ADV MATH SCI JOURNAL
Advances in Mathematics: Scientific Journal **9** (2020), no.10, 7947–7953
ISSN: 1857-8365 (printed); 1857-8438 (electronic)
https://doi.org/10.37418/amsj.9.10.28 Spec. Issue on ACMAMP-2020

CALCULATION AND SIMULATION OF VOLTAGE HAZARD IN COMBINED CYCLE POWER STATION

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ABSTRACT. The electrical system is subjected many times to ground faults, giving rise to voltage hazards, such as Step Voltage, Touch Voltage and Ground Potential Rise, which are dangerous and could result into electric shock and/or loss of life to O&M personnel, stakeholder or animal. Electrocution constitutes around 3.0% of total accidental and suicidal death, having a continuous rising trend in India. Because of earth fault, a system which is ungrounded and not energised becomes energised, having measurable voltage to ground. The objective of the paper is to mathematically calculate the Step Voltage & Touch Voltage in a CCPP and compare with that obtained from CAPELINE software, to validate the earthing design for the safety of plant, O&M personnel and animal.

1. INTRODUCTION

The underground earth grid is designed for 30-50 years, 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

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2010 *Mathematics Subject Classification.* 00A72, 00A73.
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.

Voltage, resulting into electric shock and/or loss of life and panic to O&M personnel, stakeholder or animal. The objective of the paper is to mathematically calculate the Step Voltage & Touch Voltage in a CCPP and compare with that obtained from CAPELINE software, to validate the earthing design for the safety of plant, O&M personnel and animal.

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.

In last 73 years, there has been unprecedented growth of power sector [1,4], 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].

3. Earthing Design, Analysis and Results

Buried earth mat conductor of 32 mm MS rod is selected because 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.

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, $L_R = 3$ metre and length of buried conductor, $L_C = 11000$ metre. Therefore, the total buried length of MS Rod conductors, $L_T = 11000m + (90 * 3) = 11270$ 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. The regulation requirement is fulfilled.

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

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 - Mesh potential is the potential difference in volts from grid conductor to ground surface at centre of mesh grid, developed 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.

3.3. **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.
So,

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

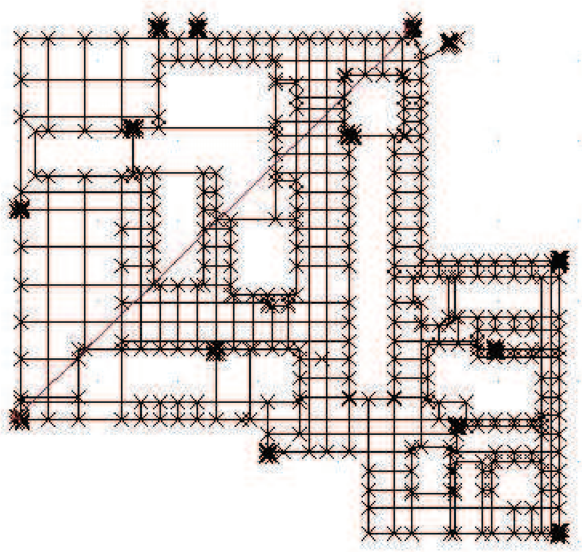

FIGURE 1. Plot plan having underground earth grid of 32mm diameter of Mild Steel Rod

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

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

where 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.

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

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

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

Here,
- K_S is the step factor for Step Voltage (simplified method) = 0.220
- K_i is the correction factor for grid geometry (simplified method) = 3.75

Entire plot plan having underground grid network of 32mm Mild Steel (MS) Rod conductor including ground rods, etc is developed into CAPELINE. The program is run to obtain Step Voltage and Touch Voltage (Fig.-2). They are found to be almost equal and comparable with that obtained mathematically.

TABLE 1. Summary of underground earthing grid

Item	Unit	Allowable	CAPELINE	Actual	Remarks
Diameter of MS conductor	mm	–	32	32	–
Resistance of U/G Grid	Ohm	<1	0.10	0.10	Achieved
Touch Voltage	Volts	732.26	730	396.4	Achieved
Step Voltage	Volts	2438.13	2450	155.19	Achieved

Thus, as per grid design and calculation, E_s and E_t are Safe as Calculated Values < Tolerable Max Values.

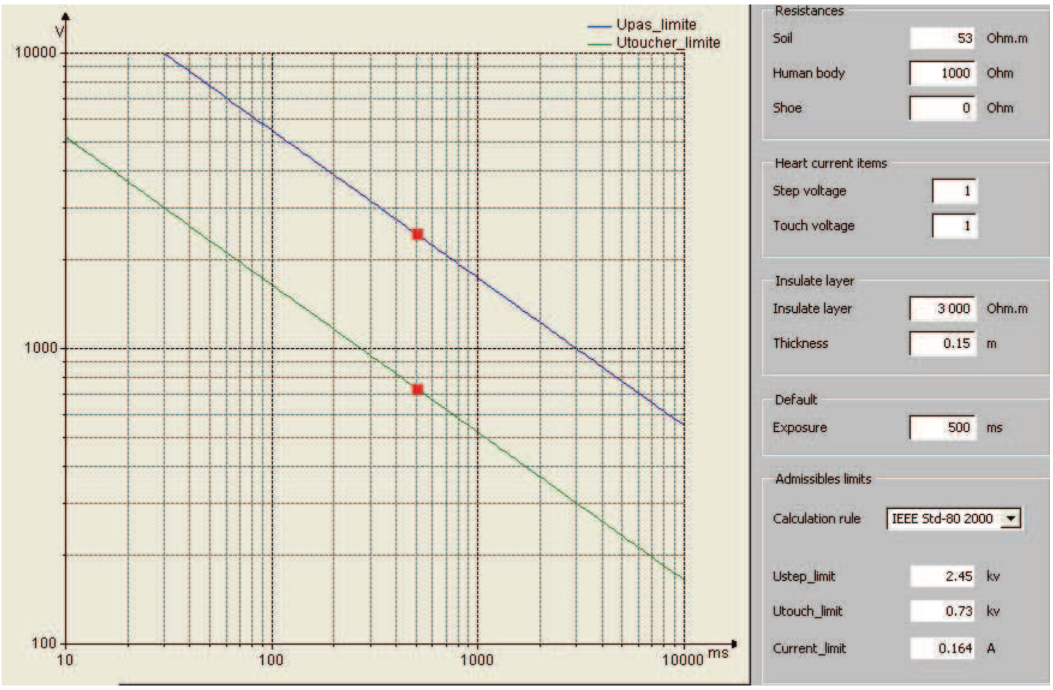

FIGURE 2. Maximum Tolerable Step and Touch Voltage in CAPE-LINE. Red dot on Blue and Red line is E_S and E_t respectively

4. CONCLUSION

The mathematical results and those obtained from CAPELINE simulation are comparable. The outputs from CAPELINE helps to get the desired curves, to validate and achieve a safe design. This facilitates to avoid exposure to sudden high voltage to sensitive electrical, control and instrumentation panel, communication system and IT system, which might cause failure. XL based calculations cannot provide the same.

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