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MATHEMATICAL CALCULATION OF GROUND POTENTIAL RISE 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. This could be a ground potential rise, which is dangerous and result into electric shock and/or loss of life to O&M personnel, stakeholder or animal. In 2018, there was death of 12,154 people due to electrocution alone, constituting 3.0% of total accidental and suicidal death in India. Unfortunately, this has a rising trend over the years. The ground potential rise is part of earthing grid design, which plays an important role to electrical safety. The purpose of the paper is to mathematically calculate the ground potential rise in a CCPP and compare with that obtained from CAPELINE software, in order to facilitate the earth grid design for safety of plant, O&M personnel.

1. INTRODUCTION

Power station is designed for a useful life of 25 years effective from date of commercial operation, however, may be operated beyond after life extension, or Renovation & Modernization. The associated underground earth grid is designed for 30-50 years as per project technical specification. During lifetime,

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the power system is subjected many times, to electrical ground fault with different degree of fault level or short-circuit levels. The after effect of the fault results into sudden change in plant operating parameter because of abnormally high current and/or over voltage, leading to tripping of power plant or tripping and/or possible damage of plant equipment [1]. It gives rise to GPR (a voltage hazard), resulting into electric shock and/or loss of life, panic to O&M personnel, stakeholder or animal. GPR is part of underground earth grid design of a power station or sub-station, playing an important role to electrical safety. So, GPR is calculated mathematically and compared with GPR Plot obtained from CAPELINE, for design of sub-station.

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].

Table 1. Death from electrocution in India in 2014-18 [3]

Year	Death from Electrocution*
2014	9606
2015	9986
2016	11126
2017	12004
2018	12154

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 [4]. Between 1997 - 2020, there was significant growth of 2,82,895 MW in 23 years [4]. The earthing design is based on max fault level,as envisaged 30-50 years ago.

3. Design Calculation, Analysis and Results

As per Industry practice, earth grid is designed based on maximum fault current and other parameters as per standards [5][6][7][8][9], Safety regulation [2], Project technical specification, data sheet, etc.

With capacity addition and grid Interconnection, fault level increases, lead in 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 the plant design, usually furnished by plant owner:

- I = Max. Fault current of 40kA for 1 sec at 220kV.
- Shock duration is 0.5 sec (Note-tripping time includes Relay & circuit breaker operating time kept less than 500 millisecond).
- t_c = 1 Sec, Duration of fault current for earth-mat sizing
- Fault current division factor of 0.7.
- Weight of Operating personal = 50 kg to determine Permissible Step and Touch Potential.
- Earth mat conductor material: MS rod (Note-could be Copper, decided by Owner). Conductor type for buried earth mat and risers: Mild Steel rod.
- Equivalent Earth resistance to be achieved in Power Plant area less than 1.0 Ohm.
- Resistivity of concrete surface/ rock = 3000 Ohm-m.
- Earth mat in different areas of the Power Plant are interconnected
- Mean Soil resistivity = 53 Ohm-m.
- Corrosion factor for buried mild steel conductor: 15%. (Note - 53 Ohm-m is categorized as mild corrosive and 15% corrosion allowance [6]. Corrosion in steel is about six times faster than copper, however. MS rod is widely used because of cost economics.

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]:

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

where:

- 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 ^0C

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

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

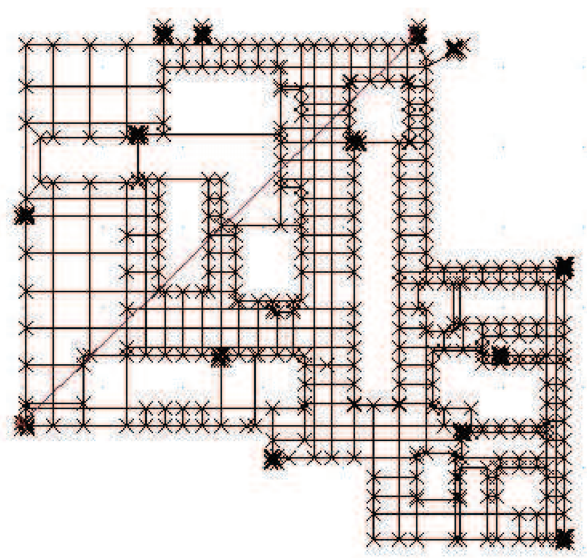

FIGURE 1. Plot Plan with underground earth grid of Power Station

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 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 is area occupied by the ground grid is 60105.5 m^2;
- no of ground rod is 90,
- length of MS Rod is 3 metre
- 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.**

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

where,

- 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, Decrement factor for entire duration of Fault of 30 cycles (0.5 s or more as per IEEE 80).

Entire plot plan having underground grid network of MS Rod conductor is developed into CAPELINE. The program is run to obtain GPR Plot (Fig.-2). GPR

TABLE 2. Comparison of Ground Potential Rise during fault

Calculation	CAPELINE Program	Remarks
2800 V	2637 V	Acceptable

can be reduced by deep driven rod. GPR voltage is useful in ascertaining the location of various switch gear room and control room, layout of sensitive electrical, control and instrumentation panels in Power Plant so that they don't experience high voltage, which otherwise would cause failure of the electronic cards

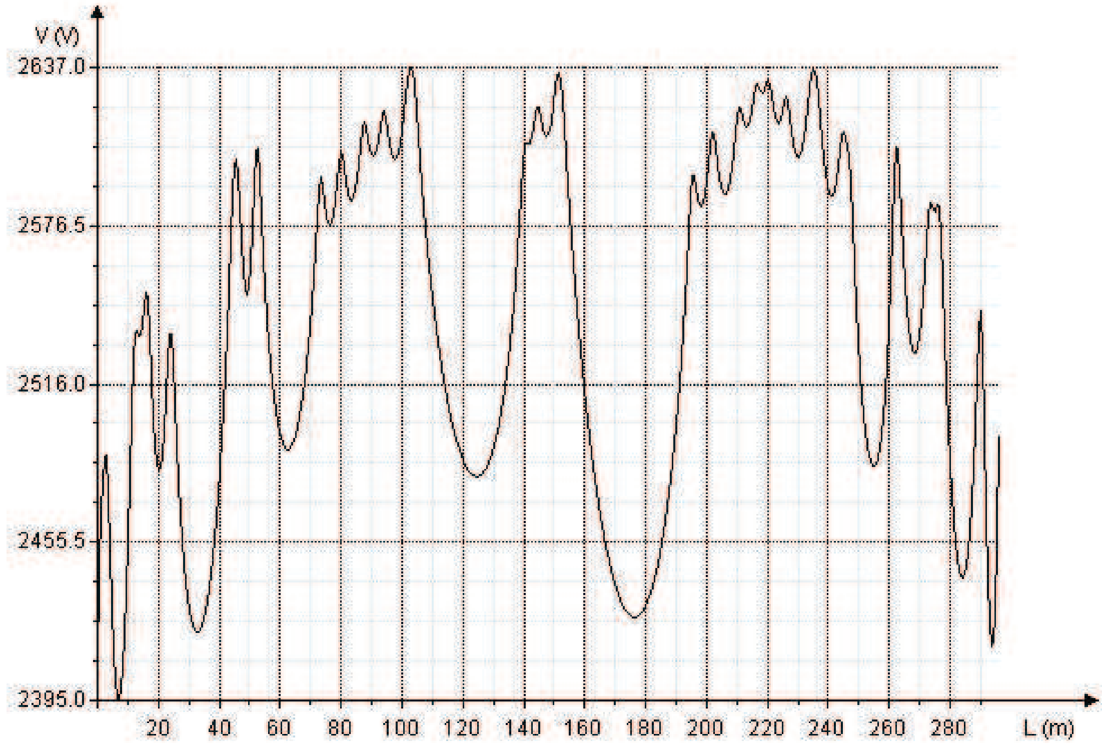

FIGURE 2. CAPELINE's GPR plot along diagonal red line shown in Fig.-1

4. CONCLUSION

The mathematical calculation of GPR is comparable with that obtained from CAPELINE program, acceptable to industry. Various GPR can be obtained along various profile of the earth grid, which is used to complete design of electrical installation. XL based calculations cannot provide the same.

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