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CALCULATION AND SIMULATION OF GROUND POTENTIAL RISE IN COMBINED CYCLE POWER STATION

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ABSTRACT. The electrical power system is subjected to ground faults several times, during lifetime, raising the ground potential (GPR), dangerous and might result into electric shock and/or loss of life to O&M personnel, stakeholder or animal. There are various software programs commercially available, widely used and acceptable to industries. The purpose of the present paper is to calculate GPR in a CCPP, compare the result with that obtained from CAPELINE & CDEGS program and demonstrate that they meet the general safety requirement of the Indian electricity regulation for safety of plant, O&M personnel and animal.

1. INTRODUCTION

Power station is designed for a useful life of 25 years, however may be operated beyond after life extension, or Renovation & Modernization. During lifetime, the power system is subjected to electrical ground fault with different degree of fault level [1]. The earth fault gives rise to GPR, resulting into electric shock and/or loss of life or equipment damage. The present work involves calculation & comparison of GPR with the results obtained from CAPELINE &

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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.

CDEGS program, meeting the regulation [2] for 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 and suicidal deaths, which is more than the death from snake bite (8962) in India in 2018 [3].

The 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, the installed capacity addition of power station has been unprecedented, increasing short circuit or fault level of power system. Between 1947 to 1997 i.e., 50 years, there was addition of 84433 MW [1][4]. Between 1997 - 2020, there was significant growth of 2,82,895 MW in 23 years [4].

3. DESIGN CALCULATION, SIMULATION, ANALYSIS AND RESULTS

As per Industry practice, earth grid is designed based on maximum fault current and other parameters as per standards [5-9], Safety regulation [2], Project technical specification, datasheet, etc.

With capacity addition and grid Interconnection, fault level increases, leadin to equipment failure, if fault current exceeds the short circuit rating of equipment [1]. Maximum fault level at point of common coupling (i.e., AIS or GIS voltage level) is considered for earth grid design calculation.

3.1. **Underground Conductor Sizing.** Following data are considered for calculation, usually supplied by plant owner:

- 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 = 60105.5 m^2

Amm^2 = Minimum cross-sectional area of the Mild Steel conductor required to avoid fusing is given by the formula as per IEEE 80 [5]:

$$I = A\sqrt{\frac{TCAP.10^{-4}}{t_c\alpha_r\rho_r}\ln\frac{K_0 + T_m}{K_0 + T_a}}$$

Here,
- TCAP = 3.749 $J/cm^3 -^0 C$ is the thermal capacity per unit volume
- $\rho_r = (15 * 10^{-6})$ Ohm-m is the resistivity of the ground conductor at reference temperature T_r
- $\alpha_r = 0.00423 - (1/^0C)$ is the thermal coefficient of resistivity at reference temperature T_r
- t_c = 1 Sec, Duration of fault current for earth-mat sizing
- $K_0 = \frac{1}{\alpha_O}, = 216.4^0C$
- $T_m = 500^0C$, maximum allowable temperature of welded MS joints
- T_a = is the ambient temperature in ^{0}C

On substituting the different values, Cross-sectional area of MS Rod
A = 523.801 mm^2 i.e., Radius of conductor of MS Rod = 12.91 mm
So diameter of the conductor of MS Rod = 2*12.9 = 25.8 mm
15% corrosion allowance [6] over 25.8 mm = 3.9 mm
The size of MS Rod conductor = 25.8 + 3.9 = 29.7 mm
Therefore, Selection based on available Standard MS rod from Steel Plant = 32.00 mm

The underground earth grid designed from 32mm dia MS rod is shown for a Combined Cycle Power Station at Fig.-1.

3.2. **Resistance of Earth grid as per IEEE-80.** Earth grid resistance R_g and the voltage gradients within power station including switchyard are directly dependent on the soil resistivity. As soil resistivity vary horizontally and vertically

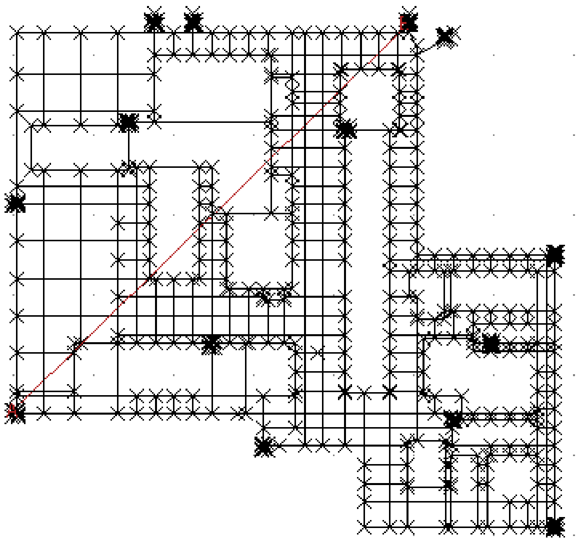

FIGURE 1. Plot Plan with underground earth grid of Power Station

though out the year, so adequate data are collected during geo-technical survey of the plant.

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

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

- R_g is the overall power station including switchyard i.e., sub-station ground resistance in Ohm
- ρ is soil resistivity is 53 Ohm-m
- $A : areaoccupiedbythegroundgridis 60105.5 m^2$
- No of ground rod is 90, length of MS Rod is 3 metre and length of buried conductor is 11000 metre. Therefore, the total buried length of MS Rod conductors, L_T = 11000 m + (90 * 3) = 11270 metre
- $h = 1$ metre is the depth of the underground grid.

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., assuming 70% of fault current flowing through h soil and 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 and therefore

So,

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

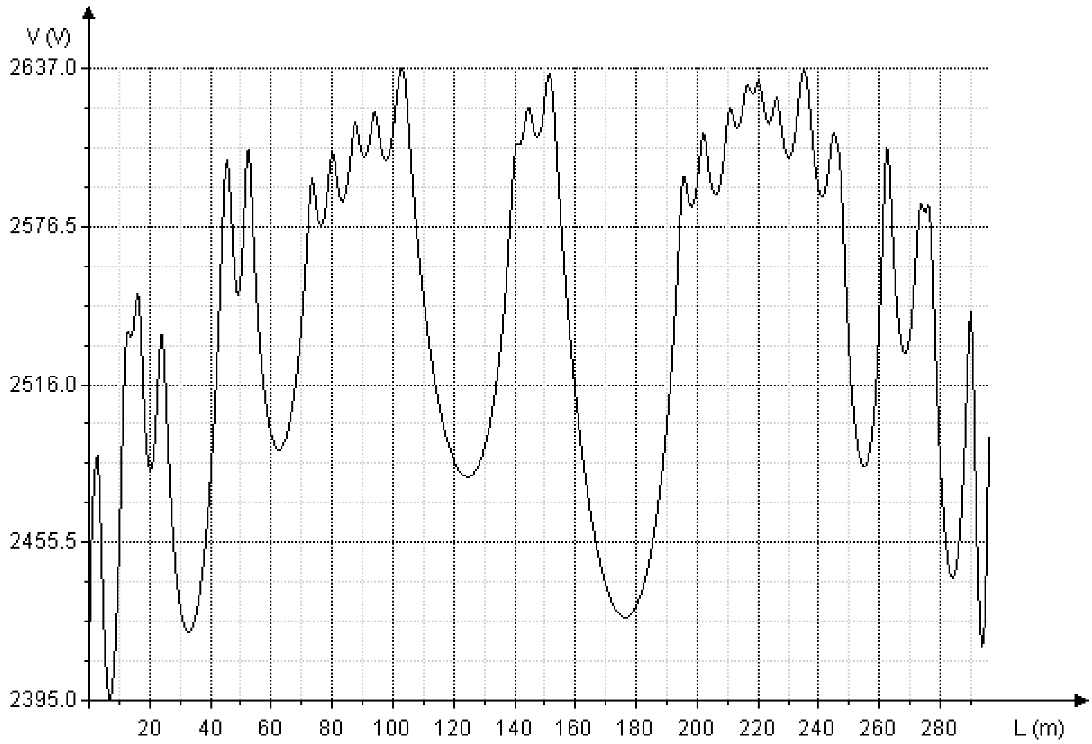

FIGURE 2. CAPELINE's GPR plot along diagonal red line of Fig.-1

The underground grid of 32mm diameter MS conductor is developed into CAPELINE and CDEGS program. The output Both the program were run individually to obtain GPR Plot (Fig.-2 & Fig-3). The three values of GPR are found to be comparable with that obtained mathematically (Refer table-1).

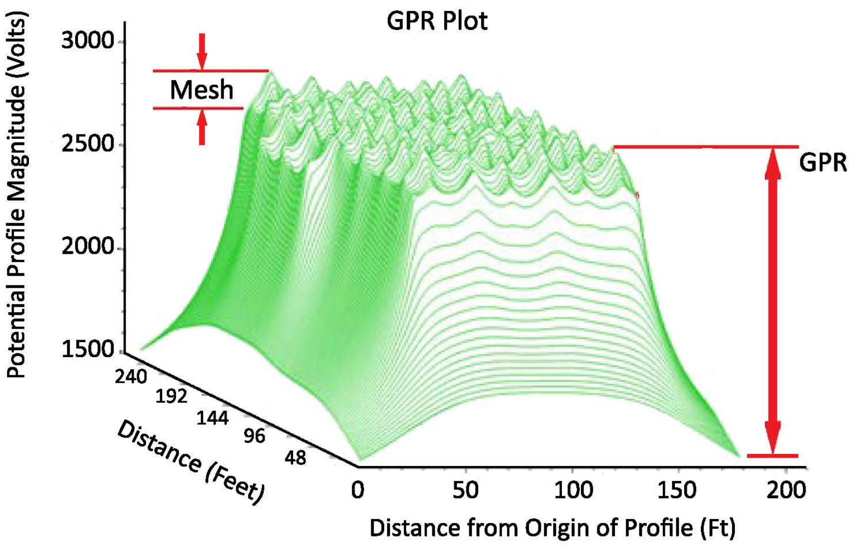

FIGURE 3. CDEGS's GPR plot along diagonal red line of Fig.-1

TABLE 1. Comparison of Ground Potential Rise during fault

Calculation	CAPELINE Program	CDEGS Program	Remarks
2520 V	2637 V	2510 V	Comparable & Acceptable

4. CONCLUSION

The values of ground potential rise are comparable and acceptable to power station, meeting the regulation requirement as well. These software are useful to ascertain the layout of sensitive electrical, control and instrumentation panel, communication system and IT system based on various voltage profile, so as to avoid exposure to sudden high voltage due to fault, which otherwise would cause failure.

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