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MATHEMATICAL CALCULATION AND SIMULATION OF EARTHING GRID DESIGN IN COMBINED CYCLE POWER STATION

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ABSTRACT. The electrical system is often subjected to faults, giving rise to voltage hazards. Because of earth fault, even an ungrounded system or structure becomes energised, having measurable voltage to ground. So, voltage hazard (step, touch & GPR) are dangerous and result into electric shock and/or loss of life to O&M personnel, stakeholder or animal. The purpose of the present paper is to mathematically calculate the ground potential rise, step voltage & touch voltage in a CCPP and compare the results with those obtained from CAPELINE & CDEGS software.

1. INTRODUCTION

The underground earth grid is designed for 30-50 years as per project technical specification. The power system is subjected many times, to electrical ground fault with different degree of fault level [1], giving rise voltage hazard. Electrocution has caused deaths of 12,154 Indians in 2018, constituting 3% of total accidental & suicidal deaths, with increasing trend [3].

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Key words and phrases. AIS - Air Insulated Switchyard, CCPP - Combined Cycle Power Plant, CEA - Central Electricity Authority, GIS - Gas Insulated Switchyard, GPR - Ground Potential Rise, O&M - Operation and Maintenance.

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].

In last 73 years, there has been increase of fault level, dangerous to both equipment and life [1]. Earth grid is designed based on max. fault level and parameters as per Safety regulation [2], Project technical specification, datasheet & standards [5-9]. The purpose of the paper is to mitigate voltage hazard through ground grid design of CCPP, calculated and compared with that obtained from CAPELINE & CDEGS program.

2. Earthing grid design, Calculation, Simulation and Analysis

The choice of buried earth mat conductor depends upon the brownfield or greenfield project. For brownfield project, earth grid of 32 mm MS rod is selected as a practical case for earthing design of a 370MW CCPP including substation.

2.1. **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, $L_R = 3$ metre and length of buried conductor, $L_C = 11000$ metre. Therefore, the total buried length of MS Rod conductors, $L_T = 11000 + (90 * 3) = 11270$ metre
h = 1 metre is the depth of the underground grid.
- Area occupied by the ground grid after design is A = 60105.5 m^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. Therefore, the regulation [2] requirement is fulfilled.

2.2. **Step Potential, Touch Potential and Mesh Potential.** As per standards [5][6]& regulation [2]:

Step Potential 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 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 during fault. E_s and E_t are Safe if Calculated Values < Tolerable Max Values.

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.

2.3. **Ground Potential Rise.**

$$\text{GPR} = I_G R_g = D_f I_g R_g = D_f S_f I_f R_g$$

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).

- R_e is value of all earth electrodes = 28.21 Ohm. After paralleling with R_g, the combined value becomes equal to 0.09 Ohm.

Therefore

$$\text{GPR} = 1 * 0.7 * 40000 * 0.09 = 2520 \text{ V} .$$

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

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

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

Therefore, $E_{\text{touch}}(\text{tolerable}) = E_t(\text{tolerable}) = 732.26V$

As Ground Potential Rise (2520 V) is greater than Permissible E_t of 732.26 V, therefore further design evaluations are necessary.

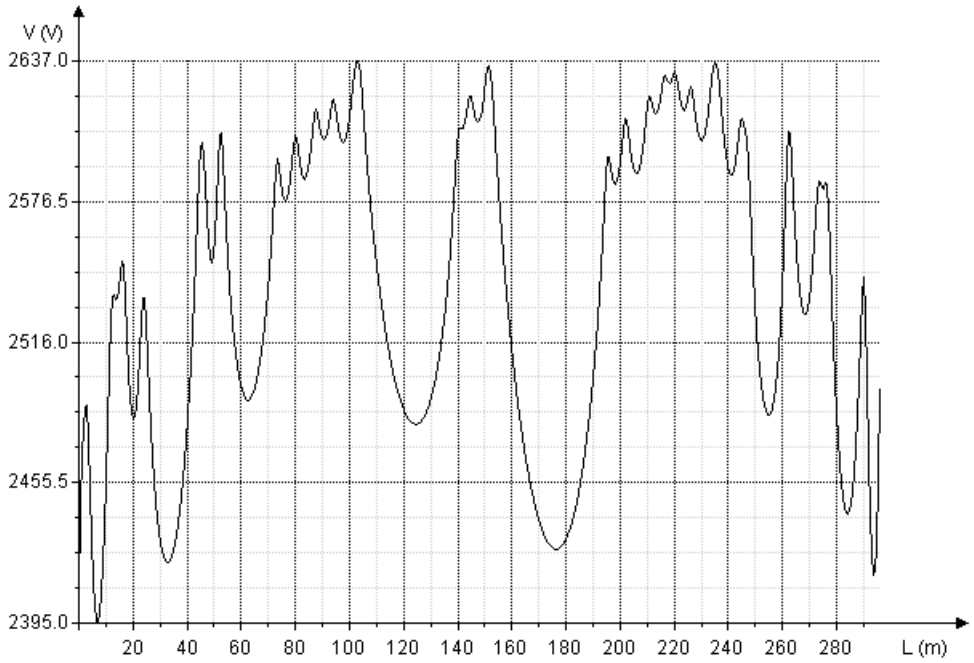

FIGURE 1. CAPELINE's Ground Potential Rise

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

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

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

Where, K_S - Step factor for Step Voltage (simplified method) = 0.220 (as calculated)

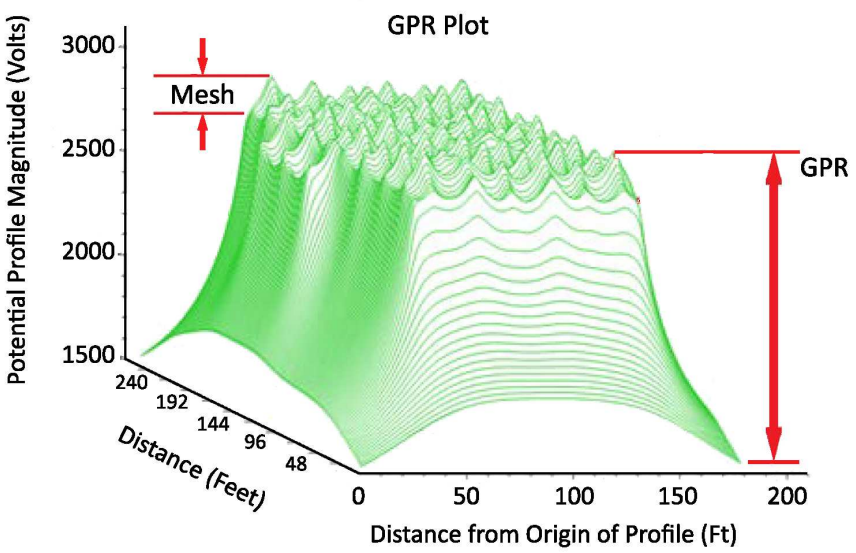

FIGURE 2. CDEGS's GPR & Mesh Voltage for various sub-soil profile throughout the plant

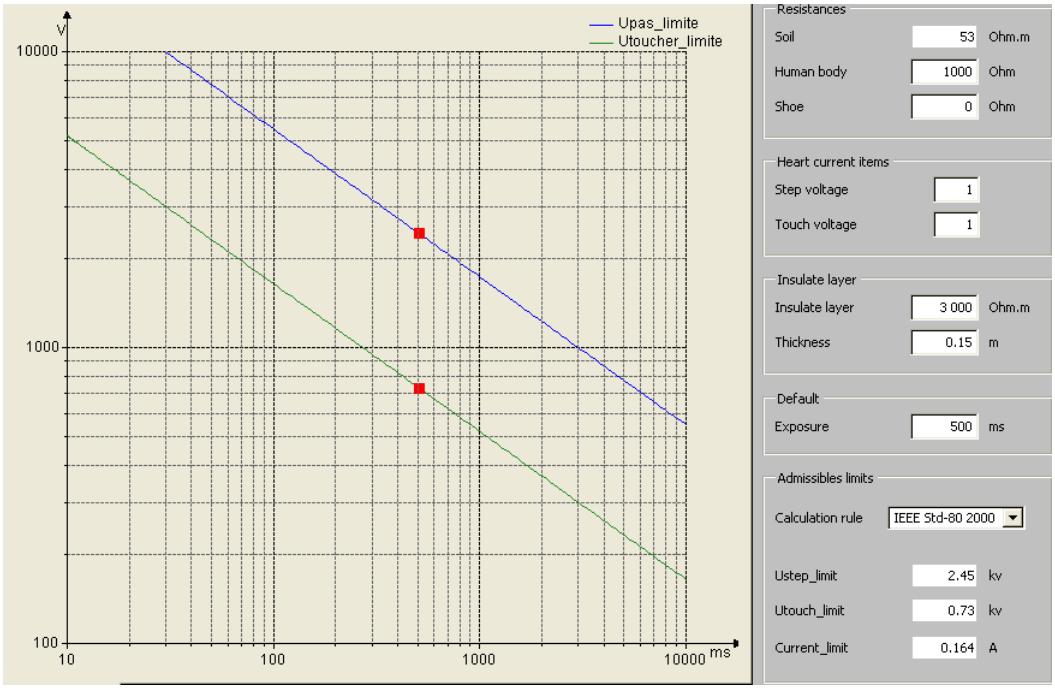

FIGURE 3. CAPELINE's Step and Touch Potential

K_i - Correction factor for grid geometry (simplified method) = 3.75

The entire plot plan with underground grid of 32mm dia Mild Steel Rod conductor including ground rods, etc are developed into CAPELINE & CDEGS program. The program is run to obtain Ground Potential Rise, (GPR), Step Voltage and Touch Voltage (Refer Table-1). They are found to be almost equal and comparable with that obtained mathematically.

TABLE 1. Safe design of 32mm MS underground earthing grid based on design, simulation and calculation

Item	Unit	Allowable	CAPELINE	CDEGS	Calculation
Touch Voltage, E_t	Volts	732.26	730	735	396.4
Step Voltage, E_s	Volts	2438.13	2450	2445	155.19

It is found that E_s and E_t are Safe as Calculated Values < Tolerable Max Values.

3. CONCLUSION

The calculation & simulation results are comparable and acceptable to industry. The simulation output curves for various sub-soil profile can not be obtained from XL calculations.

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