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MODERN APPROACH TO EARTHING SYSTEM DESIGN AND ITS ANALYSIS USING ETAP INTELLIGENT SOFTWARE

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Abstract

Due to the complexity involved in the equations of modeling and the characteristics of soil in which the earth grid is to be buried, it is somewhat difficult to analyze ground grid in depth for the purpose of optimization. The soil almost exhibits vertical and horizontal variations due to the atmospheric factors and/or artificial treatments such as gravelling, add-on of some chemicals etc.

Keywords- ETAP, *step potential, touch potential, Finite Element Method (FEM), Ground potential rise (GPR).*

I. INTRODUCTION

As far as the soil model is uniform and continuous, the programs can be developed to analyze the performance of earthing system or in some case two layer soil models can also be adopted as good approximation for analysis purpose. But in case of worst soil characteristics and some other conflictions regarding the values to be considered in modeling and design of earthing grid, it is quite acceptable and appreciable to use computer software to design and analyze the grounding mesh. The best software for this purpose is **ELECTRICAL TRANSIENT ANALYZER PROGRAM (ETAP)**.

ETAP facilitates an engineer to carry out ground grid design as well as analysis with considerations specified in various standards such as IEEE-80-1986, IEEE-80-2000 and IEEE-665-1995. Moreover, this software also provides finite element modeling (FEM) of the ground grid for detailed analysis. This software analyzes the ground grid technically as well as economically. The additional features of ETAP are summarized as follows:

- There are 3 simultaneous views of earthing system:
  1) 3-D View
  2) Soil view
  3) Top view
- Optimization of earthing conductors and rods on the base of safety and cost (by IEEE method).
- Integration and more effective utilization of single line diagram.
- Flexible soil characteristics.
- Variety of soil characteristics.
- Individual conductor modeling.
- 3-D graphical representation of various plots (by FEM method only), e.g. Step and touch potential profile throughout the grid area.
- Unlimited conductors and ground rods can be added.
- Eligible to design and analyze the ground grid area up to 10,000 square meters.
- Location of maximum touch and step potential can be known by FEM method from the plots.
- Case study library.

II. EASE OF CALCULATION FOR STEP AND TOUCH POTENTIAL USING ETAP

In normal practice for earthing design and analysis we use the ETAP software just to calculate the step and touch potentials, as their calculations are tedious and time-consuming. We can design an earthing grid and place the earth electrodes using ETAP. It can also optimize the use of electrodes considering the cost in concern. We can obtain the 3-D graphs for the step and touch potentials. There are basically two methods available for the step and touch potential calculations. They are **finite element method (FEM)** and **IEEE method**. We can choose any of these methods as per our convenience. The best option is finite element method because it is flexible as compared to IEEE in designing the shape of the grid. If we choose FEM method then can model any shape of grid as per the plan dimensions while in case of IEEE method some specific shapes are given. We cannot design any complex shape of grid in IEEE method. So it is better if we choose FEM method.

One more important consideration is the type of soil considered. In ETAP we can choose different layers of soil (2-3). In international standards for earthing system design generally multiple layers of soil are considered. The top most layers will have more resistivity than the deeper layers. Top most level generally consists of gravels which have higher resistivity. In ETAP the approximate values of resistivity of different layers are given and they can be edited if required.

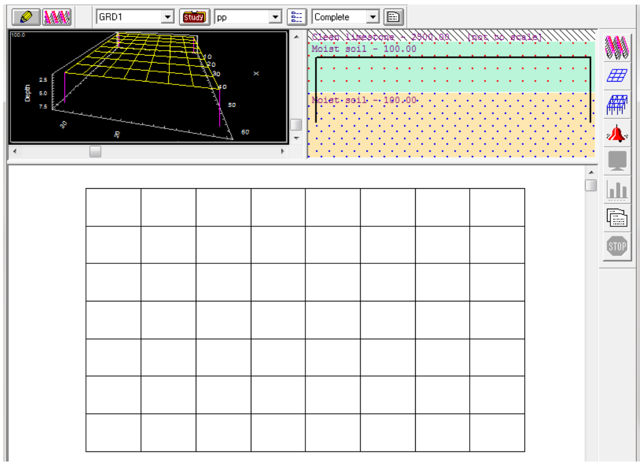
The short-circuit studies are to be performed for getting the values of fault current, X/R ratio for equipments present in the area under consideration. Generally this information is already given. The earth electrodes can be placed at any side of the grid. ETAP has the option of selecting optimization of earth electrodes where it suggests the placement of earth electrodes in the grid.

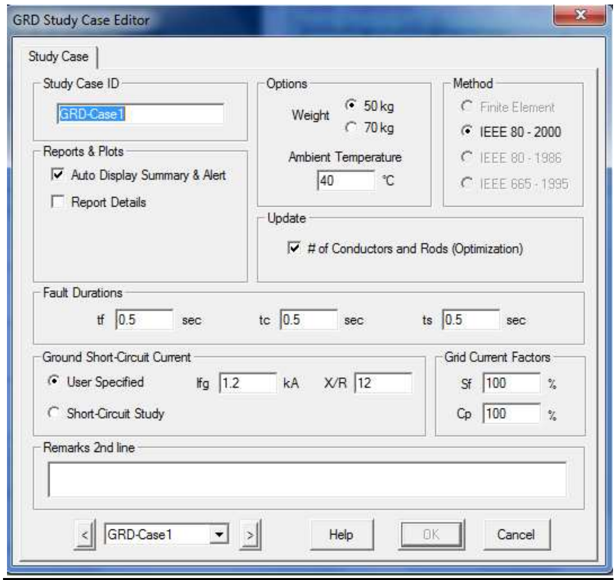
III. CASE STUDY: DESIGN DATA

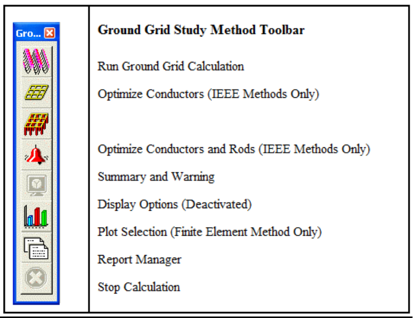
FOR SYSTEM HAVING SQUARE GRID WITH GROUND RODS ONLY:

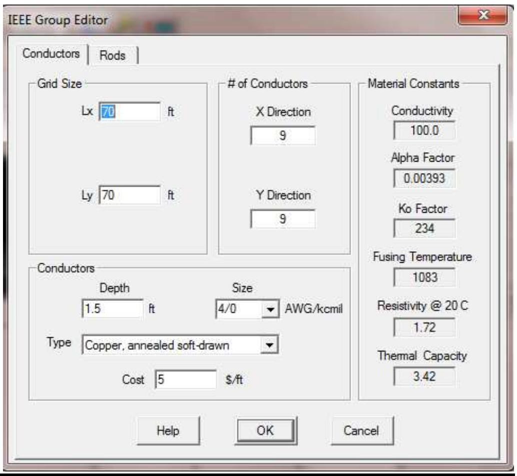
- Fault Duration (t_f)= 0.5s
- Positive Sequence Equivalent System Impedance (Z_1)= 4+j10Ω (115kV side)
- Zero sequence equivalent system impedance (Z_0)= 10+j40Ω (for 115kV side)
- Current division factor (s_f)= 0.6
- L-L voltage at worst-fault location= 115000V
- Soil resistivity (ρ)= 400Ω-m
- Crushed rock resistivity (wet) (ρ_s)= 2500Ω-m
- Thickness of crushed rock surfacing (h_s)= 0.102m
- Depth of grid burial (h)= 0.5m
- Available grounding area (A)= 63m*84m
- Transformer impedance (Z_1 and Z_0)= 0.034+j0.014Ω (for 13kV side)
  (Z= 9% at 15 MVA, 115/13 kV)

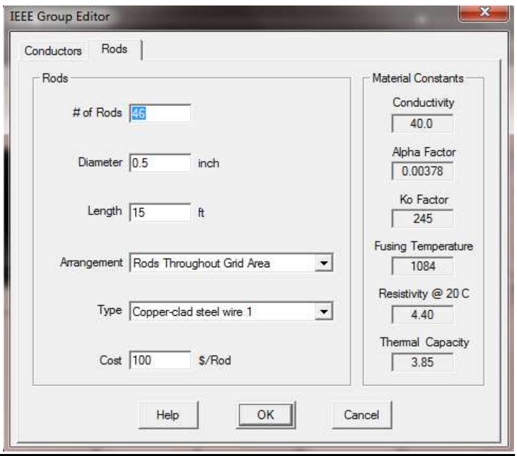
In this case study a normal earthing design is done using ETAP. As per the standard steps of earthing system design the values of fault current, conductor size, grounding resistance is to be found out using the associated formulas as per IEEE-80. All this data is fed to the ETAP and the grid design is done as shown in figure. The step and touch potential plots are generated are generated when the calculated values are fed. It also compares the tolerable and attainable step and touch potential value and alerts the user if the attainable value exceeds the tolerable value.

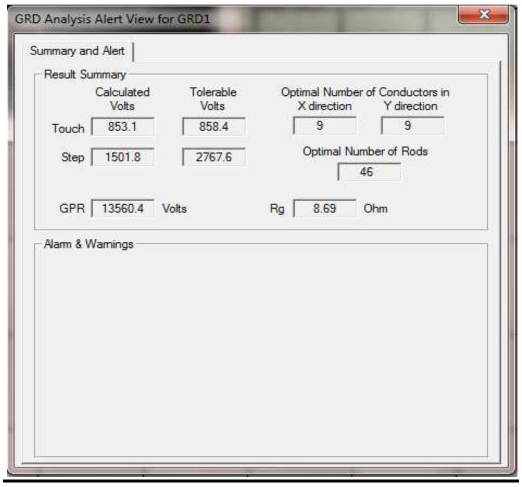












IV. Stepwise Calculations:

STEP1:

The property map and general location plan of the substation should provide good estimates of the area to be grounded. The **soil resistivity test** has to be carried out which will determine the soil resistivity profile and soil model needed.

The **Wenner four-pin method** is most commonly used method for determining the soil resistivity. In this method four probes are driven into the earth along the straight line at equal distances ‘a’ apart, driven to a depth ‘b’. The voltage between the two inner potential electrodes is then measured and divided by the current between the outer electrodes to give a value of resistance R.

$$\rho_a = 2\pi a R$$

If b is small as compared to a, then the above equation is to be used. The approximate uniform soil resistivity may be obtained by taking an arithmetic average of the measured apparent resistivity data. Normally 15 values of soil resistivity (ρ_a) are to be calculated on the estimated area that is to be considered.

STEP2:

The conductor size is to be determined by following equation,

$$A_{kcmil} = I * K_f * \sqrt{t_c}$$

Where,

A_{kcmil}= the area of conductor in kcmil

I= rms fault current in kA

t_c= current duration in seconds

K_f= constant

From A_{kcmil} value we can find out the value of A_{mm}^2,

$$A_{mm2} = A_{kcmil}/1.974$$

From the above area we can find out the diameter of the conductor,

$$d = \sqrt{(4 A_{mm2}/\pi)}$$

Also determine the fault current **(I_f) = $3I_0$= 3E/ (3*R_f+ (R1+R2+R0) +j(X1+X2+X0))**

And the X/R ratio is to be given.

STEP 3:

Touch and Step criteria

For 70 kg person (optimum design),

$$E_{step} = (1000+6C_s*\rho_s) * (0.157/\sqrt{t_s})$$

$$E_{touch} = (1000+1.5\ C_s*\rho_s) * (0.157/\sqrt{t_s})$$

For 50 kg person (worst case),

$$E_{step} = (1000+6C_s*\rho_s) * (0.116/\sqrt{t_s})$$

$$E_{touch} = (1000+6C_s*\rho_s) * (0.116/\sqrt{t_s})$$

Generally **worst case** is preferred.

Where,

C_s= surface layer de-rating factor

$$=1 - [\frac{0.09\left(1-\frac{\rho}{\rho s}\right)}{2hs+0.09}]$$

Where,

h_s is the thickness of the material

ρ is the resistivity of the earth beneath the surface material

ρ_s is the surface material resistivity

t_s is the duration of the current exposure or fault clearing time, which is based on the judgment of the design engineer.

STEP 4:

Assume a preliminary layout of the grid with equally spaced conductors. This layout should include a conductor loop surrounding the entire grounded area, plus adequate cross conductors to provide convenient access for equipment grounds, etc. The initial estimate of conductor spacing and ground locations should be based on the current I_G and the area being grounded.

STEP 5:

Calculate the grounding grid resistance (R_g) as follows:

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

Where,

ρ = soil resistivity in ohm meter

A = area occupied by grounding grid in meters

L_t = total length of buried conductors in meters

h = depth of the grid in meters

STEP 6:

Determine the maximum grid current (I_G),

$$I_G = D_f * I_g$$

Where,

D_f = decrement factor for the entire duration of fault t_f, given in seconds (value can be obtained from table-10 IEEE 80)

I_g = rms symmetrical grid current in amperes

$$Ig = 3 * S_f * I_0$$

S_f = fault current division factor

STEP 7:

Now it is necessary to determine the GPR= $I_G * R_g$, which should be compared with the E_{touch} voltage.

If GPR<E_{touch} and E_{step} then no further calculations are necessary. Only one conductor is necessary to provide access to equipment grounds.

If GPR>E_{touch} and E_{step}, then further calculations are to be done.

STEP 8:

The calculations of mesh/touch and step voltages are to be done as follows:

$$\mathbf{E_m = \rho * K_m * K_i * I_G/L_M}$$

Where,

K_m= geometrical factor

$$Km = 1/2\pi[\ln\left(\frac{D^2}{16*h*d}\right) + \left(\frac{(D+2h)^2}{8*D*d}\right) - h/(4*d)] + (Kii/Kh)\ [\ln(8/\pi(2*n-1))]\ ]$$

Kii= 1 for grids with ground rods in the grid corners as well as both along the perimeter and throughout the area.

Otherwise,

Kii= $1/(2n)^{2/n}$, for no or few ground rods, none of located at the corners or perimeter

$K_h = \sqrt{(1+(h/h_0))}$

H_0 is the reference grid depth

The effective number of parallel conductors (n) = $n_a * n_b * n_c * n_d$

Where,

$n_a = 2L_c/L_P$

n_b= 1 for square grid,

n_c= 1 for square and rectangular grids

n_d= 1 for square, rectangular and I-shaped grid

Otherwise,

$n_b = \sqrt{(L_p/(4\sqrt{A}))}$

$$n_c = \left[\frac{Lx*Ly}{A}\right]^{\left[\frac{0.7*A}{Lx*Ly}\right]}$$

$n_d = D_m/(Lx^2+Ly^2)$

L_c= total length of the conductor in the horizontal grid (m)

L_p= peripheral length of grid (m)

A= area of the grid (m^2)

Lx= maximum length of the grid in x direction (m)

Ly= maximum length of the grid in y direction (m)

D_m= maximum distance between any two points on the grid (m)

D=spacing between parallel conductors (m)

d= diameter of the grid conductor (m)

h= depth of the ground grid conductors (m)

Ki= irregularity factor

= 0.644 + 0.148n

$L_m = L_c + L_R$

Where, L_R = total length of all ground rods in m

For grids with ground rods in the corners, as well as along the perimeter and throughout the grid, the effective buried length, L_m, is

$$L_m = L_c + [1.55 + 1.22(Lr/\sqrt{Lx^2+Ly^2})]Lr$$

Where, L_r= length of each ground rod (m)

$\mathbf{E_s = \rho * K_S * K_i * I_G/L_S}$ (Step voltage in volts)

Where,

$L_s = 0.75L_c + 0.85L_R$

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

STEP 9:

If the computed mesh voltage is below the tolerable touch voltage, the design may be complete. If the computed mesh voltage is greater than tolerable touch voltage, the preliminary design should be revised. (See step 11)

STEP 10:

If both the touch and step voltages are below tolerable voltages, the design needs only the refinements required to provide access to equipment ground. If not, the preliminary design is revised. (See step 11)

STEP 11:

If either the step or touch tolerable limits are exceeded, revision of the grid design is required. These revisions may include **smaller conductor spacing**, **additional ground rods,** etc.

STEP 12:

Result		Case1	Case2
Conductor	Total no.	19	16
	Total length	1365m	1134m
	Cost	4505$	3742$
Rod	Total no.	5	20
	Total length	30m	200m
	Cost	500$	2000$
Total Cost		5005$	5742$

After satisfying the step and touch voltage requirements, additional grid and ground rods may be required. The additional grid conductors may be required if the grid design does not include conductors near equipment to be grounded. Additional ground rods may be required at the base of the surge arrestors, transformer neutrals, etc. The final design should also be reviewed to eliminate hazards due to transferred potential and hazards associated with special areas of concern.

Table 1-

Result		Case1	Case2
Conductor Depth		1.5 mm^2	1.5 mm^2
No. Of conductors	X-direction	11	10
	Y-direction	8	6
Separation	X-direction	9m	12.6m
	Y-direction	8.4m	9.3m
Cost per unit		3.3$	3.3$

Table 2-

Result		Case1	Case2
Resistance (Rg)		1.184Ω	11.9Ω
GPR		3733.4 Volts	37525 Volts
Touch potential	Tolerable	762.3 V	762.3 V
	Calculated	758.2 V	753 V
Step potential	Tolerable	2557 V	2557 V
	Calculated	1137.7 V	954 V

Table 3-

V. CONCLUSION

All the metallic parts and structures such as equipment bodies, fences, doors, support structures, etc is connected to station earthing system. Earthing grid for instrumentation, lightning and electronic equipment are provided separately.The attainable and tolerable values of touch and step potential are compared and alarm is signaled if the attainable value exceeds the tolerable value. When soil characteristics are to be considered, generally according to Indian standards, a uniform and continuous soil is preferred. But in case of international standards multiple layers (generally 2 or 3) and preferred. These conditions can easily be evaluated by the software. Earth electrode optimization option is available which suggests the placements of earth electrodes in the earthing grid.

REFERENCES

[1] Ground Potential rise on the HV Substation during lightning strike measurement and simulation results by Jarosław Wiater, Electrical Department, Białystok Technical University

[2] Design of earthing system for new substation project (Shwe Sar Yan) Myanmar" by Ei Ei Cho, and Marlar Thein Oo.

[3] Design and Optimization of Substation grounding grid based on IEEE STD.80-2000 using GUI and MATLAB codes by Dr. ATTIA A. EL-FERGANY, SENIOR MEMBER ((IACSIT), MEMBER (IEEE)

[4] Determination of two layer earth structure parameters" by Ioannis F. GONOS, Vassiliki T. KONTARGYRI, Ioannis A. STATHOPULOS, National Technical University of Athens and Antonios X. MORONIS, Anastasios P. SAKARELLOS, Nikolaos I. KOLLIOPOULOS Technological Educational Institute of Athens, Department of Energy Technology.

[5] Design of Grounding systems in sub-stations by ETAP Intelligent software- N.M. Tabatabaei 1 S.R. Mortezaeei 2

[6]IEEE-80, Guide for substation is AC substation grounding.