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SOIL RESISTIVITY AND EARTHING SYSTEM

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Abstract:

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 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 soil resistivity and earthing system.

Key Words: Soil resistivity, Earthing, Safety, Step voltage, Touch voltage

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I. INTRODUCTION

A fault in a power plant or a substation consists of soil resistivity measurement and its interpretation, fault current distribution computations, and grounding system analysis. Safety assessment includes GPR (Ground Potential Rise) and ground resistance of the substation grounding grid, touch and step voltages in the substation area, body current when a person is subjected to a touch or step voltage under fault conditions. The grounding system performance and safety are closely related to soil characteristics. This is logical that the highest soil resistivity results in the highest GPR (Ground Potential Rise). The faults in any electrical system are unavoidable. Every electrical equipment, appliance, system must be earthed or grounded to obtain a low resistance path for dissipation of current into the earth. In literature [1] study of soil effects on grounding system performance has been discussed. The maximum safe current a person can tolerate and still release grip of energize object differs from person to person. It depends on body resistance (varies from 500Ω to 100KΩ) at the time of accident (Man-9ma, Woman-6ma, Child-4.5ma). Grounding strongly affects personnel safety, equipment safety and operation, power distribution systems, soild-state system and computers and static-and lightning protection systems. Improper earthing installations can result in equipment damage or improper operation, especially in solid state equipment. Improper earthing system can result in not only electrical injuries and shocks, but may have resulted in electrocution [2].

II. EARTHING SYSTEM FOR SUBSTATION

The earth means a place of zero potential, a place where fault current can be directed of sufficient capacity to enable fuses to rupture. In reality, it is usually the substance beneath our feet and we connect to this in a number of different ways. Buildings are connected to the ground and therefore the floors on which we stand are at the same potential. The distribution transformer will have an earth connection usually in the form of a copper rod anchored in the ground. Lightning conductors that are found on tall buildings will also be rooted in the ground, so that in the event of a lightning strike the current passes harmlessly to ground and not in to structure of the building, thus saving the building from damage. When a phase-to-ground fault occurs on a grounded power network, the current returns to the generating sources through and neutral conductor. The magnitude of the fault current and its distribution in soil and neutral conductors are of a prime importance to, design safe grounding installation, calculate accurately electromagnetic induction on neighboring circuits and determine the optimum setting of the protective relays [3].

An effective substation earthing system typically consists of earth rods, connecting cables from the buried earthing grid to metallic parts of structures and equipments, connections to earthed system neutrals, and the earth surface insulating covering material. Current flowing into the earthing grid from lightning arrester operation, impulse or switching surge flashover of insulators, and line to ground fault current from the bus or connected transmission lines all cause potential differences between earthed points in the substation. Without a properly designed earthing system, large potential differences can exist between different points within the substation itself. Under normal circumstances, it is the current constitutes the main threat to personal.

An effective earthing system has the following objectives:

1) Ensure such a degree of human safety that a person working or walking in the vicinity of earthed facilities is not expressed to the danger of a critical electric shock. The touch and step voltage produced in a fault condition have to be at safe values. A safe value is one that will not produce enough current within a body to cause ventricular fibrillation.

2) Provide means to carry and dissipate electric currents into earth under normal and fault conditions without exceeding any operation and equipment limits or adversely affecting continuity of services.

3) Provide earthing for lightning impulses and the surges occurring from the switching of substation equipment, which reduces damage to equipment and cables.

4) Provide a low resistance for the protective relays to see and clear ground faults, which improves protective equipment performance, particularly at minimum fault.

III. SOIL CHARACTERISTICS

Soil is one of the most important natural resources. It is indispensable for the existence of plants and animals. Soils are formed by the combined work of rocks, topography, climate and plants. Soils of different country may be different. Soils are classified based on their colour structure and place where they are found. The wetter the soil, the lesser the resistance it will have. This is the reason buildings have their own earth connection and do not rely on earth point at the distribution transformer. There are various reasons of measuring soil resistivity. These are:

i. Such data is used to make sub-surface geophysical surveys as an aid in identifying core locations, depth to bed rock and other geological phenomena.
ii. Soil resistivity directly relates to an increase in corrosion activity and therefore dictates the protective treatment to be used.
iii. 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 most economical grounding system.

When a grounding system is designed, the fundamental method to ensure the safety of human beings and power apparatus is to control the step and touch voltages in their safe regions. In different seasons, the resistivity of the surface soil layer would be changed, which would affect the safety of grounding system, and the grounding resistance, step and touch voltage would move to the safe side, or to the hazard side. In rainy 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 safety of human beings, but the raining season perhaps leads the touch voltage higher than its limit value, so the influence of raining on the safety of grounding grid should be considered. The touch voltage of the ground surfaces 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, 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. Then 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 resistivity of the freezing soil layer. Even if a granite layer is added, the limit of touch voltage is still smaller than the actual touch voltage. Adding vertical grounding electrodes can effectively decreases 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 freezing soil layer on the safety of grounding system [4].

A. Resistivity Measurement

The method mostly used method to determine the soil resistivity depth is the four-point method. The Wenner method, (see Figure 1). The four rods are arranged with the same spacing a, five measurements with the spacing a = 2 m, 4, 8, 16 and 32 m are carried out, b is the depth of the electrodes in m. For each measurement a current I is injected between the probes C1 and C2 and the voltage between P1 and P2 is measured [10].

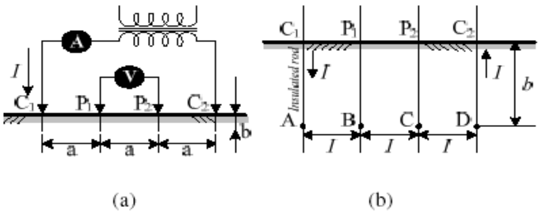

Fig.1 (a)Principle diagram of an earthing tester [9]

(b) Current injection into the soil. [9]

The resistivity ρ in the terms of the length units in which a and b are measured is:

$$\rho_a = \frac{4\pi aR}{1+\dfrac{2a}{\sqrt{a^2+4b^2}}-\dfrac{a}{\sqrt{a^2+b^2}}} \qquad (1)$$

It should be noted that this does not apply to ground rods driven to depth b; it applies only to small electrodes buried at depth b, with insulated connecting wires. However, in practice, four rods are usually placed in a straight line at intervals a, driven to a depth not exceeding 0.1 a. Then we assume b = 0 and becomes [6], [10].

$$\rho_a = 2\pi aR \qquad (2)$$

And gives approximately the average resistivity of the soil to the depth

B. Two-Layer Soil Apparent Resistivity

A resistivity determination using the Wenner method (see Figure 2) results in an apparent resistivity which is a function of the electrode separation, a in terms of the above parameters the apparent resistivity (ρ_a) can be shown to be:

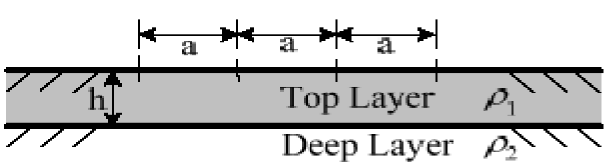

Fig.2 Two-layer earth.

Where,

h First layer height.

ρ_1 First layer resistivity, in Ω.m

ρ_2 Deep layer resistivity, in Ω.m

$$\rho_a = \rho_1 \left(1 + 4\sum_{i=1}^{\infty} \frac{K^n}{\sqrt{1+\left(2n\frac{h}{a}\right)^2}} - \frac{K^n}{\sqrt{4+\left(2n\frac{h}{a}\right)^2}} \right) \quad (3)$$

A two-layer soil model can be represented by an upper layer soil of a finite depth above a lower layer of infinite depth. The abrupt change in resistivity at the boundaries of each soil layer can be described by means of a reflection factor. The reflection factor (see Figure 3), K, is defined by Equation (4) [11].

$$K = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \quad (4)$$

IV. FACTORS AFFECTING SOIL RESISTIVITY

Soil resistivity is the key factor that determines what the resistance of a grounding electrode will be, and to what depth it must be driven to obtain low ground resistance. The resistivity of the soil varies widely throughout the world and changes seasonally. Soil resistivity is determined largely by its content of electrolytes, which consist of moisture, minerals and dissolved salts. A dry soil has high resistivity if it contains no soluble salts. The ground does not have a homogenous structure, but is formed of layers of different materials. The safety of a grounding system in homogenous soil can be analyzed by the provided methods in China National Standard [5] or IEEE Standards [6]. The resistivity of a given ground varies widely (in Table 1) and is very dependent on moisture content.

Table 1

Type of ground	**Ground resistivity in Ω-m**	
	Range of values	**Average values**
Boggy ground	2-50	30

Adobe clay	2-200	40
Silt and sand-clay ground , humus	20-260	100
Sand and sandy ground	50-3000	200(moist)
Peat	>1200	200
Gravel (moist)	50-3000	1000(moist)
Stony and rocky ground	100-8000	2000
Concrete:1 part cement+3 parts sand	50-300	150
1part cement+5 parts gravel	100-8000	400

Two samples of soil, when thoroughly dried, may in fact becomes very good insulators having a resistivity in excess of 10^7 Ω-m. The resistivity of the soil sample is seen to change quite rapidly until approximately 20% or greater moisture content is reached (in Table 2).

Table 2

Moisture Content % by Weight	**Resistivity in Ω-m**	
	Top Soil	**Sandy Soil**
0	$>10^7$	$>10^7$
2.5	2500	1500
5	1650	430
10	530	185
15	190	105
20	120	63
30	64	42

The resistivity of the soil is also influenced by temperature. Table 3 shows the variation of resistivity of sandy loam, containing 15.2% moisture, with temperature changes from 20^0 C to -15^0 C. In this temperature is to vary from 72 to 3300 Ω-m.

Table 3

Temperature		**Resistivity**
C	F	**Ω-m**
20	68	72
10	50	99
0	32(water)	138
0	32 (ice)	300
-5	23	790
-15	14	3300

The increasing generating capacity of power system and the growing degree of interconnection between systems are resulting in unprecedented levels of fault current in switchyards. In the same time, increasing emphasis on safety and reliability of power facilities require that voltage rise during a fault to be kept to low levels. These influences together dictate that ground resistances in switchyards must be very low, local soil resistivity, an important factor governing ground resistance, is not usually a consideration in plant site selection. Soil and bed rock with sufficient strength to support large generating units very often have high resistivity. Thus, it becomes difficult, to design a ground grid of sufficient low resistance [7]. The resistivity of water is inversely proportional to temperature implies that when water in the soil freezes, the resistivity increases appreciably. Figure 3 shows the effect of temperature on earth resistivity [12].

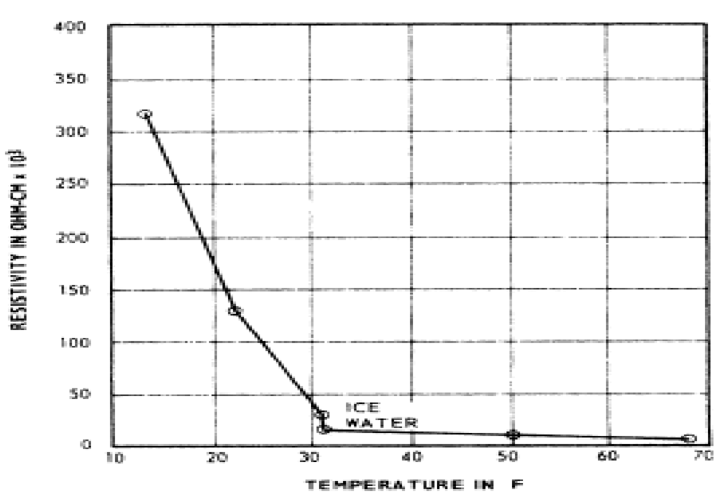

Fig. 3 Effect of resistivity of soil due to temperature variations [12].

It can be seen that resistivity of soil is dependent upon temperature, moisture, and salt content, which in turn indicates that resistivity can vary considerably from season to season. Figure 4 shows the relative resistivity of typical ground rods over a period of 16 months. Thus it can be seen that the last and largest of the components, the resistance of the earth, is a widely varying factor with the resistivity ranging from 500 to 300 000 Ω-cm. Consequently, establishing this value is the principal criteria in the design of grounding systems [12].

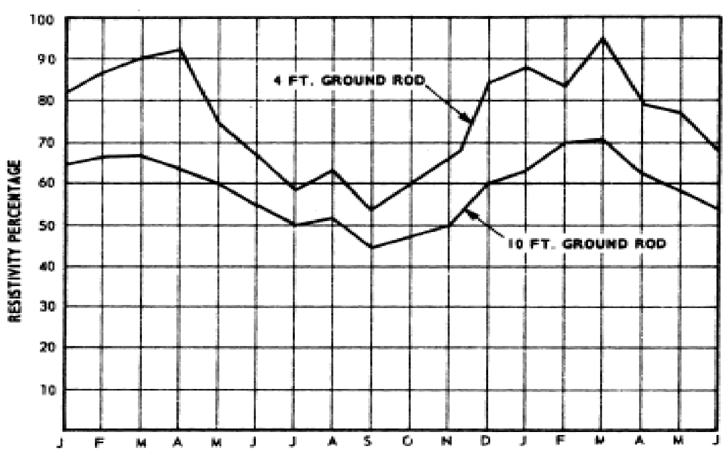

Figure 4. Seasonal variation of earth resistivity [12]

V. STEP AND TOUCH POTENTIALS AND POTENTIAL HAZARDS

The flow of ground current between parts of the ground gives rise to a step potential**.** Step potential is defined as the difference in surface potential experienced by a person bridging a distance of 1 m with his feet without contacting any other grounded object. The value of the maximum safe step potential depends on the resistivity of the top layer of surface material, and on the duration of the current flow. For example, for a substation with a 10 cm layer of crushed rock and current flowing for 0.5s, the maximum value of the step potential is approximately 3100 V.

Touch potential is the potential difference between a surface potential at a point a person is standing, and a grounded metallic structure at a normal maximum reach (1m). For the same situation the maximum safe touch potential is approximately 880 V.

Major accidents happen due to improper earthing and leakage (i) A person dies after touching pole. It was observed that pole was not earthed and live wire inside had deteriorated insulation which came in contact with the pole. (ii) In a sugar factory a person was stacking sugar bags by climbing on a steel ladder. He took support of roof truss and got shock. The fitting erected on truss was short and leakage passed to the labourer.

For step voltage criteria [6], the step voltage limit is:

$$E_{step50} = \left(1000 + 6C_s(h_s,K)\rho_s\right)\frac{0.116}{\sqrt{t_s}} \quad (5)$$

$$E_{step70} = \left(1000 + 6C_s(h_s,K)\rho_s\right)\frac{0.157}{\sqrt{t_s}} \quad (6)$$

Where,

C_s = 1 for no protective surface layer

ρ_s = the resistivity of the surface material in Ω-m

t_s = duration of shock circuit in sec

For touch voltage criteria[6] , the touch voltage limit is:

$$E_{touch50} = \left(1000 + 1.5C_s(h_s,K)\rho_s\right)\frac{0.116}{\sqrt{t_s}} \quad (7)$$

$$E_{touch70} = \left(1000 + 1.5C_s(h_s,K)\rho_s\right)\frac{0.157}{\sqrt{t_s}} \quad (8)$$

VI. SIGNIFICANCE OF EARTHING /GROUNDING SYSTEM

It would, perhaps be more accurate to define a ground or grounding system as a means to establish a potential reference normally taken to be zero. A grounding system can be divided in to three portions and for clarity this will be done as follow:

i. The grid system or that portion installed within the earth. When the automobile, airplane or missile is considered, the metal frame or structure corresponds to the grid system.

ii. Permanent connections between the grid system and building frame, steel structure ,transformers, fuel tanks and similar permanent installations.

iii. Distribution interconnections are subsequent connections to secondary power system, racks, cabinets, etc., which are not usually permanent installations [8].

iv. Every practical equipment or appliance must be 'Earthed' or 'Grounded' for the safety of equipment network as a whole and operating personnel.

v. Ground fault current directly has an impact on human safety. Major accidents happen due to improper earthing. Leakage current passes through human body and fatality occurs.

vi Every overhead line/ substation /generator station which is exposed are liable to injury from lightening.

vii The purpose of earthing in electric power system is to limit, with respect to the general mass of earth the potential of current carrying conductors which are part of the equipment, non-current carrying metal works associated with the equipment , apparatus and appliance connected to the system.

VII. CONCLUSION

Soil resistivity plays an extremely vital part while designing any grounding system. The earthing/grounding system depend on both soil properties and earth resistivity. Soil properties are characterized by earth resistivity which changes over a wide range from few Ω.m up to few thousand Ω.m depending on the type of ground and its structure as well as its humidity. As a result it is difficult to calculate exact value of earthing resistance. Neither very low resistivity nor very high resistivity is safe for human safety under power system fault conditions. Soil resistivity affects the value of grounding resistance as well as grid resistance. Soil resistivity changes earthing resistance.

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