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MATHEMATICAL CALCULATION OF VOLTAGE HAZARD IN POWER STATION

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ABSTRACT. During lifetime of a power station, the electrical system is subjected many times to ground faults, giving rise to voltage hazards. Voltage hazard could be due to Step Voltage, Touch Voltage and Ground Potential Rise. They are dangerous and result into electric shock and/or loss of life to O&M personnel, stakeholder or animal. Electrocution in India, constitutes a substantial death among total accidental and suicidal death, with continued rising trend. Because of an earth fault, an ungrounded system or structure becomes energised, creating panic due to measurable voltage to ground. The purpose of the present paper is to mathematically calculate the Step Voltage & Touch Voltage of a power station and demonstrate that the earthing grid design is suitable, meeting the general safety requirement of CEA regulation.

1. INTRODUCTION

The underground earth grid is designed for 30-50 years as per project technical specification. During lifetime, the power system is subjected many times, to electrical ground fault with different degree of fault level. The after effect of the fault could result into abnormally high current and/or over voltage [1]. The fault gives rise to a voltage hazard in terms of Step Voltage & Touch Voltage,

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resulting into electric shock and/or loss of life and panic to O&M personnel, stakeholder or animal. The purpose of the present paper is to mathematically calculate the Step Voltage & Touch Voltage of a power station and demonstrate that the earthing grid design is suitable, meeting the general safety requirement of the regulation [2].

2. Literature and Industry Survey

Electrocution has caused deaths of 12,154 people, constituting 3% of total accidental & suicidal deaths, having increasing death in India in 2018 [3].

Indian safety regulation requires that 'All electric supply lines and apparatus shall be.... constructed, installed, protected, worked and maintained in such a manner as to ensure safety of human beings, animals and property' [2].

Equivalent earth resistance of the grid is to be always maintained less than 1.0 Ohm [2].

In last 73 years, there has been unprecedented growth of power sector, increasing fault level of the Indian Power System. Increase of fault level leads to possible equipment failure, if fault current exceeds the short circuit rating of equipment [1]. In view of that, the Industry practice is to design earth grid, based on max. fault level and parameters as per Safety regulation [2], Project technical specification, datasheet & standards [5-9], etc.

3. Earthing Design calculation, Analysis & Results

Buried earth mat conductor of 32 mm MS rod is selected based on case of brownfield expansion. Underground earth grid is designed to achieve equivalent earth resistance less than 1.0 Ohm, actual step voltage and actual touch voltage less than permissible step potential & touch potential respectively, in the entire 370MW CCPP including sub-station as per fig-1.

3.1. **Earth grid resistance R_g.** Following data are considered for calculation:

- I_G = Max. Fault current of 40kA for 1 sec at 220kV.
- t_c = 1 Sec, Duration of fault current for earth-mat sizing
- Fault current division factor of 0.7 and Shock duration is 0.5 sec.
- Resistivity of concrete surface/ rock = 3000 Ohm-m.

- h_s = 0.15 metre is thickness of the Concrete Surface layer
- Mean Soil resistivity, ρ= 53 Ohm-m
- No of ground rod = 90, length of MS Rod, $L_R = 3$m and length of buried conductor, $L_C = 11000$m. Therefore, the total buried length of MS Rod conductors, $L_T = 11000\text{m} + (90 * 3) = 11270\text{m}$
- h = 1 metre is the depth of the underground grid.
- Area occupied by the ground grid after design is A = 60105.5m^2

$$R_g = \rho \left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}} \left(1 + \frac{1}{1 + h\sqrt{20/A}} \right) \right]$$

On substituting the different values, R_g = 0.10 Ohm, which is less than the required 1.0 Ohm. The regulation requirement is fulfilled.

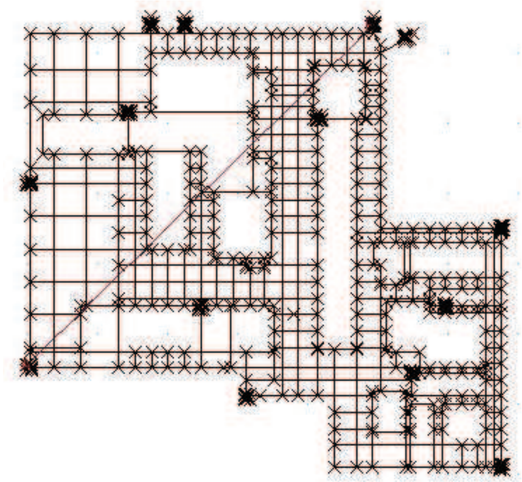

FIGURE 1. Plot Plan with underground earth grid of Power Station

3.2. **Step Potential, Touch Potential and Mesh Potential.** As per IS/CEA Regulation:

Step Potential (E_s) is defined as The potential difference between two points on the earth's surface, separated by distance of one metre in the direction of maximum potential gradient.

Touch Potential (E_t) is defined as 'the potential difference between a grounded metallic structure and a point on the earth's surface separated by a distance equal to the normal maximum horizontal reach, approximately one metre.

Mesh Potential - maximum touch voltage, developed in the earthing grid mesh above ground during fault.

As per IS 3043, the duration of fault for calculation of step, touch and mesh potential is the actual breaker fault clearing time i.e., 500 milli sec.

3.3. **Ground Potential Rise.**

$$GPR = I_G R_g = D_f I_g R_g = D_f S_f I_f R_g = 1 * 0.7 * 40000 * 0.1 = 2800V$$

Here,
- S_f - Fault current division factor (i.e., considering 70% of fault current flowing through h = 1 metre of soil & 30% of fault current through the system
- D_f = 1, Decreament factor for entire duration of Fault of 30 cycles (0.5 s or more as per IEEE 80).

3.4. **Calculation of Tolerable Step and Touch Potential.**

$$k = \frac{\rho - \rho_S}{\rho + \rho_S} = \frac{50 - 3000}{50 + 3000} = -0.96$$

Here k is reflection factor between different material resistivities and C_s is the surface layer derating factor.

$$C_s = 1 - \frac{0.09\left(1 - \frac{\rho}{\rho_s}\right)}{2h_S + 0.09} 1 - \frac{0.09\left(1 - \frac{50}{3000}\right)}{2h_S + 0.09} = 0.77$$

1) E_{step} (tolerable) = $(1000 + 6C_s\rho_s)\frac{0.116}{\sqrt{t}} = (1000 + 6 * 3000 * 0.77)\frac{0.116}{\sqrt{0.5}}$

Therefore, $E_{step}(tolerable) = E_s(tolerable) = 2438.13V$

2) $E_{touch}(tolerable) = (1000 + 1.5C_s\rho_s)\frac{0.116}{\sqrt{t}} = (1000 + 1.5 * 3000 * 0.77)\frac{0.116}{\sqrt{0.5}}$

Therefore, $E_{touch}(tolerable) = E_t(tolerable) = 732.26V$. As Ground Potential Rise (2800 V) is greater than Permissible E_t of 732.26 V, therefore further design evaluations are necessary.

3.5. **Max. attainable mesh voltage and Max. attainable Step Voltage.**

$$E_{mesh} = \frac{K_m K_i \rho I_G}{L_T} = \frac{0.562 * 3.75 * 53 * 40000}{11270} = 396.4V$$

$$E_s = \frac{K_S K_i \rho I_G}{L_T} = \frac{0.220 * 3.75 * 53 * 40000}{11270} = 155.19V$$

Here,
- K_S - Step factor for Step Voltage (simplified method) = 0.220 (as calculated)
- K_i - Correction factor for grid geometry (simplified method) = 3.75 (as calculated)

TABLE 1. Safe design of underground earthing grid based on design and calculation

Item	Unit	Allowable	Actual	Remarks
Diameter of MS conductor	mm	–	32	–
Resistance of U/G Grid	Ohm	<1	0.10	Achieved
Touch Voltage	Volts	732.26	396.4	Achieved
Step Voltage	Volts	2438.13	155.19	Achieved

It may be noted that E_s and E_t are Safe if Calculated Values < Tolerable Max Values.

The voltage gradients are greatest near the earthing grid electrodes and decrease rapidly with distance.

When cattle shelter under trees during a storm, they are subject to greater risk from step potential than a human would be, since the distance between their hind and forelegs is greater than a person's stride and the voltage would be applied across the animals' cardiac region [10].

4. CONCLUSION

The mathematical calculations for overall earthing resistance is less than 1.0 Ohm. Step and touch voltage are within acceptable limit for 32mm diameter of Mild Steel Rod, which is widely used in underground earthing grid of Indian power station. This meets the general safety requirement of CEA regulation.

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