soil to rise to the surface and vaporize, dispersing into the atmosphere. The longer the soil is subjected to the heating process, the drier the soil becomes. Excessive drainage can also quickly percolate away the salts in the soil and dry out the deeper soil strata. The water molecule ionizes the minerals in the soil and the ionized mineral becomes conductive. Without moisture, an electrical connection to earth cannot be achieved [9].

3.1.2 Chemical treatment

The use of iron- producing chemical compound like sodium chloride, magnesium sulphate (Epsom salt), copper sulphate (blue vitriol), and calcium chloride around the earth electrodes, decreases the soil resistivity and electrode resistance

The most used chemical is magnesium sulphate. It is Low-cost, and has strong electrical conductivity, it also has little corrosive effect.

Though ordinary rock salt is cheap economically, but common salt (sodium chloride) is highly corrosive. This corrosive effect of sodium chloride may cause nearby metal objects to deteriorate. In spite being an excellent conductor of electricity, the adverse effect of sodium chloride removes it from the list of preferred chemicals.

Chemical treatment indirectly increases the thickness of electrode by altering its surrounding soil. When the soil is porous, the solution permeates quickly into large volume of earth mass, making a large equivalent diameter, with quick results. On the other hand, when the soil contracts, the chemicals take time to spread, and results are produced more slowly. This method requires caution, as local authorities may prohibit the use of chemicals if chemicals are not considered environmentally friendly [10]

3.1.3 Use of Bentonite

Addition of bentonite to the soil reduces the soil resistivity and the earth electrode resistance. Bentonite is a fine-grained of highly plastic clay and formed by volcanic action. It may be replaced as soil replacement and filter material for electrical earthing in places with high soil resistivity. Bentonite is chemically hydrated, innately stable, and retains its properties over time. Bentonite is used to absorb moisture from the surrounding soil and swell up the soil up to several times of its dry volume. It adheres to the surface of the earthing rods and cables that are laid in trenches thereby reduces the contact resistance and increasing contact thickness artificially. The water content in the pores allows the electrical currents to move through bentonite. Bentonite performance is highly dependent on the amount of rainfall, soil moisture content, and temperature at the site. In hot climates, bentonite does not perform optimally as desired because of the drought [9].

Aizat et al [1], in their review of the use of enhancement materials for grounding system posited that, the natural materials do not alter the original properties of the soil. Hence, the soil condition can be maintained. On the other hand, the chemical enhancement materials could alter the soil properties such as PH level, fertility, and minerals significantly. They maintained that in high soil resistivity area such as rocky soil, Bentonite is most and favored due to its ability to absorb moisture while maintaining humidity.

3.1.4 Chemical Rod

Chemical Rods are suitable for high resistivity soils such as rocky, mountain tops, sandy soil, and places with excessively high or low temperatures. Chemical rod is in a tubular form filed with mineral salts circulated evenly. It has holes along its length, to allow the entry of soil moisture. The moisture combines with the salts and dissolves them. The saline solution then leaks out through the hole and soaks into the surrounding soil, continually to condition the large volume of soil around it.

3.1.5 Ground Enhancement fill

Another method of soil treatment is application of ground enhancement fill. This method is achieved by replacing all or part of the soil around an electrode with a low resistivity soil, which will facilitate the achievement of low electrode resistance. The higher the percentage of earth swap that is involved, the lower the earth resistance. Ground enhancement fill may have as low as 50Ω-cm (much lower) than bentonite It works in trenches, around earth electrode or substation earthing conductors, either in dry or in slurry soil. The properties of Ground enhancement fill are constant resistance, low resistivity, support moisture, stability, low freezing point, resistance to leaching, non -corrosive, and maintenance free.

While all methods of soil treatment are effective, the choice will depend on the site's specific conditions and the ability to conduct proper maintenance when required. [9]

3.2 Electrode Spacing

Kalyani [9], the resistance of electrode buried in the soil within a few meters below the earth surface. The electrode resistance area should be as large as possible. When several electrodes are connected in parallel, the electrode should be spaced apart evenly as far as possible. The pipes or rods should be evenly spaced so that electrodes within the resistance areas do not overlap the best way of making the resistance area covered by the electrode as large as possible is to install several numbers of small electrodes rather than a small number of large ones considering the installation cost.

3.3 Increase Electrode cross-sectional Area

Increase in cross -sectional area of the Electrode is another method to reduce the resistance of the electrode. As the cross- sectional area of the electrode is increased, the electrode resistance reduces with increase in the cross -sectional area of the earth electrode. Though the length of the electrode does not change and so the movement of the electrons did not get faster but with increase in cross sectional area the amount of electrons increases and the total movement of electrons within a given time is greater and current flow increases. With increase in current flow, there is corresponding reduction in the resistance of the electrode [8],

Apart from the advantage of mechanical strength, there is little advantage to be gained from increasing the earth electrode diameter (cross-sectionally). Increasing the depth and the length of earth electrode deeper into subsoil has much more influence on earth electrode resistance traits than has its diameter.

3.4 Deeper driven Electrode

One of the key major players in any effective earthing performance is water content of the soil. Dry soil account for majorly high resistance which is also associated with hot temperature. Well known and undisputed and proven fact is that high resistivity is directly proportional to high electrode resistance. Deeper driven electrode is the sure way to meeting abundance of water in the sub soil without any form of soil treatment or addition of any form salt in the quest of resistance reduction. So many authors have alluded to this fact with the several results of their studies, experiments and works as explained in the earlier related literature. Considering this over other methods, deeper driven should become the preferred method considering firstly humans, economic cost, electrical conductivity of electrode, low temperature in the subsoil, availability of abundance of water content in subsoil, non-addition of chemical or any of the salts that may trigger corrosion in the long term and shot term life span. Again, merits of deeper driven

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outweighs other method of achieving electrode resistance reduction though subject to the conditions of the environment where installation is to be made.

Deep-driven of earth electrodes, if possible, should always be used under all situations. The advantage of doing so is to be able to achieve low earth electrode resistance as the electrode is driven deeper to the moistened part of the subsoil. However, implementing this method in rocky soil is very costly and may damage the rods if the electrode is forced into the hard soil while during installation [11]

In this study, because of the variation of soil resistivity from location to location, measurement of electrodes whose resistance was investigated was carried out in field to avoid error of calculation. The initial field measurement as base case resistance while the final field resistance as an improved case. Both the base and improved resistance values were compared and analyzed, and conclusion drawn. Digital Earth tester (DET4TC2) was used to measure the Electrode resistance at set voltage of 50V

4. DISCUSSION AND RESULTS.

Table 1: Base case field resistance Values at 6m depth

S/N	Electrode No.	Base case Depth (m)	Base case length (m)	Soil Nature	Soil Resistivity	Base Case Resistance (Ω)
1	E-320-2C	6	6	Sandy	High	169.2
2	E-320-4C	6	6	Sandy	High	142.8
3	E-320-2A	6	6	Sandy	High	138.8
4	E-320-5A	6	6	Sandy	High	135.9
5	E-09	6	6	Sandy	High	135.6
6	E-320-1A	6	6	Sandy	High	134.9
7	E-603	18	18	Sandy	High	9.4
8	E-604A	18	18	Sandy	High	8.9

Table 1 is the table of the measured field electrode resistance recorded and corresponding length and depth. From the table 1, 6 out of 8 electrode resistance values are above the set maximum standard values of 10 ohms. Those 6 electrodes with high resistance values were improved upon in 4 steps from 6m to 30m deep using deeper driven method

Table 2: Resistance values and corresponding current values. at set voltage of 50V.

S/N	ELECT. NO.	RES.@ 6m	Curr. @ 6m	RES.@ 12m	Curr. @ 12m	RES.@ 18m	Curr. @ 18m	RES.@ 24m	Curr. @ 24m	RES.@ 30m	Curr.@ 30m
1	E-320-2C	169.2	0.295	70.2	0.71	41.7	1.19	19.2	2.6	2.4	20.8
2	E-320-4C	142.8	0.35	78.1	0.64	40.9	1.22	18.3	2.73	1.66	30.1
3	E-320-2A	138.8	0.36	69.2	0.72	40.2	1.24	19.9	2.51	1.34	37.3
4	E-320-5A	135.9	0.367	77.3	0.64	43.5	1.15	19.8	2.52	1.52	32.8
5	E-09	135.6	0.368	68.3	0.73	39.5	1.26	19.8	2.52	1.25	40
6	E-320-1A	134.9	0.37	68.0	0.73	36.7	1.36	18.9	2.64	1.4	35.7

Table 2 is the table of the resistance values of the 6 electrodes with the corresponding current at each depth. There is decrease in resistance as the electrode depth increases and increase in corresponding values of current at that depth meaning that as the electrode length increases with increase in depth, the rate of current dissipation increases with decrease in electrode resistance.

Using MATLAB software to plot the resistance values against corresponding current values, the resistance vs current characteristics is shown below.

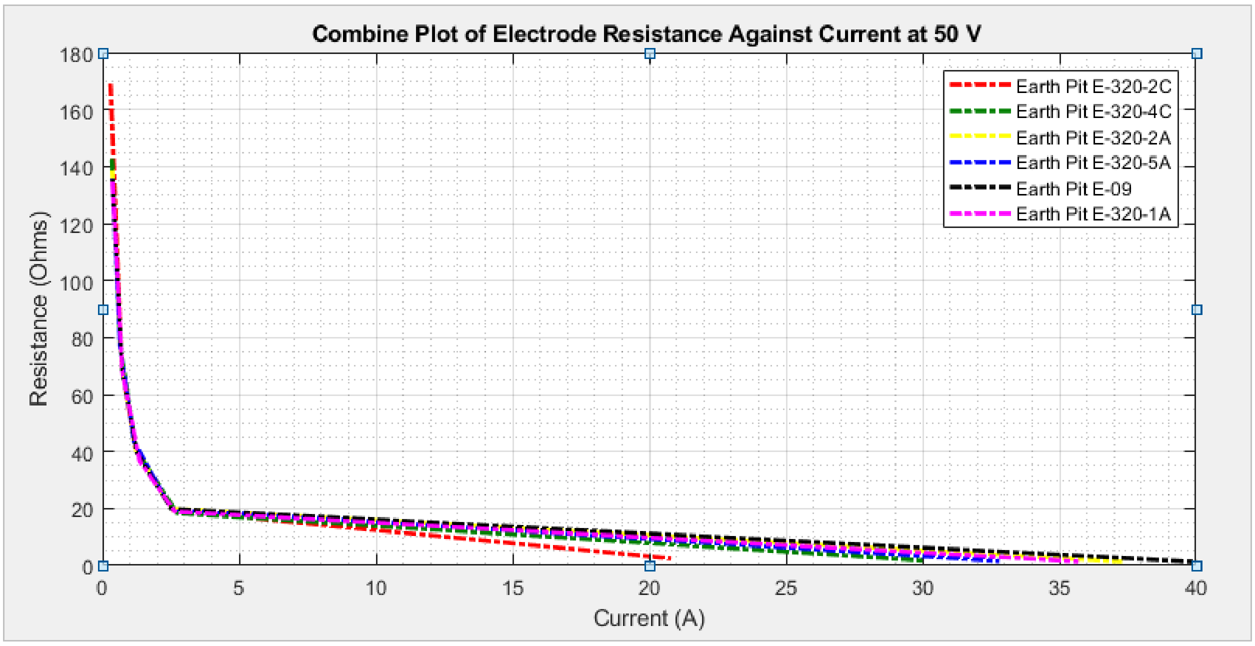

Figure 1: Resistance vs Current characteristics.

5. CONCLUSION.

From the results of the improved electrodes resistance values when compared with the base case resistance, after the deeper driven method of resistance reduction was conducted on electrodes with high resistance value above the set maximum standard of 10 ohms and looking at the plot characteristics of resistance vs current, it is concluded that the experiment worth its value. Further conclusions are below.

Firstly, Electrode resistance can be reduced significantly with increase in the length of electrode and depth vertically.

Secondly, the rate of current dissipation through electrode increases with decrease in electrode resistance as the resistance of electrode decreases with increase in depth.

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