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Design and Validation of Plate Earthing System for Equipment Earthing

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Abstract

Earthing system is an essential part of electrical installation as it helps in eliminating electrical shock hazards and also provides a zero-voltage reference point for the equipment. Design of an earthing system involves measurement of soil resistivity of the proposed site for the electrode system installation and determining the conductor type and required number of earth electrodes to achieve earth resistance value. This paper describes the methodology followed in the design and validation of a plate electrode earthing system for the equipment earthing in a new test laboratory, which had an earth resistance requirement of less than 1 Ohm as mandated by the equipment supplier. This will be helpful for personnel involved in the design of the earthing system.

Keywords: Earthing System, Earth Resistance, Plate Electrode, Soil Resistivity

1. Introduction

Earthing system is of prime importance for safe operation of any electrical installations. It protects the personnel from hazards of electrical shocks and also act as a point of reference during the operation of an electronic equipment. In this paper we design and validate an earth system for electronic system earthing, which is designed as per the requirement of the equipment manufacturer. The desired value of earth resistance is less than 1Ω, and the same was achieved using a combination of plate electrodes and strip electrode. The methodology followed for both design and validation of this earthing system is discussed in the paper.

2. Design of Earthing System

Soil resistivity plays a major role in the design of the earthing system and is directly proportional to the earth resistance value[1-3]. Soil resistivity value provides an insight about the nature of the soil at various depths below the ground. The site for the proposed plate electrode earthing system installation is of 23m x 6m. Soil resistivity was carried out using earth tester to ensure the compatibility of the site for the installation of earthing system.

Following are the methods suggested in IEEE 81-2012 for soil resistivity measurement:

i. Schlumberger method
ii. Three Probe Method
iii. Wenner's method

The instrumentation and accessories necessary to carry out the above measurements are as follows:

- Four terminal earth tester
- Spikes
- Wires
- Tapes

2.1 Soil Resistivity Measurement using Earth Tester

The soil resistivity measurement at the site is carried out by the most popularly adopted Wenner's method. The procedure followed is as mentioned in clause no. 7.2.3 of IEEE Std. 81/2012 and 40.3 of IS 3043/2018. The soil resistivity measurement setup as per Wenner's method is shown in Figure 1. In this method, four spikes are buried at a burial depth 'b' and spacing 'a', as indicated in the figure. The earth tester injects a current of approx. 50mA at 128Hz through the outer spikes/terminals C1 and C2. The voltage is measured

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at the inner spikes/terminals, P1 and P2. The resistance R is obtained by dividing the voltage by the current.

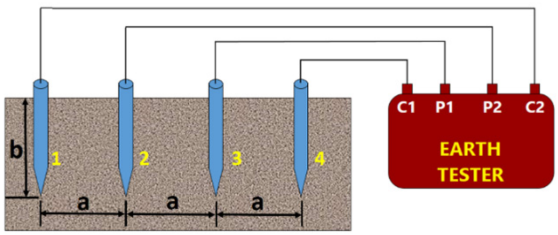

Figure 1. Soil resistivity measurement setup using Wenner's method.

The soil resistivity 'ρ' is given by Equation 1[1,2]

$$\rho = \frac{4\pi a R}{1 + \frac{2a}{\sqrt{a^2+4b^2}} - \frac{a}{\sqrt{a^2+b^2}}} \quad (1)$$

The above formula is applicable in cases were the equidistant electrode spacing "a" is comparable with the driven spike length "b". In real application, the equidistant spike spacing is comparatively large compared to spike driven length (b< 0.1a). For such measurements, the above formula reduces to

$$\rho = 2\pi a R \quad (2)$$

where,

ρ = resistivity of the soil in Ω-m.

a = equidistant spacing of the spike in meters.

R = Resistance in Ω.

As per the Wenner's method, the soil resistivity value obtained for an equidistant spike spacing "a" corresponds to the resistivity of the soil at a depth "a" meters below the ground[4]. Table 1 shows the results of soil resistivity measurements corresponding to various spacing/depth.

Table 1. Results of soil resistivity measurements

Soil Resistivity Measurements (Sl. No.)	Results of Wenner's Measurements		
	Equidistant Spacing of the Spikes, a (m)	Resistance (Ω)	Soil Resistivity (Ωm)
1	0.5	6.15	19.3
2	1.0	2.77	17.4
3	2.5	0.92	14.4
4	5.0	0.41	12.8
5	7.5	0.24	11.1
		Average	15.0

The average value of soil resistivity obtained for measurements at various spacing is 15 Ωm. The soil at the site is said to be homogeneous as all the soil resistivity values obtained is within ±30% of the average value. Therefore, the average soil resistivity value of 15 Ωm is considered for design purposes.

The design computation of the grounding system is performed with the measured value of soil resistivity. We have implemented the earthing system with both plate electrodes and strip electrodes. The strip electrodes are used to interconnect the plate electrodes and the equipment. Design computation for the electrodes are given below.

2.2 Plate Electrode Design

The formula for computation of earth resistance of plate electrode is as follows:

$$R = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \quad (3)$$

where,

ρ = soil resistivity (assumed uniform) (in Ωm), and

A = area of both sides of the plate (in m^2).

We have used copper plate electrode of 600 mm x 600 mm in our installation. Since the resistance of a single plate is higher than the required value, we have to use multiple plates with sufficient spacing of more than 2 m. This spacing will ensure that the net resistance will not surpass more than 20% of parallel resistance i.e., single plate electrode resistance divided by the number of parallel plate electrodes. Figure 2 shows the configuration of copper plate electrode. Figure 3 shows the plate electrode at fabrication stage.

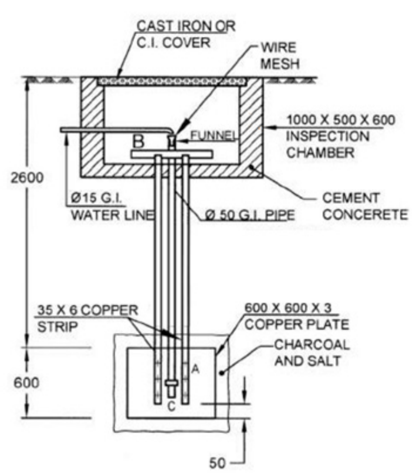

Figure 2. Copper plate electrode configuration

Figure 3. Plate electrode at fabrication stage.

2.3 Strip Electrode Design

The formula for computation of earth resistance of strip electrode is as follows[5]:

$$R = \frac{100\rho}{2\pi l} loge\left(\frac{2l*l}{wt}\right) \quad (3)$$

where,
ρ = soil resistivity (assumed uniform) (in Ωm)
l = strip length (in cm)
w = is the depth of burial of the electrode (in cm)
t = width of the strip, (in cm)

Strip electrode helps in interconnecting the plate electrodes as well as the equipment to be earthed. Since the equipment under consideration is electronic equipment, both the fault current and fault duration are significantly low, therefore even copper plate electrodes of 600 mm x 600 mm and copper strip electrode of lower size (40 mm x 8 mm) was sufficient enough to carry the fault current even after considering a corrosion factor of 25%.

The calculation of earth electrode resistance is as per Table 2 for the electrode configuration as per Figure 4. The computed value of the earth resistance of an individual plate electrode is 7.83Ω. Therefore, a minimum of four plate electrodes were necessary to achieve the lower value of resistance of 2.35Ω. The strip electrode interconnecting the plate electrodes offered an earth resistance of 1.29Ω. The combined resistance of the earthing system, including both strip and plate electrodes, is 0.83Ω, which is less than the desired value of 1Ω.

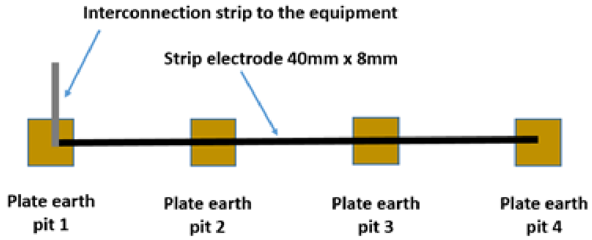

Figure 4. Layout of electrode configuration of earthing system.

3. Validation

Validation of the earthing system design was performed a month after the installation. Validation is done by measuring the earth resistance of the earthing system. Worldwide accepted E. B. Curdt's method was adopted for measuring the resistance of the earthing system. A four terminal earth tester is used for the measurement. C1 and P1 of the earth tester is connected to the test joint of the earthing system. The remote current spike (C2) is placed far away from the

Table 2. Calculation of earth electrode resistance

Input parameters	**Calculation of Earth Electrode Resistance**	
	Values	**Resistance (Ω)**
Soil resistivity (Ωm)	15.0	
Plate area (m2)	0.72	
Single Plate Electrode Resistance		**7.83**
No. of parallel plate electrodes	4	
Total Plate Electrode Earth Resistance considering 20% Factor		**2.35**
Strip length (m)	18	
Burial Depth of strip (cm);	100	
Width of the strip, (cm).	4	
Strip Electrode Earth Resistance		**1.29**
Combined Resistance of the Earthing System		**0.83**

earthing system, and the potential spike (P2) is placed at 61.8% of the remote current spike (C2) distance. The earth resistance measurement taken for this configuration will correspond to the earth resistance of the earthing system. Multiple measurements are taken by varying C2 and P2 spikes, and the average of the values obtained is considered as the final earth resistance of the system. Figure 5 shows the configuration of E. B. Curdt's method.

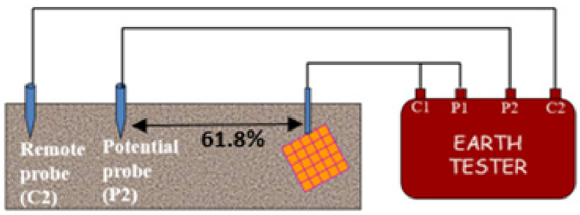

Figure 5. Configuration of E. B. Curdt's method.

Results of the earth resistance measurement is shown in Table 3. Measurements are performed at remote current spike (C2) distance of 35m and 40m. The potential spike (P2) is placed at 61.8% of C2 distance. The average earth resistance of the earthing system obtained from the measurements using E. B. Curdt's method is 0.556 Ω, which is less than the design value.

Table 3. Measurement of earth resistance

Earth Resistance Measurement (Sl. No.)	Readings		
	Remote Current Spike Distance (C2) (m)	Potential Spike Distance (P2) (m)	Earth Resistance (Ω)
1	35	21.63	0.565
2	30	18.54	0.546
Average			0.556

4. Conclusion

This paper adopts a systematic approach to designing a plate electrode-based earthing system for equipment earthing. The effectiveness of the strip electrode is also utilised to bring down the net earth resistance. The computations were performed as per the IEEE and IS standards to achieve an earth resistance value of less than 1Ω. The design value earth resistance was 0.83Ω and the same was validated through earth resistance measurement. The measured earth resistance value of the earthing system is 0.556Ω, which is lower than the design value, thereby fulfilling the requirement of the earthing system for this specified application.

5. Acknowledgement

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