Design and Analysis of Ground Grid System For Substation using E-TAP Software and FDM code in MATLAB

Deep B. Desai
B.E. Electrical (2014-2018)
Sardar Vallabhbhai Institute of Technology, VASAD
Vadodara, India

***Abstract*–The paper depicts about design of ground grid system for 66/11KV rectangular substation. Although it is designed by IEEE Std 80-2000, it also illustrates step potential, touch potential and absolute potential in normal and faulty condition by E-TAP intelligent software version 12.6.0. Furthermore, its graph design is analyzed by FDM (Finite Difference Method) via MATLAB code. Some of the factor which are useful in ground grid study are described below,**

1) Fault current magnitude and duration
2) Geometry of grounding mat
3) Soil resistivity
4) Human factors Such as
-Body resistance -Standard assumption on physical condition of the individual

Keywords*– *Ground grid system, FDM (Finite Difference Method) MATLAB code, E-TAP version 12.6.0 ground grid design, Substation grounding

I. INTRODUCTION

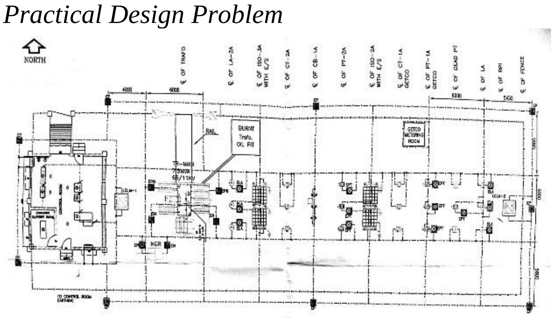
In substation earthing system is essential not only for providing the protection for people working in the vicinity of earthed facilities and equipment against danger of electric shock but also maintain proper function of electrical system. Reliability and security are to be taken in consideration as well as adherence to statutory obligations (IEEE and Indian standards on electrical safety [1-2] and environmental aspects). This paper is concerned with earthing practices and design for particular 66/11KV outdoor AC substation for power frequency in the range of 50 Hz. DC substation GIS and lightening effects are not covered in this paper. Moreover, the software output also has been seen for crosschecking of theoretical calculation. Furthermore, the analysis of software graph is done by FDM (Finite Difference Method) which is one of the mathematical solutions and it shows that how the graph generates in software.

II. EARTHING SYSTEM FOR SUBSTATION

A. Components of earthing system

An effective substation earthing system typically consists of earth rods, connecting cables from buried earthing grid to metallic parts of structures and equipment, connections to earthed system neutrals, and the earth surface insulating covering material briefly discussed in [1,3]. Current flowing into the earthing grid from lightening arrester operation impulse or switching surge flashover of insulators and line to ground fault current from the bus or connected transmission lines all cause potential differences between earthed points in the substation. Without a properly designed earthing system, large potential differences can exist between different points within the substation itself. Under normal circumstances, it is the current constitutes the main threat to personal.

B. Practical Design Problem



1. All dimensions are in mm unless otherwise specified.
2. Earth mat & earth electrode location shown are indicative. Only minor modification if any may be carried out at site.

1. Wherever earthing conductor infringes with cable trench it shall be land at 300mm below the trench.
2. Main grid conductor shall lad at minimum 600mm below figure.
3. minimum distance of 6000mm shall be maintained between any two adjacent earth electrodes.
4. wherever earthing grid infringes with foundation, grid conductor shall be diverted suitable at site.
5. Every equipment/structure shall be connected to grid by two distinct earth connections.
6. Every alternate fence post shall be earthed with 25x3mm galvanized iron flat.
7. Gate shall be earthed with 25x3mm galvanized iron flat.
8. BMKs junction for current transformer and potential transformer shall be earthed at two points with 25x3mm galvanized iron flat.
9. For standard earthing drawings of various equipment refer figure.

III. MATHEMATICAL SOLUTION

A. Given Data: -

1. Fault duration t_f=1s
2. Current division factor (s_f)=1

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3. Soil resistivity (ρ)=5.23Ωm
4. Crush rock resistivity(wet) (ρ_s)=3000Ωm
5. Thickness of crushed rock surfacing (hs)=0.1m
6. Depth of grid burial (h)=0.3m
7. Available grounding area (A)=48m×18m
8. Fault current (I_f)=25000A

B. Solution According to IEEE Std 80-2000[4]

- Conductor size

$$A_{mm^2} = I/\sqrt{\left(TCAP * \frac{10^{-4}}{t_c\alpha_r\rho_r}\right)\ln\left(\frac{k_0+T_m}{K_0+T_\alpha}\right)} \ldots (1)$$

$$A_{mm^2} = 25000/80$$

$$= 312\ mm^2$$

$$A_{mm^2} = (\pi d^2)/4$$

$$d^2 = (500*4)/\pi$$

$$= 25.23\text{mm} \ldots\ldots (2)$$

Diameter of vertical ground rod = 25.23 ×1.3 =32.799 mm (considering 30% corrosion allowance) Commercially rod of 32.799 mm diameter is not available so rod equivalent to 40.00 mm diameter is considered.

- Touch and Step Criteria

Reflection factor (K)

$$k = \left(\frac{\rho - \rho_s}{\rho + \rho_s}\right)$$

$$= -0.996$$

Here from the value of the reflection factor according to the graph of K→ h_s
Value of h_s is taken 0.1m.

Surface layer darting factor

$$C_s = \left(\left(1 - \frac{0.09\left(1-\left(\frac{\rho}{\rho_s}\right)\right)}{2h_s+0.09}\right)\right.$$

$$= 0.693 \ldots\ldots (3)$$

Step potential for 50kg and 70kg

$$E_{step50} = I_b(R_B + 6\rho_s C_s) \ldots\ldots (4)$$

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

$$= 1557.98\text{V} \ldots\ldots (5)$$

$$E_{step70} = \frac{(R_B + 6\rho_s C_s)0.157}{\sqrt{t_s}}$$

$$= 2115.41\text{V} \ldots\ldots (6)$$

Touch potential for 5kg and 70kg

$$E_{touch50} = I_b(R_B + 1.5\rho_s C_s)$$

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

$$= 476.746\text{V} \ldots\ldots (7)$$

$$E_{touch70} = \frac{(R_B + 1.5\rho_s C_s)0.157}{\sqrt{t_s}}$$

$$= 646\text{V} \ldots\ldots (8)$$

Here step and touch potential foe 50kg body weight.

- Initial Design

Grid burial depth h= 0.6m,

Total length of buried conductor (L_t)=(18*9) +(48*4) =192+162=354m

Total length of buried conductor (L_c)=26*3=78m

$$L = L_c + L_t$$

$$= 354+78$$

$$= 432\text{m} \ldots\ldots (9)$$

Area (A)=48m*18m
=864m^2 ……………………….. (10)

- Determination of Grid resistance

$$R_g = \rho\left[\left(\frac{1}{L_t}\right) + \left(\frac{1}{\sqrt{20A}}\right)\left(1 + \left(\frac{1}{1 + h\sqrt{\frac{20}{A}}}\right)\right)\right.$$

$$= 0.0885 \ldots\ldots (11)$$

- Maximum Grid Resistance

$$S_f = \frac{I_g}{3I_0}$$

$$I_G = D_f * I_g$$

$$I_G = D_f * S_f * 3I_0$$

$$= 25000\text{A} \ldots\ldots (12)$$

- Ground Potential Rise(GPR)

$$GPR = I_g * R_g$$

$$= 2208.756\text{V} \ldots\ldots (13)$$

- Mesh voltage

$$n = n_a * n_b * n_c * n_d$$

$$n_a = \left(\frac{2L_c}{L_p}\right)$$

$$= 5.3$$

$$n_b = \sqrt{\frac{L_p}{4\sqrt{A}}}$$

$$= 1.056$$

$$n_c = n_d = 1$$

n= 5.3*1.056*1*1=5.7 ……………… (14)

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$$k_h = \sqrt{1 + \frac{h}{h_o}}$$

=1.140 K_{ii}= 1

$$k_m = \left(\frac{1}{2\pi}\right)[\ln \frac{(D^2)}{(16hd)} + \left(\frac{D + 2h}{8Dd}\right) - \left(\frac{4}{4d}\right) + (\frac{k_{ii}}{k_h}) \ln(\frac{8}{\pi(2n-1)})]$$

=0.6537

K_I = 0.644 + 0.148n
= 1.487

L_C is the total length of the conductor in the horizontal grid in m
Lp is the peripheral length of the grid in m
A is the area of the grid in m^2
Lx is the maximum length of the grid in the x direction in m
Ly is the maximum length of the grid in the y direction in m
Dm is the maximum distance between any two points on the grid in m

- Mesh Voltage (E_m) & Step Voltage (E_S)

$$E_m = \frac{\rho I_a k_m K_i}{L_c + [1.55 + 1.22 \frac{L_r}{\sqrt{x^2 + y^2}}] L_r}$$

= 351.84 V < E_{touch} .... (15)

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

=0.630

Where
D = spacing between conductor of the grid in m
h = depth of burial grid conductor in m
n = number of parallel conductors in one direction

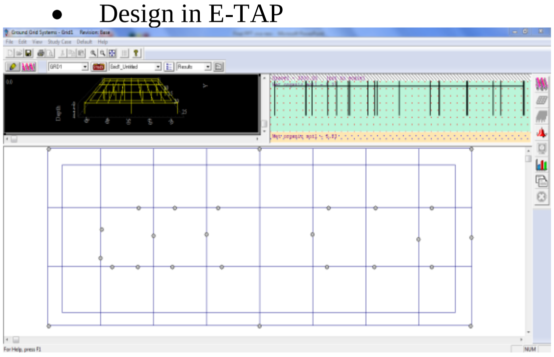
$$E_s = \frac{\rho I_g K_s K_i}{0.75 L_c + 085 L_r}$$

=368.85 V < E_{step} .... (16)

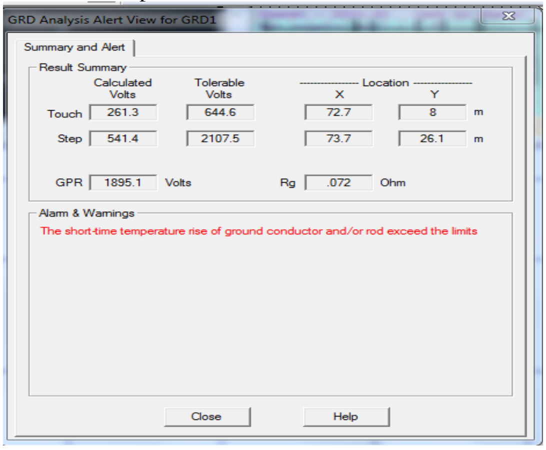
Here as shown above and computed mesh voltage and Step voltage both are much less than the step potential criteria and touch potential criteria. So, obtained design is safe.

IV. E-TAP GRAPH AND FDM MATLAB PROGRAM

- Design in E-TAP

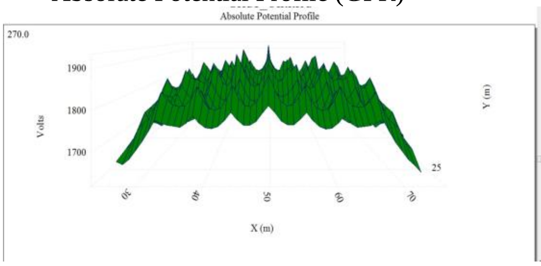


- Output in E-TAP

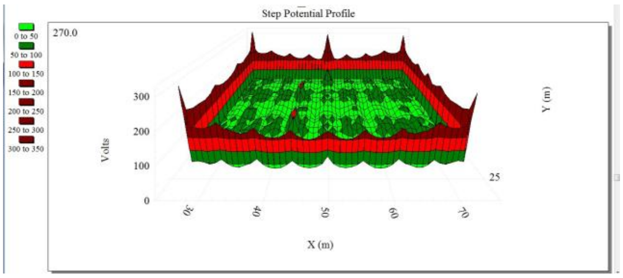


	ACTUAL VALUE	TOLERABLE
STEP POTENTIAL	541.4 V	2107.5 V
TOUCH POTENTIAL	261.3 V	644.6 V
GPR	1895.1 V	
R_g	0.072 Ohm	

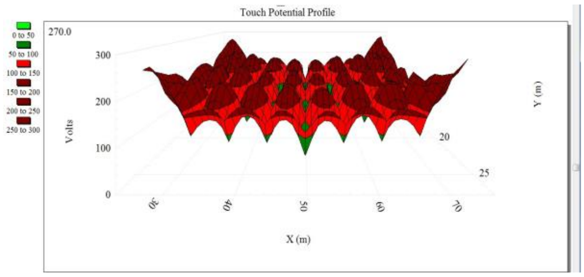
- Absolute Potential Profile (GPR)



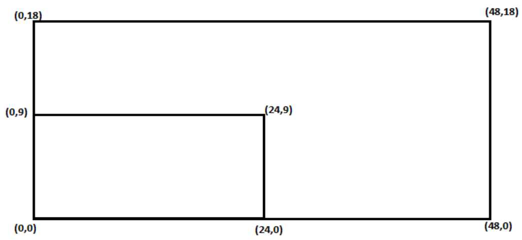
- Step Potential



- Touch Potential



- Absolute Potential Calculation using FDM (MATLAB Code) [5]



V_1	(0,0)
V_2	(24,0)
V_3	(24,9)
V_4	(0,9)

MATLAB PROGRAMME:

```
v1=2208.0;
v2=0.0;
v3=0.0;
v4=2208.0;
ni=200;
nx=25;
ny=10;
v=zeros(nx,ny);
for i=2:nx-1
      v(i,1)=v1;

   v(i,ny)=v3;
end
for j=2:ny-1
   v(1,j)=v4;
   v(nx,j)=v2;
end
v(1,1)=0.5*(v1+v4);
v(nx,1)=0.5*(v1+v2);
v(1,ny)=0.5*(v3+v4);
v(nx,ny)=0.5*(v2+v3);
for k=1:ni
   for i=2:nx-1
      for j=2:ny-1
         v(i,j)=0.25*(v(i+1,j)+v(i-1,j)+v(i,j+1)+v(1+j-1));
      end
   end
end
diary FDM.out
[v(1,1), v(6,2), v(12,4), v(24,9)]
[ [1:nx, 1:ny] v(i,j) ]
diary off
```

OUTPUT

```
ans =

 1.0e+003 * [2.2080    2.2001    2.1735    0.8082]
```

V. CONCLUSION

This paper has focus on ac substation grounding design and also compare theoretical as well as software output and analyzed mathematically calculation for generation of graph in software program by FDM coding in MATLAB.

By the calculation it has been proved that calculated step and touch potential must be less than tolerable limit of step and touch potential to made safe design for grounding system for substation. If any of the conditions or both conditions are not satisfied then varying different parameter in the calculation (i.e. soil resistivity, depth of buried rod, increasing number of earth pit in substation, use different material for rod, etc.…) and recalculate whole design until both the conditions are not satisfied.

VI. ACKNOWLEDGMENT

I hereby declare that all the given data, information and calculation are true and calculated from real example. The diagram of substation which is shown above is rear.

VII. REFERENCE

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