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Novel approach of estimating grounding pit optimum dimensions in high resistivity soils

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ABSTRACT

Good grounding arrangement is very important for safe and reliable operation of a power system and to ensure safety of the power apparatus as well as the operating personnel. In most of the inland arid desert areas, the soil resistivity is significantly high and it is difficult to get low earth resistance with conventional methods. Therefore, an economical and efficient grounding system design of the earthing pit is necessary which can be achieved by using a low resistivity material (LRM). When such material is used, it is important to optimize the pit design. The grounding resistance for different configurations were calculated and based on the results, an optimized pit configuration is discussed. The intent of this paper is to present a simple general computational technique for finding the optimum economical size of grounding pit when filled with LRM. It was found that the use of too high volume of LRM does not reduce the earthing resistance in a corresponding manner. The suggested method can be readily used by engineers to obtain a good earthing pit configuration for efficient grounding of the power system components in high resistivity soils.

1. Introduction

Over-voltages are induced in power transmission and distribution lines and are the most serious threat to in power system components/insulation. According to statistical results of power system failures in China, about 40–70% of high voltage transmission line failures were caused by lightning [1]. The power lines and substations are protected from such over-voltages by surge arresters which are provided with a low earth resistance connection to enable the large lightning and fault induced currents encountered to be effectively discharged to the earth. The earth resistance of a grounding system depends on grounding electrode arrangement and soil resistivity. The ground potential rise can causes problems such as electrical shock and can damage the equipment if it rises above a certain threshold. It can also causes interference with electronic equipment. Therefore, a lower grounding resistance is important for safety of the equipment and personnel. The first step to design an efficient grounding system is to obtain the surrounding soil resistivity data. Then the next step is to design an efficient low resistance grounding pit according to the surrounding soil structure and its resistivity. The soil resistivity depends on the type of soil, the moisture content, the quantity of salts present in the soil and the ambient temperature. An increase in the moisture content and dissolved salts or an increase in temperature reduces the soil resistivity.

To reduce the grounding resistance different materials have been proposed. These include use of bentonite, drilling rig mud, steel furnace slag, ground water accumulation using deep wells, and a variety of other materials and techniques [1–7]. Most of these materials are also utilized in the formulation of LRM.

The grounding resistance of simple grounding electrodes can be easily calculated [8]. Scale model tests with an electrolytic tank are also very useful for determining the ground resistance and surface potential distributions during ground faults in complex grounding arrangements where accurate analytical calculations may be difficult [9]. In recent years several publications have discussed the application of LRM and the performance of such and conventional materials under different conditions [1,10–13].

In Saudi Arabia, the ground resistivity varies in a large range because the geodetic terrain varies from sea shore to inland arid desert and dry mountains [14]. Therefore to get a low value of grounding resistance, a good design of the grounding pit is necessary. In some cases, LRM needs to be used in such pits. In such situations, it is important to make an efficient use of the LRM. Different parameters that affect the grounding resistance were studied in detail and an optimized pit design procedure was developed. This paper presents a simple general computational technique for finding the optimum size of grounding pit that is commonly filled with LRM. The suggested method can be readily used by engineers to obtain a good earthing pit configuration for efficient grounding of the power system components.

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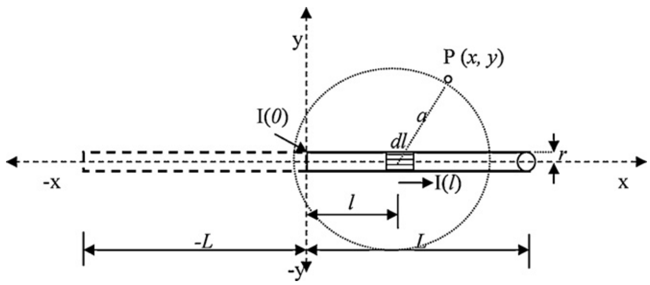

Fig. 1. Method of calculation of grounding resistance.

2. Expression for the grounding resistance

Consider a conductor extended along x-axis between $x = -L$ and $x = L$, and a current $I(0)$ is injected into the conductor as shown in Fig. 1. Assume that the conductor is buried in uniform soil of resistivity ρ Ω-m. Let dl be the conductor element at distance $x = l$ and $I(l)$ be the conductor current at distance $x = l$. The potential drop dV at a point (x, y) in the surrounding medium with resistivity ρ (Ω-m) due to the current leaving the conductor element dl is given as:

$$dV(x,y) = \frac{\partial I(l)}{\partial l}\frac{\rho}{4\pi a}dl \tag{1}$$

where

$$a = [(x-l)^2 + y^2]^{1/2} \tag{2}$$

Here, it is assumed that the potential due to the current leaving the conductor element is same as for a point source of current. The potential at point $P(x,y)$ due to the current flowing to the ground along the entire conductor is given as:

$$V(x,y) = \frac{\rho}{4\pi}\int_{-L}^{L}[(x-l)^2 + y^2]^{-1/2}\frac{\partial I(l)}{\partial l}dl \tag{3}$$

Assume constant current leakage $\partial I(l)/\partial l = 2I(0)/2L = I_0/L$ from the conductor length, then evaluation of (3) gives:

$$V(x,y) = \frac{\rho I(0)}{4\pi L}\ln[u(x,y)] \tag{4}$$

where

$$u(x,y) = \frac{\sqrt{(x+L)^2 + y^2} + (x+L)}{\sqrt{(x-L)^2 + y^2} + (x-L)} \tag{5}$$

The average potential along the conductor is obtained by substituting $y = r$ in (4) and integrating it between $x = 0$ and $x = L$. The following expression for the resistance of the conductor in a medium of infinite extent in all directions is obtained by dividing the average potential by $2I(0)$ [5,15,16]:

$$R = \frac{\rho}{2\pi L}\left\{\ln\left(\frac{2L}{r}\left[1+\sqrt{1+\left(\frac{r}{2L}\right)^2}\right]\right) + \frac{r}{2L} - \sqrt{1+\left(\frac{r}{2L}\right)^2}\right\} \tag{6}$$

The value of resistance of vertical ground rod as shown in Fig. 2(a) can be calculated using (6).

3. Grounding techniques

In the low resistivity soils, a simple copper (Cu) or copper clad steel rod of suitable length L(m) and radius r(m) is inserted in the ground as shown in Fig. 1(a) for the grounding purpose. The grounding resistance R_1 (Ω) of such an earthing rod can be expressed as in (6).

Since $r/2L \ll 1$, this term and its higher powers can be neglected. Therefore, Eq. (6) can be expressed as:

$$R_1 = \frac{\rho}{2\pi L}\left(\ln\left(\frac{4L}{r}\right) - 1\right) \tag{7}$$

The volume of ground rod (Vol_1) is given as:

$$Vol_1 = \pi r^2 L \tag{8}$$

When the surrounding soil has very high resistivity, multiple parallel rods have to be used such that the spacing between the two neighboring grounding rods must be at least twice the rod depth in order to derive maximum benefit of using multiple rods. However, when the soil resistivity is either too high or the space is insufficient to construct the grounding network of required number of parallel grounding rods, one of the following two methods of employing LRM as shown in Fig. 2(b) and (c) can be used for reducing the high grounding resistance. It will provide a low impedance path

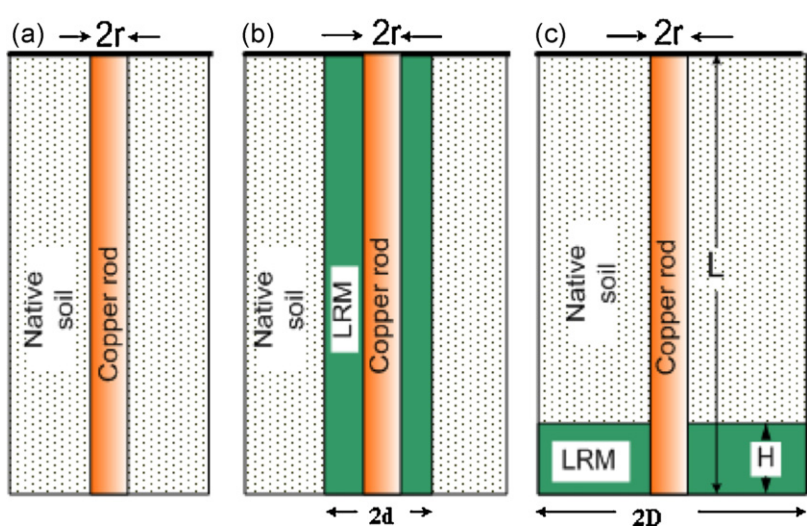

Fig. 2. Grounding arrangement [14]. (a) Grounding rod in native soil, (b) grounding rod totally surrounded by LRM and (c) grounding rod embedded partially in LRM placed in a circular pit.