Electrical Substation Earthing Design

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Abstract: Earthing is the most important part of any substation for reliable operation in substation. Earthing is provided in substation to protect equipment from getting failed and human from getting shocked in abnormal system condition. In this paper, design procedure of electrical substation earthing is explained. Through these design steps, calculation of earthing can be done easily. Calculation of earthing grid design parameters whether grid is of single area or two area can also be done. It also shows whether provided design is safe or not by comparing maximum tolerable & calculated step and touch voltage. Earthing grid area will be large as compared to substation switchyard area to ensure safety in substation.

***Index Terms* - Substation, Earthing, Step Voltage, Touch Voltage, Earthing Grid**

I. EARTHING

It is important to provide earthing in all the parts of electrical power system wherever required, whether it is provided in power generating station, transmission line or substation. It is very much important from point of view of protection of equipment and human safety. Substation is the most important place in power system where equipments like power transformer, circuit breaker, instrument transformer etc. are connected together to convert or control power between two ends of power system. All these equipments must require provision of earthing for safe and reliable operation. In substation, earthing must be provided with neutral point of transformer, reactor and with lightning arrester and with non-current carrying metal parts like structure, overhead shielding wire, body part of equipments, frames etc. for safety purpose. Human safety is also one of the main reasons behind provision of earthing in substation.

II. TYPES OF EARTHING

There are two types of earthing provided in substation. One is earthing mat or grid and other is earthing pit. Earthing pit in most the cases is pipe type earthing shown in Fig. 1 provided with lightning arrester and neutral part of transformer as well as reactor. Other than these, rest of the equipment body part, structures etc. are connected with earthing grid. Earthing grid shown in Fig. 2 is array of rod of specific dimension buried at required depth to keep the step and touch voltage within limit. Generally, the area of earthing grid has to be more than area of switchyard as all the required point in switchyard including fencing of switchyard which has to be connected with earthing grid for safety purpose. Earthing grid system can also be classified by number of area i.e. one area earthing grid and two area earthing grid which also affects the design of earthing in substation.
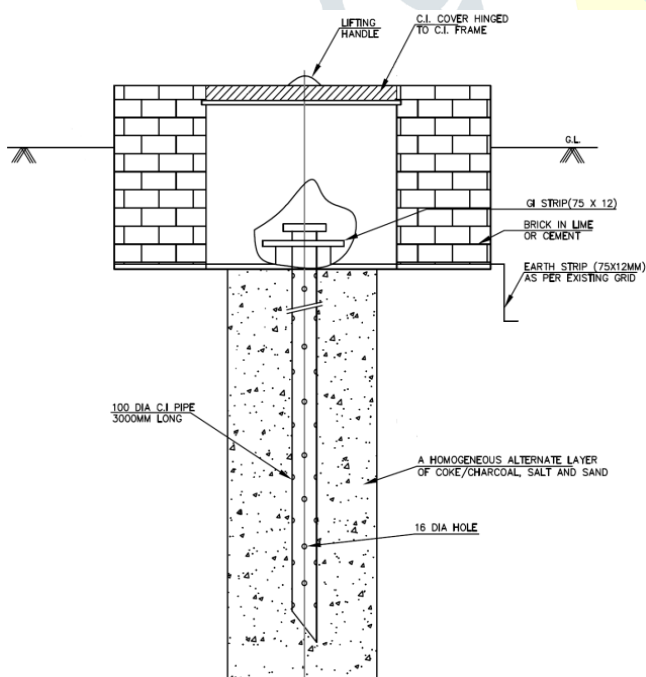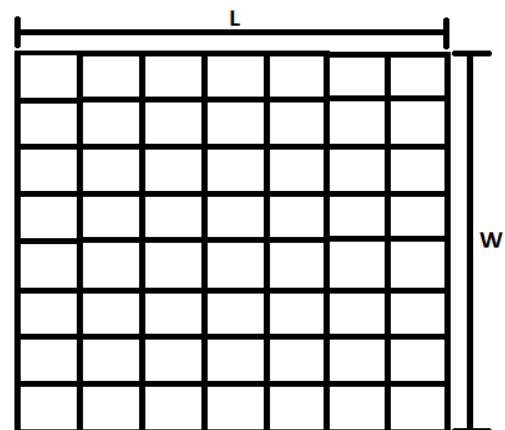

Fig. 1 Earthing Pit

Fig. 2 Earthing Grid

III. SUBSTATION EARTHING GRID DESIGN

3.1 Size of Earthing Grid Conductor

Earthing Grid Conductor Size can be calculated by

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

Where,

I = Symmetrical grid current in kA α_o = Thermal coefficient of resistivity

A_{mm^2} = Conductor cross section α_r = Thermal coefficient of resistivity at reference temperature

Tm = Maximum allowable temperature ρ_r = Resistivity of the ground conductor at reference temperature

Ta = Ambient temperature   tc = Duration of current in sec

Tr = Reference Temperature for material constants   TCAP = Thermal capacity per unit volume

Ko = 1/ α_o

After calculation of earthing grid conductor cross section, corrosion factor needs to be multiplied as per different ranges of resistivity of soil as per CBIP publication 223 [5] as grid conductor which in general is used of GI may get corrode because of soil moisture. Hence, conductor cross section needs to be multiplied with corrosion factor after which it will be verified that standard size of conductor which is actually used in grid is more than calculated which proves that used conductor will give safe design.

3.2 Grid Resistance

Value of grid resistance is given by

$$R_g = \rho * \left[\frac{1}{L} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right] \tag{2}$$

Where,

ρ = Soil Resistivity   h = Depth of grid

A = Area occupied by ground grid   L = Total buried length of conductor

3.3 Maximum grid current and Ground Potential Rise

Maximum grid current that flows between ground grid and surrounding earth which is one of the important parameter to calculate step and touch potential is given by,

$$I_G = D_f * S_f * I_g \tag{3}$$

Where,

Df = Decrement factor for duration of fault (as per table 1 [5])

Table 1 Typical values of Decrement Factor (Df)

Fault Duration (S)	Decrement Factor
0.008	1.65
0.1	1.25
0.25	1.10
0.5 or more	1.0

Ig = Symmetrical grid current

Sf = Fault current division factor (split factor)

$$S_f = \left|\frac{Z_{eq}}{Z_{eq} + R_g}\right| \tag{4}$$

Zeq = Equivalent impedance of the transmission and distribution ground system (as per IEEE 80-2000)

Ground Potential Rise is given by

$$GPR = I_G * R_g \tag{5}$$

3.4 Step and Touch Voltages

Earthing grid design mainly concentrates on two parameters i.e. Touch Voltage and Step Voltage. The potential difference between the GPR and the surface potential at the point where a person is standing while at the same time having a hand in contact

with a grounded structure is known as Touch Voltage as shown in Fig. 3 [1] - [2]. Equation 6 and 7 shows maximum tolerable touch voltage and actual touch voltage respectively.
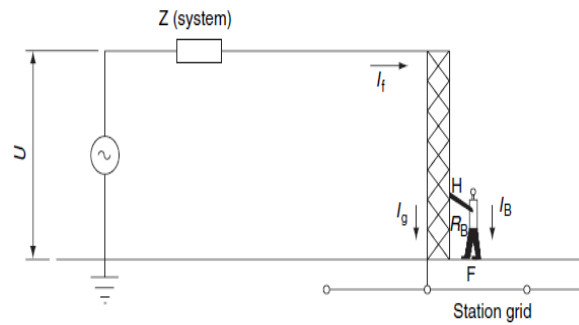

Fig. 3 Representation of Touch Voltage

$$E_{touch50} = (1000 + 1.5C_s\rho_s)\ \frac{0.116}{\sqrt{t_s}} \tag{6}$$

$$E_m = \frac{\rho K_m K_i I_G}{L_C + \ [1.55 + 1.22\left(\frac{L_r}{\sqrt{L_X^2 + L_Y^2}}\right)] \cdot L_R} \tag{7}$$

Where,

Cs = Surface layer derating factor   ts = Duration of shock for determining allowable body current
ρs = Surface material resistivity   Lc = Total length of conductor in horizontal grid
ρ = Earth soil resistivity   Lr = Length of ground rod
Km = Geometrical factor   Lx = Length of grid conductor in x-direction
Ki = Correction factor   Ly = Length of grid conductor in y-direction
IG = Maximum grid current   LR = Total length of ground rods

The difference in surface potential experienced by a person bridging a distance of 1 m with the feet without connecting any other grounded object is known as Step Voltage as shown in Fig. 4 [1] - [2]. Equation 8 and 9 shows maximum tolerable step voltage and actual step voltage respectively.
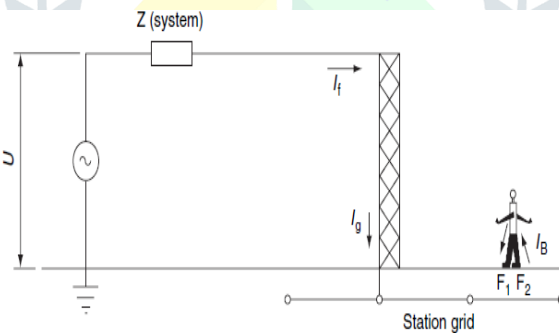

Fig. 4 Representation of Step Voltage

$$E_{step50} = \ (1000 + 6C_s\rho_s)\ \frac{0.116}{\sqrt{t_s}} \tag{8}$$

$$E_s = \frac{\rho \cdot I_G \cdot K_s \cdot K_i}{0.75 \cdot L_C + \ 0.85 \cdot L_R} \tag{9}$$

Where,

Ks = Geometrical factor   ts = Duration of Shock for determining allowable body current
LR = Total length of ground rods   Lc = Total length of grid conductor
IG = Maximum grid current   Ki = Irregularity factor

Earthing grid is important part of any substation for the protection of human as well as equipment. All the non-current carrying part in substation like structure, equipment body part will be connected with earthing grid. Calculated or actual value of touch and step voltage has to be less than maximum tolerable value. Also, value of earth resistance should be less than below given values:

For Large Power Station: 0.5 Ω
For Major Substation: 1.0 Ω
For Minor Substation: 2.0 Ω

Care needs to be taken while designing earthing grid. All the design steps mentioned above for designing substation earthing grid as per IEEE 80-2000 are given in flow chart form in Fig. 5.
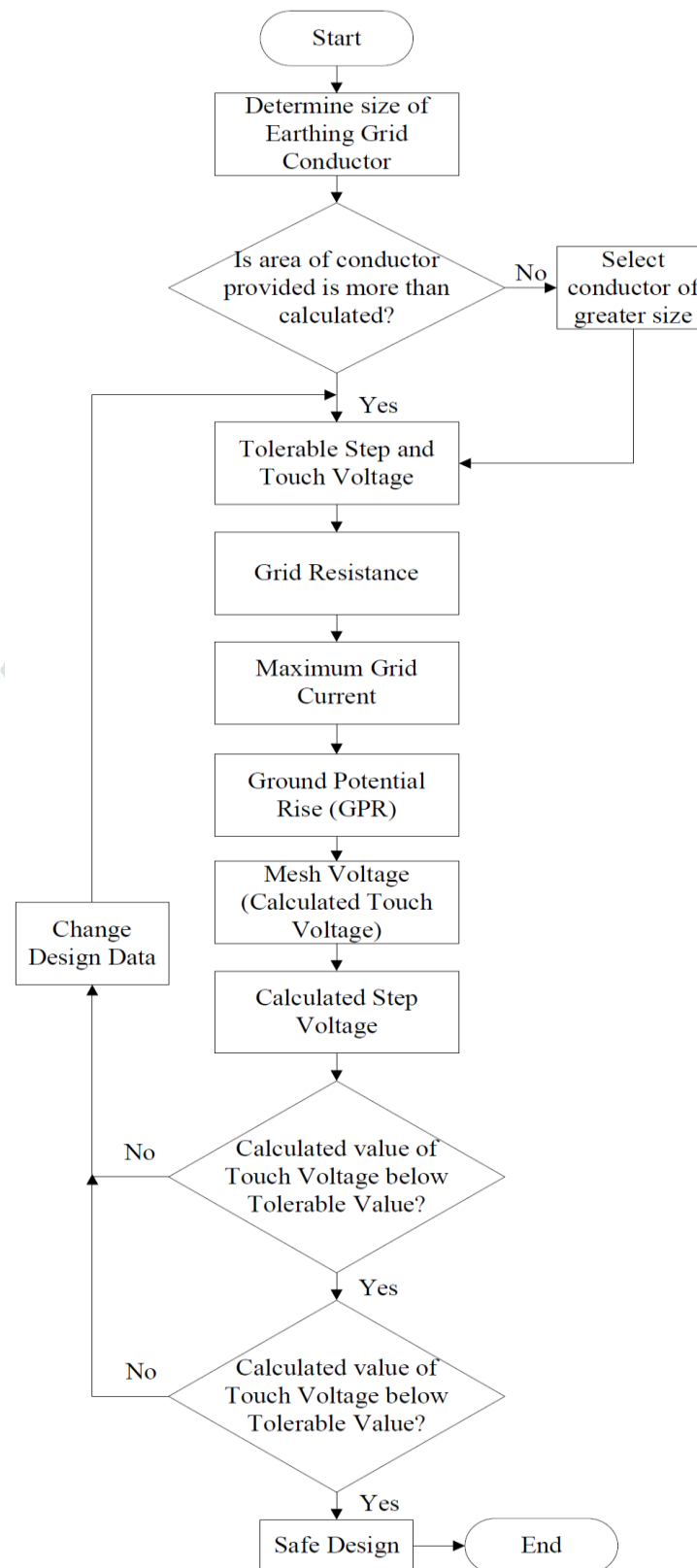
Fig. 5 Earthing Grid Design Steps

IV. DESIGN CALCULATION AND ANALYSIS

Considering substation switchyard of 132 kV having area of 165 X 96 meters whose earthing grid is to be designed with following data:

Symmetrical fault current in substation (Ig) = 32000 A
Duration of fault current for sizing ground conductor (tc) = 1 Sec
Surface layer resistivity (ρs) = 3000 Ωm
Surface layer Thickness (hs) = 0.15 m
Grid Reference Depth (ho) = 1.0 m
Soil Resistivity (ρ) = 10 Ωm
Depth of ground Grid conductors (h) = 0.5 m

Length of Grid conductor in X direction (Lx) = 170 m
Length of Grid conductor in Y direction (Ly) = 100 m
Spacing between parallel conductors (D) = 10 m
No. of Grid conductor in X direction (Nx) = 11
No. of Grid conductor in Y direction (Ny) = 18
Length of Ground rod at each location (Lr) = 3 m
Number of rods placed in area (Nr) = 10
Decrement factor for determining IG (Df) = 1.0
Equivalent earthing mat area (A) = 17000 m^2
Total length of Buried Conductor (L) = 3700 m
Total length of ground rods (L$_R$) = 30 m

For earthing conductor material, the following parameters have to be considered [1]:

Maximum Allowable Temperature (or Fusing Temperature) (Tm) = 419 °C
Ambient Temperature (Ta) = 50 °C
Reference Temperature for material constants (Tr) = 20 °C
Thermal coefficient of resistivity at 0°C (αo) = 0.00341
Thermal coefficient of resistivity at reference temperature (αr) = 0.0032
Resistivity of the ground conductor at reference temperature (ρr) = 20.1
Thermal capacity per unit volume (TCAP) = 3.93

Following above parameters, calculated value of touch voltage comes out to be 120.19 V which is less than allowable touch voltage of 732.48 V. Also, calculated value of step voltage comes out to be 93.74 V which is less than allowable step voltage of 2437.77 V. So, the design of earthing grid is safe. Soil resistivity is the parameter which affects step and touch potential in earthing grid design. Both step and touch voltage increases with increase in soil resistivity as shown in Fig. 6.
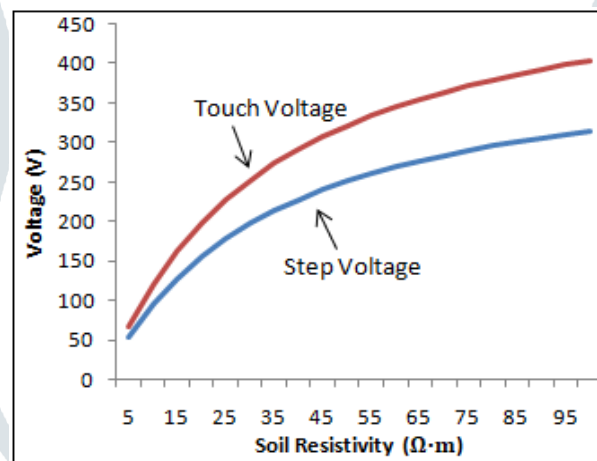

Fig. 6 Relation between Soil Resistivity and Step & Touch Voltage

V. CONCLUSION

Design of substation earthing grid can be done reliably and easily with design steps given as per flow chart of Fig. 5 according to IEEE 80-2000. Provided design steps can give safe design of electrical substation earthing grid with accuracy. From design steps, it can be observed that soil resistivity affects the step and touch voltage. Soil resistivity affects Grid Resistance as well. Also, parameters like spacing between parallel conductors, depth of ground grid conductors affects step and touch voltages which are the most important parameters in design of substation earthing grid.

VI. REFERENCES

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