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Optimal Design of Earthmat for 110kV Substation using ETAP 12.6

Jigyesh Sharma[1]

Assistant Manager, Department of Engineering & Design, Larsen & Toubro ltd, Mumbai, Maharstra, India[1]

ABSTRACT: This paper describes the design of an earthing system for 110kV switchyard in Tamilnadu state of India using ETAP 12.6.The buried earth mat is preferable to large substation because of space saving on ground level due to reduction in quantity of earth pits. Soil resistivity is measured through Wenner 4 point method. Earth mat reduces the danger of step potential or touch potential in the areas which are frequently used by substation engineers. The quantity of conductors and rods are obtained by various iterative simulations using ETAP 12.6. This paper also compares to the result obtained using manual calculation & ETAP 12.6 software.

KEYWORDS:ETAP 12.6; touch potential, step potential; earth mat; Ground potential rise (GPR)

I.INTRODUCTION

Earthing system provides low impedance path for electric current to earth without exceeding operating limits of the equipment. The accurate design of an earthing system isessential to assure the safety of the persons, to protect the equipment and to avoid interruptions in the power supply. Thus, the apparent electrical resistance of the earthing system must be low enough to guarantee that fault currents dissipate mainly through the earthing electrode into the ground, whilethe values of electrical potentials between close points on the earth surface that can be connected by a person must be kept under certain maximum safe limits [1, 2]. .Furthermore, it ensures that in the event of a fault, the current is easily dissipated into the earth without damaging the equipment's or exposing personnel on site to dangerous touch and step voltages [2]. Factors to be considered while designing an earthing system such as soil electrical resistivity, system fault level, fault clearing time, area occupied by the substation plot, etc. varies from substation to substation; it is not possible to have a common design.

Earth mat design can be done by manual calculations as well as with the help of computer software. Though manual calculation is a good, software tools ensure a detailed design so that the earth mat is neither under-designed hence safe nor overdesigned hence cost effective.

II.SOIL RESISTIVITY

Soil resistivity plays a vital role in designing of earthing system for substations. Soil resistivity has direct impact on earth grid resistance and quantity of conductors and rods required for optimum design [2] In areas where the soil resistivity is rather high or the substation space is at a premium, it may not be possible to obtain a low impedance grounding system by spreading the grid electrodes over a large area, as is done in more favourable conditions. Such a situation is typical of many GIS installations and industrial substations, occupying only a fraction of the land area normally used for conventional equipment [1, 2].

Factors affecting soil resistivity are soil type, presence of moisture, temperature, content of salt

III.EARTH MAT DESIGN

Substation earth system will have a combination of buried horizontal conductors in rows and columns and vertical electrodes. A sold metallic plate 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 form of a ground mat. This calculation is based on IEEE Std 80 (2000), "Guide for safety in AC substation earthing". There are two main parts to this calculation:

1. Earthing grid conductor sizing
2. Touch and step potential calculations

IEEE Std 80 is quite descriptive, detailed and easy to follow, so only an overview will be presented here and IEEE Std 80 is consulted for further details.

A.DETAILS OF INPUT REQUIRED

1) Fault current and duration: Maximum earth fault current into the earthing grid .The fault duration is the time for which the fault current will flow through the grid before protective devices operate and interrupt the fault. Here, a fault current of 40kA is considered and fault duration of 1 second is considered for conductor sizing whereas 0.5 second is used to estimate the permissible step and touch potential values.

2) A layout of the site: From site layout, we can find the area which the buried earth mat will cover. It will have a considerable impact on grid resistance. In our analysis we have considered a layout of 110kV switchyard at ariyalur of 66 m x 66 m.

3) Surface layer: The current through the body will be lowered considerably with the addition of the surface material because of the greater contact resistance between the earth and the feet. However, this resistance may be considerably less than that of a surface layer thick enough to assume uniform resistivity in all [1].Hence high surface resistivity will allow a smaller magnitude of current to flow on the surface. In this design surface resistivity of 3000 ohm-m and depth of 0.15 m is considered.

4) Material for conductors and rods: Material constant such as fusing temperature, thermal capacity, and conductivity will have impact on size of the conductor/rods chosen. In our case we will consider steel 1020 grade.

5) Depth of grid: It will have impact on grid resistance as per equation (52) of IEEE 80. IEEE 80 suggest that depth of burial shall be in between 0.5 m to 1.5 m below the surface. In our design depth of grid is 1 m.

6) Fault current division factor: In case where there is overhead ground wires, whole fault current does not passes though the grid. This factor is generally used to avoid overdesigning of earth mat grid. In our design current division factor is 0.6.

B. EARTH GRID CONDUCTOR SIZE

Determining the minimum size of the earthing grid conductors is necessary to ensure that the earthing grid will be able to withstand the maximum earth fault current.The minimum conductor size capable of withstanding adiabatic temperature rise associated with earth fault is given by IEEE Std 80 Equation 37 represented by (1).It is re-arranged to find Area of conductor.

$$I = A_{mm^2}\sqrt{\frac{(TCAP \times 10^{-4})}{t_c\,\alpha_r\,\rho_r}\ln\left\{\frac{K_0+T_m}{K_0+T_a}\right\}}(1)$$

where

I	is the rms current in kA
Amm2	is the conductor cross section in mm2
Tm	is the maximum allowable temperature in ºC
Ta	is the ambient temperature in ºC
Tr	is the reference temperature for material constants in ºC
α r	is the thermal coefficient of resistivity at reference temperature Tr in 1/ºC
ρ r	is the resistivity of the ground conductor at reference temperature Tr in μΩ-cm
Ko	1/α o or (1/α r) – Tr in ºC it is a constant
Tc	is the duration of current in s.

In our design, data based on IEEE-80 table 1.[2]

Table-I

I	40 kA
t_c	1 Sec
T_m	1510 ^{0}C
T_a	50 ^{0}C
α_r	0.0016 1 / ^{0}C
p_r	15.9 μΩ-cm
K_0	605 ^{0}C
TCAP	3.28 J/cm^{30}C

Hence area comes as: $A_{mm^2} = 325.37\, mm^2$

C ALLOWABLE TOUCH POTENTIAL & STEP POTENTIAL

Safe earthing grid is to protect people against lethal electric shocks in the event of an earth fault. The maximum tolerable voltages for step and touch scenarios can be calculated empirically from IEEE -80 Std Section 8.3 for body weights of 50kg and 70kg: Touch voltage limit - the maximum potentialdifference between the surface potential and the potential of an earthed conducting structure during a fault (due to ground potential rise):

$$E_{touch} = (1000 + 1.5 . C_s . \rho_s) \frac{0.116}{\sqrt{t_s}} \quad (2)$$

Where C_s is the surface layer de-rating factor.
$\rho_s$is the surface material resistivity in Ω-m
$t_s$is the duration of shock current in seconds

C_s can be obtained from:

$$C_s = 1 - \frac{0.09(1-\frac{\rho}{\rho_s})}{2h_s+0.09} \quad (3)$$

Where ρ is the soil resistivity in Ω-m.
$\rho_s$is the surface material resistivity in Ω-m
$h_s$is the depth of the surface layer in m.

In our design the value of above parameter is considered as Table II

ρ_s	3000 Ω-m
h_s	0.15 m
t_s	0.5 sec

Putting these value in equation (2) & equation (3) we get
C_s =0.7715
E_{touch}=992.91 volts.

$E_{step} = (1000 + 6.C_s.\rho_s)\frac{0.116}{\sqrt{t_s}}$(4)

Putting the values in equation 4(input data is obtained from table II) we get,

$E_{step} = 3305.54$ volts

D.Earth grid design verification

Now we just need to verify that the earthing grid design is safe for touch and step potential. The mesh voltage is the maximum touch voltage within a mesh of an earthing grid and is derived from IEEE Std 80 Equation 80 as given by

$E_m = \frac{\rho\, K_m K_i I_G}{L_m}$ (5)

Where, ρ is the soil resistivity in Ω-m.

$K_m$is the geometrical spacing factor

$K_i$is correction factor for grid geometry

$$K_m = \frac{1}{2\pi}.\left[\ln\frac{D^2}{16.h.d}+\frac{(D+2.h)^2}{8.D.d}-\frac{h}{4.d}\right] + \frac{K_{ii}}{K_h}.\ln\left[\frac{8}{\pi.(2.n-1)}\right] \quad (6)$$

Where D is the spacing between parallel grid conductors in m.

d is the cross-sectional diameter of a grid conductor in m.

h is the depth of buried grid conductors in m.

$K_h = \sqrt{1 + h}$ (7)

K_{ii} =1 (For grids with ground rods along the perimeter, or for grids with ground rods in the grid corners, as well as both along the perimeter and throughout the grid area)

L_m Effective length of Lc + LR for mesh voltage in m.

L_R is the total length of all ground rods in m

$L_c$is total length of horizontal grid conductor in m

$K_i$is irregularity factor for grid geometry.

$I_G$is the maximum grid current that flows between ground grid and surrounding earth

$K_i = 0.64 + 0.148\, n$(8)

$n = n_a . n_b . n_c . n_d$ (9)

Where $n_a = 2.\frac{L_c}{L_p}$ (10)

$L_c$is the total length of the conductor in the horizontal grid in m.

$L_p$is the peripheral length of the grid in m.

Referring to point A (2), our grid mat is design for layout 66 m x 66 m.

Considering 12 conductors in X direction & 12 conductors in Y direction. L_c = 66 x 12+ 66 x 12.

=1584 m.

Having square layout L_p= 4 x 66

= 264 m.

n_b=1 for square grids [1].

n_c=1 for square and rectangular grids [1].

n_d=1 for square rectangular and L shaped grids [1].

Putting the values of L_c&L_p in equation (9) we get n_a=12.

Putting above values in equation (9) we get n= 12.

For equation (6) & (7) with h =1 m,n=12,D=6 m,d=0.032 m.

From equation (7) K_h =1.414.

K_m=0.59334.

From equation (8) K_i =2.42.

ρ = 30 Ω-m.
$I_G = I_g . D_f . S_f$ (11)
Where I_g is symmetrical grid current in kA
$D_f$is 1 for X/R=15 and for fault duration of 0.5 sec[1]
$S_f$is 0.60(say).
Substituting these values in equation 11 we get
I_G=2400

Substituting above values in equation (5) we get E_m=617.58 V

E.STEP VOLTAGE CALCULATION

As per IEEE-80 the step voltage is

$$E_{step} = \frac{\rho . K_s . K_i . I_G}{0.75 L_C + 0.85 L_R} \quad (12)$$

L_C = total length of conductor in horizontal grid
L_R = total length of vertical rods.
In our design length of vertical rods 3m and number of rods =30.
Hence value of L_R=90 m, and value of L_C as aobtained in section D is 1584m.

$$K_s = \frac{1}{\pi}\left[\frac{1}{2.h} + \frac{1}{D+h} + \frac{1}{D}\left(1 - 0.5^{n-2}\right)\right]$$

Substituting the value in equation (12) we get
E_{step} =354.85 V.

IV. RESULTAND ANALYSIS

As can be seen from above, touch and step potential calculations can be quite a tedious and laborious task, and one that could conceivably be done much quicker by a computer. Even IEEE Std 80 recommends the use of computer software to calculate grid resistances, and mesh and step voltages, and also to create potential gradient visualisations of the site.

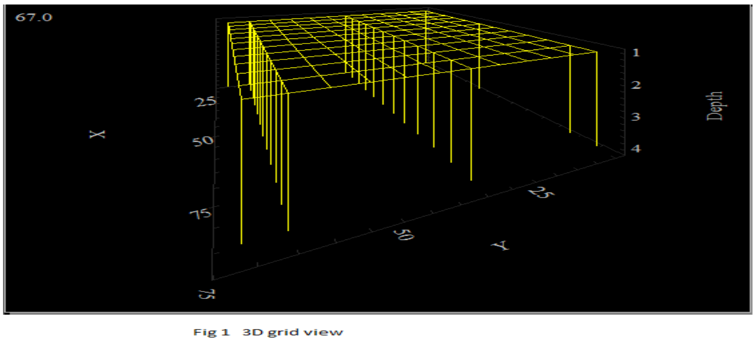
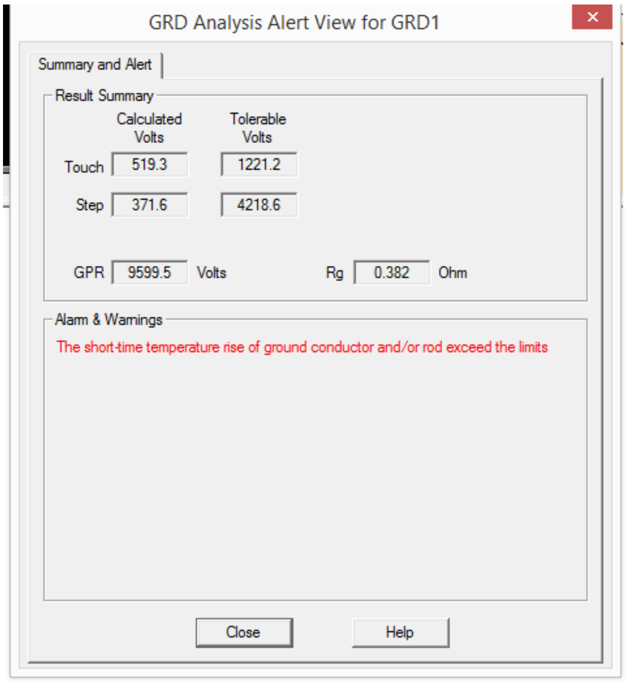


Fig 1 3D grid view of designed earthmat on ETAP 12.6

Fig 1 show the representation of grid designed on ETAP 12.6, number of conductors and vertical rods along the periphery of grid.



	Calculated Volts	Tolerable Volts
Touch	519.3	1221.2
Step	371.6	4218.6

GPR 9599.5 Volts

Rg 0.382 Ohm

Alarm & Warnings

The short-time temperature rise of ground conductor and/or rod exceed the limits

Fig 2 Etap results

Fig 2 ETAP simulation results

Fig 2 show the results of ETAP 12.6 for step potential, touch potential, ground potential rise(GPR),and overall grid resistance.

VI.CONCLUSION

A safe and reliable earthing system for 110 kV switchyard has been designed using ETAP 12.6 and results with manual calculations are compared. In table III. Manual calculations may be very tedious and difficult thus leading to incorrect results. Performing calculations and modifications to the design can be a long process. Computer programs have been developed to make the substation earthing design easier, and more accurate. In this paper, we have focused on earth mat design for large Substation. In the design optimization process, especially for complex systems, software simulation is essential. The step by step procedure for designing earth mat has been presented for which design parameters were obtained by ETAP Software.

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