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Simplified Method for Substation Grounding System Design

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ABSTRACT

This paper focused 230/66 kV, substation grounding system and calculation results of required parameters at location of Kalay region. The grounding system is essential to protect people working or walking in the vicinity of earthed facilities and equipments against the danger of electric shock. It provides the floor surface either assures an effective insulation from earth potential or effectively equipment to a close mesh grid. Calculations of grounding grid system in the substation area where the top soil-layer resistivity is less than the bottom-layer resistivity can be less the number of ground rod used in the grid because the value of Ground Potential Rise (GPR) is insignificantly different. To get desired parameters such as touch and step voltage criteria for safety, earth resistance, grid resistance, maximum grid current, minimum conductor size and electrode size, maximum fault current level and resistivity of soil are designed in detail consideration.

KEYWORDS: *substation grounding, earth resistance, soil layer resistivity, round potential rise, mesh gird*

1. INTRODUCTION

Substation grounding provides a low impedance path and carries current into ground under normal and fault conditions without adversely affecting continuity of service. Under a fault condition, the ground voltage may rise to a level that may endanger the public outside the vicinity of the substation. So, grounding system is required essentially for all power system [1].

The original purpose of the protective earth was to ensure the safety of people and property within the zone served by the earthing system. This requires a high current capacity path with relatively low impedance at the fundamental frequency so that voltages developed under high fault current conditions are not hazardous. The intent of thesis is to provide guidance and information pertinent to safe grounding practices in AC substation design. The specific purposes of this thesis are to establish, as a basic for design, the safe limits of potential differences that can exists in a substation under fault conditions between points that can be contacted by the human body. Develop criteria for safe design, practical grounding systems, based on these criteria[3]. Lightning an short circuit: the earthing system must protect the occupants, prevent direct damage such as fire, flashover or explosions due to a direct lightning strike and overheating due to a short-circuit current.

2. Ground Mat (earth-mat)

The term ground mat applies only that of path of grid which is burried in the soil. A solid metallic plate, rod or a system of closely spaced bare conductors that are connected to and often placed in shallow depths above a ground grid or elsewhere at the earth's surface, in order to obtain an extra protective measure minimizing the danger of the exposure to high step or touch voltages in a critical operating area or places that are frequently used by people. Grounded metal gratings placed on or above the soil surface, or wire mesh placed directly under the surface material, are common forms of a ground mat [4].

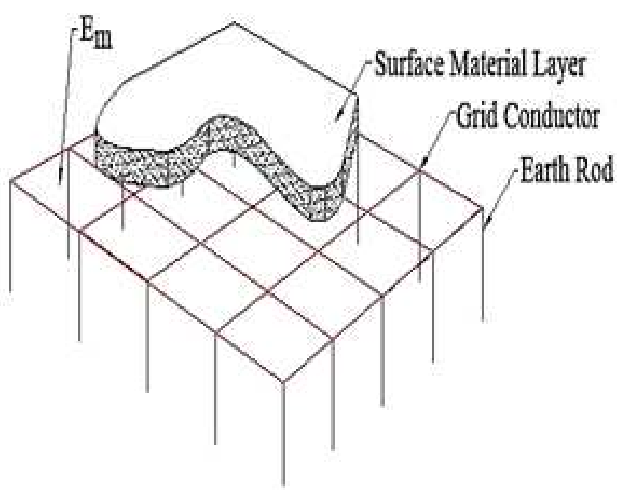

Figure1. Ground Grid Mat (earth-mat)

Busbar structures and equipment structures was earthed at two points. Marshalling boxes, cubicles and all other metallic enclosures, which are normally not carrying any current, were earthed. In the substation Disconnecting switch with earth-switch, circuit breaker, Lightning arrester, Potential transformer, Current transformer, Power transformer, Equipment's body and structures, Cubicles are installed compactly. All of these are grounded at the body of structure. All other equipments such as Circuit Breakers, CTs, Isolators, Post Insulators, etc. were earthed at two points.

3. Design Characteristics

For 230/66kV substation, 100MVA outdoor AIS substation. Need to calculate the deliverable single line to ground fault current of substation. And related transmission line impedance Z_1, Z_2, $Z_0(R+jX_L)$ values from hand calculation. Soil resistivity can be determine with visual inspection or proper measurement devices (Four Pin Earth Tester)[3]. It plotted to measure the following model. For square shaped Grid/Mat as bellows;

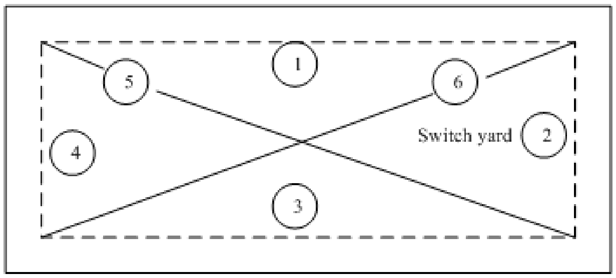

Figure2. Six Locations for Earth Resistivity Measurement

Table1. Soil Resistivity Measurement Record Table

Location	Test Pin Spacing	Meter Display Ohm-meter	Remark
Direction 1	4	65	Avg 48 Ω-m
Direction 2	4	33	
Direction 3	4	60	
Direction 4	4	36	
Direction 5	4	56	
Direction 6	4	40	

Substation Available Area,
$A = 60m \times 60m = 3600m^2$
Grid Spacing, D = 6m
Grid burial depth, h = 0.8-1 m (for 230kV and above level)
Length of each Ground rod, L_r = 4m
Max Line to Ground Fault Current, I_f = 7.0kV, 66kV Bus side
Duration of fault in sec, t_c = 1 sec
Primary Line Voltage = 230,000V
Secondary Line Voltage = 66,000V
Soil resistivity, ρ = 48 Ω-m (Wenner Four Pin Method)
Surface crushed rock resistivity, ρ_s = 2500 Ω-m
Number of Earth rod = 46 Nos

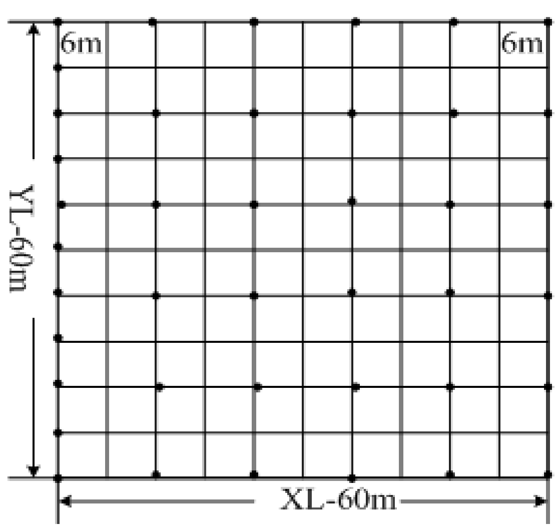

Figure3. Preliminary Calculation of Touch and Step Voltage

$$A_{kcmil} = I \times K_f \sqrt{t_c}$$ Equation (1)

Switchyard surface layer is crushed rock 4"(0.102m) thickness, with resistivity of 2500 Ω m, and for an actual inner resistivity of 48Ω.m by four pin tester. The reflection factor K is computed using the following equation;

$$K = \frac{\rho - \rho_s}{\rho + \rho_s}$$ Equation (2) (1)

Linemen or operator body's weight can be expected at least70kg, (assume RB:1000Ω). So that, consider the permissible/ tolerable step and touch voltage initially.
Fault current, If = 3I0,

$$= \frac{3 \times V/\sqrt{3}}{3 \times R_f + (R_1 + R_2 + R_0) + j(X_1 + X_2 + X_3)}$$

where; Km = geometrical factor, ρ = the soil resistivity, a corrective factor, IG = maximum grid current For square shaped mat design

$$K_m = \frac{1}{2\pi}\left[\ln\left\{\frac{D^2}{16 \cdot h \cdot d} + \frac{(D+2h)^2}{8 \cdot D \cdot d} - \frac{h}{4 \cdot d}\right\} + \frac{K_{ii}}{K_h} \cdot \ln\left\{\frac{8}{\pi(2 \cdot (n-1))}\right\}\right]$$

$K_{ii} = 1.0$ (with rods), $h_0 = 1$ (usually constant)

$$K_h = \sqrt{1 + \frac{h}{h_0}}$$

Irregularity factor; $K_i = 0.644 + (0.148 \cdot n)$
Mesh Voltage;

$$E_m = \frac{\rho \times I_G \times K_m \times K_i}{L_C + \left[1.55 + 1.22 \times \left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] \times L_R}$$

The effective buried conductor length (Ls); (with or without ground rods)

$$L_S = (0.75L_C + 0.85L_R)$$

$$K_S = \frac{1}{\pi}\left[\frac{1}{2 \cdot h} + \frac{1}{D + h} + \frac{1}{D}\left(1 - 0.5^{n-2}\right)\right]$$ Equation (3) (1)

Step Voltage; Es

$$E_S = \frac{\rho \cdot K_S \cdot K_t \cdot I_G}{L_S}$$ Equation (4)

Earthing grid resistance

$$R_g = \rho\left[\frac{1}{L_1} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]$$ Equation (5)

The Schwarz equations that are modeling the effect of earthing rods or electrodes shown as below[2].

$$R_g = \frac{R_1 R_2 - R_m^2}{R_1 + R_2 - 2R_m}$$ Equation (6)

Touch voltage limit-the maximum potential differene between the surface potential and potential of an earth conducting structure during a fault due to ground potential rise.

Etouch(50kg) = (RB+1.5ρ)*IB(50) Equation (7)

Etouch(50kg) =(1000+1.5Csρs)*IB(50) Equation (8)

Etouch(70kg) = (RB+1.5ρ)*IB (70) Equation (9)

Etouch(70kg) = (1000+1.5Csρs)*IB (70) Equation(10)

Step voltage limit-the maximum difference in surface potential experienced by a person bridging a distance of 1m with the feet without contact to any earthed object.

For 50kg, $I_B = \frac{0.116}{\sqrt{t_s}}$ Equation (11)

For 70kg, $I_B = \frac{0.157}{\sqrt{t_s}}$ Equation (12)

Estep(50kg) = (RB+6ρ)*IB(50) Equation (13)

Estep(50kg) = (1000+6Csρs)*IB(50) Equation (14)

Estep(70kg) = (RB+6ρ)*IB(50) Equation (15)

Estep(70kg) = (1000+6Cs ρs)*IB(50) Equation (16)

The minimum conductor size capable of withstanding adiabatic temperature rise associated with earth fault, Amm2

$$= I_f \times \frac{1}{\sqrt{\frac{TCPA \times 10^{-4}}{t_c \alpha_r \rho_r} Ln\left(\frac{K_0 + T_m}{K_o + T_a}\right)}}$$ Equation (17)

Where; TCAP = temperature capacity per unit volume, αr = thermal co-eff of resistivity, ρr = resistivity of ground conductor, Ta = ambient temperature,Tm = maximum allowable temperature The diameter of the grid conductor,

$$d = \frac{4 \times A_{mm}{}^2}{\pi}$$ Equation (18)

4. Results and Discussion

The large substation, the ground resistance is usually about 1Ω of less. In smaller distribution substation the usually acceptable range is from 1 to 5Ω, depending on local conditions in table (1).The designation of step voltage, mesh voltage and ground resistance are expressed in comparison situation. The effective buried conductor length;L_s(with or without ground rods), length or grid conductor, ground conductor, grid current, grid resistance, ground potential rise are focused consideration on existing substation data. In this calculation, a tolerance of $\pm 5\%$ is assumed in all parameters. The result GPR value is very important and it should be less then permissible touch voltage in table (2). Because of consideration, switchyard surface layer is crushed rock 4"(0.102m) thickness, with resistivity of 2500 Ω m, and for an actual inner resistivity of 48Ω.m by four pin tester and Resistivity of surface crushed rock causes to a reduction factor C_s.

Linemen/Operator body's weight can be expected at least70kg, (Assume R_B:1000Ω). So that, consider the permissible/ tolerable step and touch voltage initially. Finally, this allowed value will decide the obtained a safe limit design. $A_{mm}{}^2$ based on this computation, a copper wire as small as size 4.74mm could be used but due to the mechanical strength and ruggedness requirements, a larger size, d=15mm is usually as a minimum for future fault level and future generation capacity. In this case, d_{min} = 15-16 mm, standard copper wire is should be choice for better grid. In view of the above results, the earth mat design and configuration is successful and completed as shown in tables.

Table2. Comparison of Permissible and Designed Values

	Designed	Permissible/ Allowed
Step Voltage (E_s)	119.46V	<2553V
Mesh Voltage(E_m)	179.44V	<804.7V
Grid Resistance, R_g	0.38 Ω	1 Ω
Earth Mat Design is safe and Completed		

Table3. Result Table for Substation Grounding System

Reflection factor (K)	-0.96
Reduction factor (C_s)	0.7
Step voltage (E_{step70})	2553V
Touch voltage ($E_{touch70}$)	804.7V
Total length of all earth rod (L_R)	184m
Total length of horizontal conductor (L_C)	1320m
Parameter length of grid conductor (L_g)	240m
Total ground conductor length (L_T)	1504m
Grid resistance (R_g)	0.38Ω
Grid current (I_G)	4200A
Ground Potential Rise (GPR)	1596V
Geometrical factor (K_m)	0.633
Irregularity factor (K_i)	2.272
Mesh voltage (E_m)	179.44V
Effective buried conductor length (L_s)	1153.2
Step voltage (E_{step})	119.46V

Conclusions

The grounding system in a substation consists of a minimum of four earth electrodes installed around the inside perimeter of the substation and connected together with the earth mesh the exact spacing of the electrodes which will be based on local conditions, resistivity of the area and space available for electrodes. The spacing between should be greater than the electrodes' length. Although the earth mesh will often result in a low enough resistance without the use of electrodes, fifty electrodes are still necessary in this to ensure the fault level capability and forty-six electrodes are used for neutral ground grid. Electrodes are also required in case of the drying out of the soil at the depth of the earth mesh in long dry spells. The size of the high voltage grounding conductors is determined by the earth fault level but in any case shall be not smaller than 70 mm^2 copper. The size of the main grounding conductor shall not be smaller than 25 mm^2 copper.

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