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PARAMETRIC CHANGES OF GROUNDING SYSTEM FOR HIGH VOLTAGE SUBSTATIONS

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Abstract:

Design of grounding system plays crucial role in the high voltage substations. It is challenging to design a safe economical grounding system as there are a number of design related parameters. The grounding system is very important for the normal operation of the power system and the safety of the equipment and personnel. Usually, the grounding grid design is carried out with the aim of meeting the safety restrictions while minimizing its cost. A well designed substation grounding grid is extremely important part of the power system. The fault conditions in a substation can produce huge damages to transformers, circuit breakers and other substation equipments if grounding system is not designed properly. It is important that the substation ground should have a low ground resistance, adequate current carrying capacity, and safety features for personnel and equipment. The design of grounding system for high voltage substations is influenced by several factors like soil resistivity, maximum fault current, conductor selection, conductor sizing and grid resistance. The effects of heat, moisture, drought and frost can introduce wide variations in normal soil resistivity. Soil resistivity usually decreases with depth, and an increase of only a few percent of moisture content in a normally dry soil will markedly decrease soil resistivity. Conversely, soil temperatures below freezing greatly increase

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soil resistivity, requiring earth rods to be driven to even greater depths. This study will briefly explain soil resistivity, conductor material, and ground mat, getting into earth and driving methods.

Keywords: *Soil Resistivity, Grounding Grid, Ground Rod, Substation, Ground Mat, Driving Methods*

I.INTRODUCTION

Applications of advanced technologies, the demands on the safety, stability, and economic operation of power system, becomes higher, a good grounding system is the fundamental insurance to keep the safe operation of power system. Modern power system to the direction of extra high voltage, large capacity, far distance transmission, and applications of advanced technologies, the demands on the safety, stability, and economic operation of power system, becomes higher, a good grounding system is the fundamental insurance to keep the safe operation of power system. The grounding system should ensure that the ground potential rise due to ground fault would not lead power apparatus to be destroyed, and in the meantime, should ensure that the step voltage and the touch voltage would not harm the operators or other people. Simple grounding systems consist of a single ground electrode driven into the ground. The use of a single ground electrode is the most common form of grounding and can be found outside your home or place of business. Complex grounding systems consist of multiple ground rods, connected, mesh or grid networks, ground plates, and ground loops. These systems are typically installed at power generating substations, central offices, and cell tower sites. Complex networks dramatically increase the amount of contact with the surrounding earth and lower ground resistances. Soil Resistivity is the most necessary when determining the design of the grounding system for new installations (green field applications) to meet your ground resistance requirements. Ideally, we would find a location with the lowest possible resistance. But conditions can be overcome with more elaborate grounding systems. The soil composition, moisture content, and temperature will impact the soil resistivity. Soil is rarely homogenous and the resistivity of the soil will vary geographically and at different soil depths. Moisture content changes seasonally, varies according to the nature of the sub layers of earth. Since soil and water are generally more stable at deeper strata, it is recommended that the ground rods be placed as deep as possible into the earth, at the water table if possible. Also, ground rods should be installed where there is a stable temperature, i.e. below the frost line. For a grounding system to be effective, it should be designed to withstand the worst possible conditions.

Two similar terms have distinct meanings and must not be confused or transposed: resistance and resistivity. The former, as it applies to grounding, indicates a relationship between a grounding electrode and its environment in the soil. Resistivity, on the other hand, is a natural property of soil itself, largely independent of human activity. The electrical characteristics of the ground have an effect on the resistance of the whole grounding system, and, therefore, to the electrical safety of the personnel that operates and uses electrical devices [1].

Soil resistivity is a basic parameter necessary for the design of effective grounding and lightning protection systems. The resistivity of rocks or soils is, in general, a complicated function of their porosity, permeability, ionic content of pore fluids, and mineralization. In most rock materials, the porosity and the ionic content of the pore fluid are more important in governing resistivity than the conductivity of the constituent mineral grains. In situations where the porous rocks lie well above the water table and the fraction of the pores filled with fluid is negligibly small, mineralization starts to contribute. Igneous rocks tend to have higher resistivity than sediments.

The selection of a suitable grounding system is an important aspect in the construction of a high voltage substation. The aim of the grounding system is to drive the ground fault current efficiently to the earth, and to protect the people within and in the surroundings of the substation. To ensure these two aspects, proper upper limits for the step and the touch voltages have been set by international standards. The knowledge of the grounding system resistance is essential for the calculation of these voltages in cases of faults. The grounding systems commonly used, consist of single rods, rod beds or arrays of rods, grounding grids and combinations of the previous types. The grounding resistance of a system can be calculated by various methods.

Grounding grid performance, which can be measured in terms of ground resistance, touch voltages and step voltages, is heavily dependent on soil structure. Although two layer soil models can represent the real soil structure in some cases, the use of multilayer soil models is unavoidable to accurately model most soil structures. Some representation of the soil structure is usually taken into account at the time a grid is designed. However, the top soil characteristics can vary significantly even after the grid is installed. For example, the resistivity of surface soil can increase by as much as two orders of magnitude when the soil freezes and it is also sensitive to the moisture content of the soil [3]. To ensure fault currents are dissipated in a safe manner, three parameters must be calculated: ground potential rise (GPR), step voltages as defined in [5], and touch voltages as defined in [5]. As discussed in [9], if the measured ground resistance is found to be consistent with the calculated ground grid resistance, there is reasonable assurance that the step and touch voltages will not be suspect. These step and touch voltage limits are selected such that the possible electric body current in an operator or bystander should not exceed the defined limit under any adverse conditions [5], [9].

II. SOIL RESISTIVITY

Soil resistivity is the resistance measured between two opposing surfaces of one cubic meter of homogeneous soil material, usually measured in ohm meters. Soil resistivity has a direct effect on the resistance of the grounding system. The property of resistivity can be defined for any material. As applied to soil, resistivity is an indication of a given soil's ability to carry electric current. The flow of electricity in the soil is largely electrolytic, determined by the transport of ions dissolved in moisture. Pure water has an almost infinite resistivity and is, in fact, utilized as an insulator in specialized adaptations. This property of water frequently leads to confusion and frustration in practical grounding when wet soil turns out to provide a very poor ground in the face of optimistic expectations to the contrary. Soil resistivity is, in fact, influenced by many factors and it fluctuates constantly.

Soil contamination is caused by the presence of chemicals or other alteration in the natural soil environment. This type of contamination typically arises from the rupture of underground storage tanks, application of pesticides, and percolation of contaminated surface water to subsurface strata, oil and fuel dumping, leaching of wastes from landfills or direct discharge of industrial wastes to the soil. The most common chemicals involved are petroleum hydrocarbons, solvents, pesticides, lead and other heavy metals. This occurrence of this phenomenon is correlated with the degree of industrializations and intensities of chemical usage. The concern over soil contamination stems primarily from health risks, both of direct contact and from secondary contamination of water supplies. Mapping of contaminated soil sites and the resulting cleanup are time consuming and expensive tasks, requiring extensive amounts of geology, hydrology, chemistry and computer modeling skills. The knowledge of soil resistivity is very important for calculating step and touch voltage from safety point of view, as it is clear from Eqn.1 and Eqn.2.

$E_{step} = I_B (R_B + 6)$ (Eqn.1)

$E_{touch} = I_B (R_B + 1.5\,\rho)$ (Eqn.2)

Where ,

I_B is the tolerable body current in milliamperes

R_B is the human body resistance in ohms

ρ is the soil resistivity

Therefore, maximum allowable voltage criteria [5] must be followed. In raining season, the low resistivity soil layer leads the grounding resistance and the step voltage smaller than the respective values in normal condition, it is good for the safety of human beings, but the raining season perhaps leads the touch voltage higher than its limit value, so the influence of raining season on the safety of grounding grid should be considered.When the surface soil layer forms high resistivity layer in freezing season, the grounding resistance of grounding grid increases with the thickness or resistivity of the high resistivity layer. When the thickness of the high resistivity layer exceeds the burial depth of grounding grid, the grounding resistance would increase to 1.7 to 3.0 times of that of the grounding system in normal condition. The touch voltage of the ground surface increases with the thickness or the resistivity of the freezing soil layer. When the thickness of the freezing soil layer exceeds the burial depth of the grounding system, the touch voltage sharply increases. If the resistivity of the freezing soil layer reaches 5000Ω.m, then the touch voltage will increase to 12 times of the respective value in normal condition. The high resistivity soil layer would lead step voltage higher than the respective value of the grounding system in normal condition. The step voltage increases with the resistivity of the freezing soil layer. Even if a granite layer is added, the limit of the touch voltage is still smaller than the actual touch voltage. Adding vertical grounding electrodes can effectively decrease the touch voltage to improve the safety of grounding system. In high freezing areas, the design of grounding grid should strictly analyze the influence of the freezing soil layer on the safety of the grounding system [4]. Table 1 shows effect of soil types on soil resistivity [8].

Table1 Effect of soil types on soil resistivity

Types of Soil	**Resistivity (Ω.m)**
Chalcopyrite, bornite, pyrite, galena, magnetite, etc.	0.000001 ~ 0.01
Schists, slates, shale, etc.	10 ~ 100

Paddy of clay and swamps	10 ~ 150
Farmland of clay	10 ~ 200
Peat, loam and mud	5 ~ 250
Clay and sand mixtures	4 ~ 300
Seaside sandy soil	50 ~ 100
Decomposed granites, gneisses, etc.	50 ~ 500
Zinc blendes, hematite	10 ~ 10000
Paddy or farmland with gravel stratum	100 ~ 1000
Mountains	200 ~ 2000
Granites, gneisses, basalts, etc.	1000
Pebble seashore, parched river bed, gravel	1000 ~ 5000
Rocky mountains	2000 ~ 5000
Moraine gravel	40 ~ 100000
Ridge gravel	3000 ~ 30000
Solid granite	10000 ~ 50000
Sandstone or rocky zone	100000 ~ 1000000000

It is found that earth resistivity varies from 0.01 to 1 Ω.m for sea water, and up to 10^9 Ω.m for sandstone [9]. The resistivity of the earth increases slowly with decreasing temperatures from 25oC, while for temperatures below 0oC, the resistivity increases rapidly. In frozen soil, as in the surface layer in winter, the resistivity may be exceptionally high. Soil resistivity measurements are used to obtain a set of measurements that may be used to yield an equivalent soil model for the electrical performance of the earth. The results, however, may be unrealistic if adequate background investigation is not made prior to the measurement. The background investigation includes data related to the presence of nearby metallic structures, as well as the geological, geographical, and meteorological information of the area. For instance, geological data regarding strata types (soil layer) and thicknesses would give an indication of the water retention properties of the upper layers and therefore their expected variation in resistivity between the layers; then make a comparison of recent rainfall data against the seasonal average. Such background investigation is usually included as a part of the soil measurement procedure and is used in the determination of the soil model to be used in the determination of the grounding grid resistance [9].

III. GROUNDING GRID AND GROUND ROD

For the construction of grounding grid the method of construction, or combination of methods chosen, will depend on a number of factors, such as size of a grid, type of soil, size of conductor, depth of burial, availability of equipment, cost of labor, and any physical or safety restrictions due to nearby existing structures or energized equipment. There are two commonly employed methods to install the ground grid. These are the trench method and the cable plowing method. Both of these methods employ machines. Where these machines are not employed due to lack of space to move them or small size of the job site, the ground grid is installed by hand digging. A ground grid is normally installed after the yard is graded, foundations are poured, and deeper underground pipes and conduits are installed and backfilled. The security fence may be installed before or after the ground grid installation. In cases where deeper underground pipes and conduits are not installed before ground grid installation, an attempt should be made to coordinate the trenching procedure in a logical manner [5].

Grounding grid is a system of horizontal ground electrodes that consists of a number of interconnected, bare conductors buried in the earth, providing a common ground for electrical devices or metallic structures, usually in one specific location. Grids buried horizontally near the earth's surface are also effective in controlling the surface potential gradients. A typical grid usually is supplemented by a number of ground rods and may be further connected to auxiliary ground electrodes, to lower its resistance with respect to remote earth. A conductor embedded in the earth and used for collecting ground current from or dissipating ground current into the earth is called ground electrode. A solid metallic plate or a system of closely spaced bare conductors that are connected to and often placed in shallow depths above a ground grid or elsewhere at the earth surface, in order to obtain an extra protective measure minimizing the danger of the exposure to high step or touch voltages in a critical operating area or places that are frequently used by people. Grounded metal gratings, placed on or above the soil surface, or wire mesh placed directly under the surface material, are common forms of a ground mat [5].

At one time or another, all manners of conductor materials and shapes have been installed in the ground to provide an electrical earth. These materials range from cast iron plates, tubes, galvanized steel stakes, copper strip, metallic rod, wire and water pipe. Taking into account conductivity, high resistance to atmospheric corrosion and soil attack, ease and economy of installation and overall reliability, the steel rod clad with either copper or stainless steel has proven its superiority over all others. The clad steel rod is simple to install, its connection to the grounding system is easily made, and the installation is readily accessible for inspection and test. Additionally, by the use of deep driving techniques, extendible earth rods have been developed to reach underlying strata of low permanent resistivity unaffected by seasonal drying. Electrically, a good ground rod should have a low intrinsic resistance and should be of sufficient capacity to carry high currents without damage when called upon. Mechanically, its physical properties should exhibit strength, have a rigid core for easy driving and be of durable, corrosion resistant material.

IV. THE RESISTANCE OF GROUNDING SYSTEM

The most commonly used expression for the calculation of a single rod resistance in uniform soil can be found in the classical electromagnetic theory as shown in Eqn.3:

$$R = \frac{\rho[In\,(\frac{4L}{d})]}{2\pi L} \qquad \text{(Eqn.3)}$$

The resistance of an grounding installation by ground rod is calculated according to the following formula which has been proposed by Schwarz [2] and has been used in the IEEE Standard is [5] as shown in (Eqn.4):

$$R = \frac{\rho[In\,(8\,L)-1]}{2\pi L d} \qquad \text{(Eqn.4)}$$

Where,

R = resistance of earth rod in ohms in Eqn.3 and Eqn.4

ρ = soil resistivity in ohm meters in Eqn.3 and Eqn.4

L = length of earth rod in meters in Eqn.3 and Eqn.4

d = diameter of earth rod in meters in Eqn.3 and Eqn.4

A different expression for the calculation of the resistance of a single vertical rod has been proposed by Sullivan in [7]. For cases of more complex grounding systems, consisting of rod beds, grounding grids and combinations of rods and grids in uniform soils, expressions have been suggested by both Schwarz [2] and Sullivan [7].

If the diameter of the earth rod is halved (or doubled), the resistance is changed by some 12.5%. The combined resistance of parallel rods is a complex function of the number of rods, rod diameter, rod length, rod separation, configuration of earth rods and soil resistivity. In most cases, fewer rods coupled together for deep driving will achieve a lower resistance than the same number in parallel. The earth rod spacing should not be less than the earth rod length to avoid overlap or resistance areas. This is because multiple earth rods, unless spaced well apart, so not follow the law of resistance in parallel as their earth conducting paths overlap. Accordingly, the installation of multiple earth rods at sufficient distances apart takes up a large area, involves long cabling and many connections, all adding up to higher costs in time, labour and equipment.

V. MATERIALS FOR CONDUCTOR AND RELATED PROBLEMS

Each element of the grounding system, including grid conductors, connections, connecting leads, and all primary electrodes, should be so designed that for the expected design life of the installation, the element will:

- Have sufficient conductivity, so that it will not contribute substantially to local voltage differences.
- Resist fusing and mechanical deterioration under the most adverse combination of a fault magnitude and duration.
- Be mechanically reliable and rugged to a high degree.
- Be able to maintain its function even when exposed to corrosion or physical abuse.

Copper is a common material used for grounding. Copper conductors, in addition to their high conductivity, have the advantage of being resistant to most underground corrosion because copper is cathodic with respect to the most other metals that are likely to be buried in the vicinity. Steel may be used for ground grid conductors and rods. Of course, such a design requires that attention is paid to the corrosion of the steel. Use of a galvanized or corrosion resistant steel, in combination with cathodic protection, is typical for steel grounding systems. The short time temperature rise in a ground conductor,or the required conductor size as a function of conductor current. The conductor current must be calculated [5].

There are different kinds of air gaps not only in hard rocks but also in incompact sedimentary soil, which provide the necessary space for the storage and movement of the groundwater in soil, and the essential condition for utilizing the groundwater to decrease grounding resistance of a grounding electrode. Deep well is the most effective method to gather the groundwater. It is a feasible method to utilize deep well to decrease grounding resistance of a grounding electrode [6].

VI. GETTING DOWN TO EARTH AND DRIVING METHODS

Earth rods are installed by one of two methods. More often than not, the rod can be driven into the ground by either a hand held hammer or mechanically operated hammer. However, where driving is difficult or progress non-existent, the only option is to drill a hole to take the earth rod. Where holes are drilled, the gap between the earth rod and wall of the drilled hole is commonly filled with a water expanding compound. Such a compound is Earthrite. This is a mixture of Bentonite and Gypsum with a small amount of Sodium Sulphate to reduce the resistivity of the backfill. Earth rods up to 3m long can be driven satisfactorily in one length. There are a variety of methods for driving earth rods in to the ground from the simple hand held hammer to power operated mobile rigs. The nature of the soil and terrain, the length of drive needed to secure minimum resistance, and the number of rods to be driven dictate their use.

The various driving methods are:

(1) Hand Held Hammer: The Hand Held Hammer is an effective method for most domestic installations encountered in suburban lots. The earth rod should be driven lightly using a hammer of around 1.5kg-3.0kg, keeping the force of the blows axial to the rod to obviate the risk of whipping. A large number of comparatively light hammer blows are more effective, and preferable, to heavy blows which are destructive to the metal and can cause deformation to the rod end as well as bending and possible splitting. The fitting of a guide to the rod will assist rigidity and reduce whipping when the rod comes up against resistance to penetration

(2) Mechanical Hammer: The Mechanical Hammer which can be one of three types:

(i). **Electric Hammer**: Electric hammers are suitable for light driving to medium depths. A heavy duty hammer is suited to deeper driving and heavier earth rods but should be rig mounted because of its size and weight.

ii. **Pneumatic Hammer**: Pneumatic hammers in the 7kg range with speeds of around 2000 blows per minute.

iii. **Petrol Engine Driver Hammers:** These have the advantages of being self-contained and independent of compressed air or electricity supply for operation.

Driving an earth rod with a mechanical hammer calls for special care to ensure the force of the blows is axial to the rod. While it may be possible to maintain this when manually using a light type hammer, it is certainly advisable to use rig mounting to ensure correct driving when it comes to driving the longer earth rods. These power operated aids are used when soil conditions are not suited to hand driving and when long earth rods have to be driven to great depths. It should be kept in mind that very light and very heavy hammers with a long stroke are not suited to earth rod driving. Medium tools in the 7.5 kg to 12kg ranges with a stroke of approximately 58mm to 108mm delivering 2200 blows per minute are ideal for normal applications.

VII. CONCLUSION

The soil resistivity affects maximum allowable voltage criteria because soil resistivity differs in homogenous and non homogenous earth structure. Soil resistivity is a basic parameter necessary for the design of effective grounding and lightning protection systems. The resistance of grounding system is affected by the soil resistivity, diameter and length of ground rod. The galvanized or corrosion resistant steel, in combination with cathodic protection is typical for steel grounding systems. Driving a ground rod with a mechanical hammer a special care is required to ensure that the force of the blows is axial to the rod.

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