ETAP MODEL FOR EARTH MAT DESIGN

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Abstract— with the incessant increase of power system capacity and voltage grade, the safety of grounding grid becomes more and more prominent. In substation, earthing system is essential not only to provide the protection to people working or walking in the vicinity of earthed facilities and equipment's against the danger of electrical shock, but also to maintain the proper function of the electrical system. This paper presents the design of earthing systems for 66KV substation and the case study for calculating required parameters and reviews substation grounding practices with special reference to safety and development criteria for a safe design. In this paper, a real time case study has been considered and the design was done using ETAP (Electrical Transient Analyzer Program) software. Simulation of power system analysis using computer software's enables better understanding of the large system and provides better solution to problem.

Keywords: Earthing / Grounding, Ground Resistance, Step Potential, Touch Potential, Ground Potential Rise, Earth mat, Electrodes, Software and Simulation.

I. INTRODUCTION

Electricity today is playing an ever increasing role in the lives of everyone in the civilized world. Increased use of electricity has resulted in increased danger to human beings. Not only defects at consumer's premises, but even at Supply Authority's premises can electrocute a customer at his own premises. Earthing protects humans from danger of electrocution. A lightening strike on a tall building can seriously injure the occupants or even completely demolish that building. Tall buildings or structures like towers are more prone to lightening strikes. Earthing tall structures protects them against lightening. Earthing provides return path for large number of electronic equipments or RF antennas etc. For example, a 3phase star wound generator must have its neutral point at earth potential. Earthing a tower / equipment means connecting that tower /equipment to general mass of earth by means of an electrical conductor. Connection to earth is achieved by embedding a metal plate or rod or conductor in earth. This metal plate or rod or conductor is called as "Earth electrode". Effectiveness of the Earthing connection made by embedding a metal plate in earth is quantified as "Earth Resistance". This earth resistance is measured in ohms.

In general earthing installations will be required at power stations and substations for:

a) The neutral points of each separate electricity system which has to be earthed at the power station or substation

b) Apparatus framework or cladding or other non-current carrying metalwork associated with each system, for example, transformer tanks, power cable sheaths;

c) Extraneous metalwork not associated with the power systems, for example boundary fences, sheaths of control or Communication cables.

The function of an Earthing and bonding system is to provide an Earthing system connection to which transformer neutrals or Earthing impedances may be connected in order to pass the maximum fault current. The Earthing system also ensures that no thermal or mechanical damage occurs on the equipment within the substation, thereby, resulting in safety to operation and maintenance personnel. The Earthing system also guarantees equipotential bonding, such that there are no dangerous potential gradients developed in the substation. In designing the substation, three voltages have to be considered.

Touch voltage: This is the difference in potential between the surface potential and the potential at earthed equipment whilst a man is standing and touching the earthed surface

Step Voltage: This is the potential difference developed when a man bridges a distance of 1 m with his feet while not touching any other earthed equipment Mesh Voltage: This is maximum touch voltage that is developed in the mesh of earthing grid.

This paper briefly discusses about the earth mat design and procedure for the same. It covers some of the practical aspects of Earthing in detail. The goal of this paper is to design earth mat / earth grid, conductor size, vertical electrode size, permissible potential difference, grid resistance, maximum grid current, ground potential rise by a computer modeling. Here, the design uses ETAP (Electrical Transient Analyzer Program) software. ETAP is the most comprehensive enterprise solution for design, simulation, operation, control, optimization, and automation of generation, transmission, distribution and industrial power systems.

II. CONVENTIONAL EARTHING & EATH MAT DESIGN

A. *Conventional Earthing*

The conventional system of Earthing calls for digging of a large pit into which a GI pipe or a copper plate is positioned amidst layers of charcoal and salt. It is cumbersome to install only one or two pits in a day. Types of conventional Earthing are shown below:

a. Pipe Earthing

b. GI Pipe Earthing
c. Cast Iron Plate Earthing
d. Copper Plate Earthing

The conventional system of GI pipe Earthing or copper plate Earthing requires maintenance and pouring of water at regular interval.

B. 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.

Advantageous of Earth mat:

1. Earth mat is preferable for large substations
2. To minimize the danger of high step or touch voltages in critical operating area or places that are frequently used by people
3. Space saving on the ground level due to substantial reduction of earth pits which leads to easy of coordination

III. EARTHING SYSTEM FOR SUBSTAION

An effective substation Earthing system typically consists of earth rods, connecting cables from the buried earthing grid to metallic parts of structures and equipment, connections to earthed system neutral and the earth surface insulating covering material. Current flowing into the Earthing grid from lightning 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 with the substation itself. Under normal circumstances, it is the current constitutes the main threat to personal

An effective earthing system has the following objectives:

a. Ensure such a degree of human safety that a person working or walking in the vicinity of earthed facilities is not expressed to the danger of a critical electric shock. The touch and step voltage produced in a fault condition have to be at safe values. A safe value is one woll not produce enough current within a body to cause ventricular fibrillation

b. Provide means to carry and dissipate electric currents into earth under operation and equipment limits or adversely affecting continuity of services

c. Provide earthing for lightning impulses and the surges occuring from the switching of substation equipment, which reduces damage to equipment and cables

d. Provide a low resistance for the protective relays to see and clear ground faults, which improves protective equipment performance, particularly at minimum fault

IV. DESIGNOF GROUNDING SYSTEMS FOR LIMITED AREA HIGH RESISTIVITY STATIONS

The design of grounding system for rocky areas requires special measures to obtain safe step and touch potentials for grounding system. Some of the measures to reduce the grounding

A. Use of vertical Grounding Rods

A grounding system at a power station often requires the form of a horizontal grid supplemented by number of vertical rods. The ground rods are of particular value when the upper layer of soil in which grid is buried is of much higher resistivity than that of the soil beneath. The information about the soil strata's can be obtained from the interpretation of the measured soil resistivity data. A number of computer algorithms have been developed in [12, 14] for interpretation of soil resistivity data obtained by wenner method or driven rod method [13]. If the analysis of measured soil resistivity data suggests lower resistivity medium at shallow depth, use of vertical rods can helpful and convenient to obtain safe design of the grounding system.

B. Use of Counterpoise Mesh

A counterpoise mesh is a closely spaced mesh of horizontal conductors placed at a shallow depth above main grounding system. If this additional mesh could be placed to occupy area other than occupied by the main grid, its contribution would have been higher. The main and counterpoise mesh has no electric connection and a considerable improvement by the use of mesh has been reported

C. Chemical treatment of Soil and use of bentonite

Chemical treatment or backfilling of the soil in a close proximity of a ground electrode is very effective method of improving the performance of a grounding system [1, 16]. Addition of common salt, charocoal and soft coke around the ground electrode has been traditionally used for lowering the ground resistance. This treatment requires regular watering in order to keep ground resistance low. In the high resistivity soil area, bentonite clay can be used to decrease the grounding resistance effectively. It consists of hydrous aluminum silicate and acts as an excellent backfill if sufficient amount of water is added to it. It has been observed that fly ash disposal poses serious problem in thermal power plants and since ash possesses similar characteristics as of bentonite, it can be used as a backfill to reduce ground resistance

D. Use of penstock as an Earthing system element

At many hydroelectric stations, long penstocks are necessary to carry water to the turbines. If the penstock liner is buried in the earth, it can be made part of the station Earthing systems

E. Current diversion by overhead earth wires

The overhead earth wires, when connected to the station grounding system, divert substantial portion of the ground current away from the station ground [1, 19]. The ground potential rise (GPR) of the grounding system is substantially reduced

F. Use of satellite electrode

An extra ground electrode in an adjoining area of lower soil resistivity and connected to the station grounding system is called a satellite electrode. The satellite electrode is an effective way to reduce ground resistance and potential gradients. The grounding system of station and satellite electrode can be connected by an overhead wire or an underground wire. When an underground wire is used, the wire also becomes a part of the grounding system and is effective compared to overhead interconnection. However, with underground tie wire, potential gradients around the tie wire must also be determined in order to safeguard the living beings moving around the tie wire. For computation of ground resistance and earth surface potentials, the grounding system placed in two different areas of different soil resistivity has to be represented by suitable mathematical model.

V. IMPORTANT FACTORS TO BE CONSIDERED

A. Current Density

To efficiently design a safe grounding system it is necessary to have knowledge of how various parameters affect the performance of the grounding system. Some of these parameters include grid conductor spacing and arrangement, number of ground rods, location and length and soil resistivity parameters (that is homogeneous or multilayered with various surface layer thickness and values of k the reflection factor coefficient) For a grounding system consisting only of grid conductors, the current along any one of the conductors is discharged into the earth in a fairly uniform manner. However, a larger portion of the current is discharged into the soil from the outer grid conductors rather than from the conductors at or near the center of the grid. An effective way of making the current density more uniform between the inside and periphery conductors is to employ a non-uniform conductor spacing, with the conductor spacing larger at the center of the grid and smaller toward the perimeter.

B. Step and touch voltages

Since most of the current in uniformly spaced grid is discharged into the earth from the outer conductors, the worst touch and step voltages occur in the outer meshes, especially in the corner meshes. Increasing the number of meshes (decreasing the conductor spacing) tends to reduce the touch and step voltages until a saturation limit is reached. Beyond this number of meshes, reduces the conductor spacing has minimal effect n reducing the voltages. This saturation limit is the vertical component of voltage caused by the depth of burial of the grid, and is changed only with a change in depth of the grid.

The grid burial depth also influences the step and touch voltages significantly. For moderate increases in depth, the touch voltage decreases, due mainly to the reduced grid resistance and corresponding reduction in the grid potential rise. However for very large increases in depth, the touch voltage may actually increase. The reduction in grid potential rise reduces to limit of approximately half its value at the surface as the depth of the grid approaches infinity, while the earth surface potential approaches zero at infinite depths. Therefore, depending on the initial depth, an increase in grid burial depth may either increase or decrease the touch voltage, while the step voltage is always reduced for increased depths.

VI. RECOMMENDATIONS FOR RESISTANCE VALUES FROM DIFFERENT STANDARDS:

A. NEC

The National Electric Code (NEC), Section 250-84, requires that a single electrode consisting of rod, pipe or plate that does not have a resistance to ground of 25 ohms or less shall be augmented by one additional electrode of the type listed in section 250-81 or 250-83. Multiple electrodes should always be installed so that they are more than six feet (1.8m) apart. Spacing greater than six feet will increase the rod efficiency. Proper spacing of the electrodes ensures that the maximum amount of fault current can be safely discharged into earth.

B. CPWD (Central Public Works Department)

The earth resistance at each electrode shall be measured. No earth electrode shall have a greater ohmic resistance than 5 ohms as measured by an approved earth testing apparatus. In rocky soil the resistance may be up to 8 ohms

Where the above stated earth resistance is not achieved, necessary improvement shall be made by additional provisions, such as additional electrodes, different type of electrode or artificial chemical treatment of soil etc., as may be directed by the Engineer-in-charge

C. IS 3043

The choice of using a common earth or separate earths for the system of different voltages at a transforming point effect:

The probability of breakdown occurring in a transformer between the higher and lower voltage sides due to lighting or other surges and

The safety of consumers or their property supplied by any low voltage system distributed from the station against arise of potential of the earthed neutral by a high voltage system earth fault at the station

The former risk is reduced by use of a common earth system and the latter danger only arises if the resistance of the earth electrode system is not sufficiently low to limit the rise of earth potential to a safe value. There is advantage in using a common earth where the earth electrode resistance, Including the parallel resistance of any bonded metalwork, etc, to earth is 1 ohm or less as is usual at power stations large outdoor substations or substations supplying a network of cables whose sheaths have a low impedance to earth

VII. COMPUTATIONAL METHODOLOGY

For step voltage criteria the limit is:

$E_{step50} = (1000+6Cs.\ \rho s)\ 0.116/ \sqrt{t_s}$

$E_{step70} = (1000+6Cs.\ \rho s)\ 0.157/ \sqrt{t_s}$

Where

Cs = 1 for no protective layer

ρs = the resistivity of the surface material In ohm-m

$t_s =$ duration of shock circuit in sec

The touch voltage limit is

$E_{touch50} = (1000 + 1.5\ Cs.\ \rho s)\ 0.116 / \sqrt{t_s}$

$E_{touch50} = (1000 + 1.5\ Cs.\ \rho s)\ 0.157 / \sqrt{t_s}$

Formula for calculating conductor size:

$A_{mm}^2 = I \text{ x } \sqrt{[t_c \text{ x } \alpha_r \text{ x } \rho_r \text{ x } 10^4/ TCAP] / \ln [1 + (T_m - T_a)/ (K_0 + T_a)]}$

$A_{cmils} = 1973.52 \text{ x } I \text{ x } \sqrt{[t_c \text{ x } \alpha_r \text{ x } \rho_r \text{ x } 10^4/ TCAP] / \ln [1 + (T_m - T_a)/ (K_0 + T_a)]}$

Where

I = rms value in KA

A_{mm}^2 = conductor sectional size in mm^2

T_m = maximum allowable temperature in °C

T_a = ambient temperature for material constant in °C

α_0 = thermal coefficient of resistivity at 0°C

αr = thermal coefficient of resistivity at reference temperature T_r

ρ_r = the resistivity of the ground conductor at reference temperature Tr in μΩ-cm

K0 = $1/\alpha_0$ or $1/ \alpha_0 - T_r$

t_c = time of current flow in sec

TCAP = thermal capacity factor

For calculating grounding resistance the following formula is used:

$Rg = \rho\ [\ I/L_t + 1/\sqrt{20A}\ (\ 1+ 1/(\ 1+h\sqrt{\ 20/A}))]$

Where

ρ = soil resistivity

Lt = total length of grid conductor

A = total area enclosed by earth grid

h=depth of earth grid conductor

For calculation of grid current:

$I_g = S_f \text{ x } 3\ I_0$

Where

Ig = maximum grid current

3 I0 = symmetrical fault current in substation for conductor sizing in A

Sf = current diversity factor

Equation for Ground Potential Rise (GPR):

$GPR = I_g\ R_g$

Formula for calculating mesh and step voltage:

$E_m = \rho\ K_m\ K_i\ I_g / L_g + 1.15\ L_r\ N_r$

$E_s = \rho\ K_i\ K_s\ I_g / L_g + 1.15\ L_r\ N_r$

Where

E_m = mesh voltage

E_s = step voltage

K_m = spacing factor for mesh voltage

K_i = correct factor for grid geometry

Equation for Km is given below:

$Km = 1/\Pi\ [\ \ln\ (\ D^2 / 16hd + (D+2h)^2 / 8Dd - h / 4d\ ) + Ki / Kh\ \ln\ (\ 8 / \Pi\ (2n-1))]$

The maximum step voltage is assumed to occur over a distance of 1 m, beginning at and extending of the perimeter conductor at the angle bisecting the most extreme corner of the. For the usual burial depth of 0.25m < h < 2.5m

$Ks = 1/\Pi\ [½.h + 1/ D+h + 1/D\ (1- 0.5^{n-2})]$

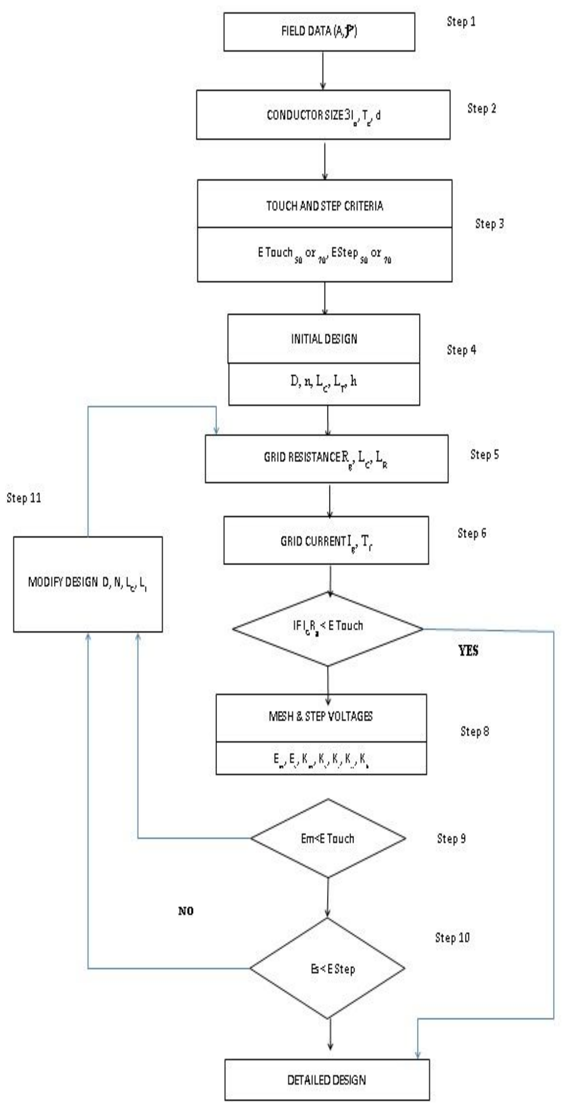
Where

D = Spacing between adjacent grid conductor

H = depth of burial grid conductor

D = diameter of grid conductor

Flow Chart:



VIII. CASE STUDY

A real time project considered for this case study and a computer modeling was developed to carry out the earth mat design. This project has 66/11 KV GIS substation and 11/0.433 KV building substations. Earth mat proposed for GIS as well as for building substations to reduce cost & to get better resistance value. Soil resistivity tests were conducted at project site area and same data was used for doing design calculations. Soil resistivity is the key factor which determines the resistance or performance of an electrical grounding system. Below are the input data details

Surface layer resistivity - 3000 ohm-m
Top layer resistivity – 50 ohm-m
Lower layer resistivity – 50 ohm-m
Conductor & Rod type – MS

In order to maintain equipotential, all earth mats had been interconnected in the system. This also resulted in achieving better ground resistance value. Based on site area, we decided to choose rectangular grid pattern (different grid patterns are available-L shape, T-shape) and spacing between conductors is 2.5 – 3 meters. Grid was buried at a depth of 0.27m. The configuration of the grid is shown in the below Fig1. In order to reduce cost we went for mild steel conductor and the required number of conductors was 50 and the rods were 366 as per the calculations. Also, extra CI pipes were considered for achieving better resistance value. The values arrived at were used subsequently as input for the manual calculations to allow direct comparison of observed and simulated values. It was found that both manual and simulated vales are satisfactory.
The Load data and fault current details are given in below table.

Table I: Load and Fault current details

Total Load MVA	Transformer Capacity	DG Capacity	Fault Current at HT side (40 KA)	Fault current at LT side (KA)
14.9 MVA	2 No's 12.5 MVA	(9 No's 2000 KVA) 100 % back up	40	60

CALCULATION:

STEP 1: Soil resistivity data Upper layer ρ =3000 ohm-m, Top layer ρ = 50 ohm – m, lower layer ρ = 50 ohm-m

STEP 2: Calculate Conductor size Conductor type = steel Size of the conductor = 750 sq.mm

STEP 3: calculate tolerable touch and step voltages Tolerable touch voltage = 702.6 Volts, Tolerable step voltage = 2339.5 Volts

STEP 4: calculate resistance value Rg = 0.34

STEP 5: Grid current (IG)

STEP 6: Ground Potential Rise (GPR), no further analysis is required if GPR is below the tolerable touch voltage 12575.1 Volts

STEP 7: Calculation of mesh and step voltages Em = 525.4 Volts, Es = 2322.6 Volts

STEP 8: If the computed mesh voltage is below the tolerable touch voltage, the design may be complete

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Fig1: Grid Configuration

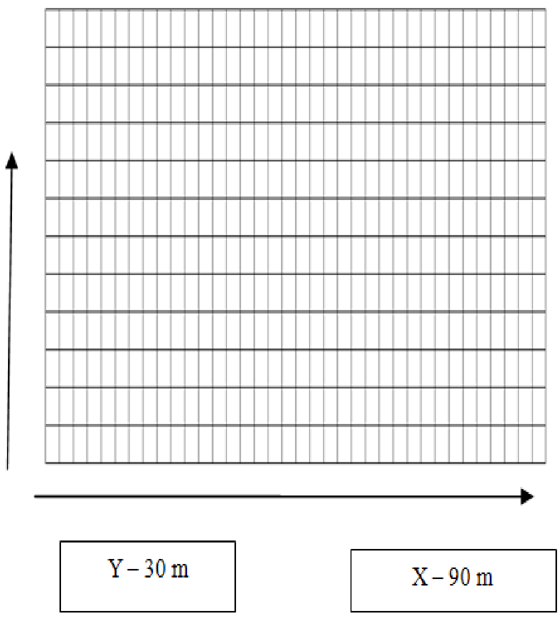

Table II: Earth Mat Results

Touch Voltage		Step Voltage		GPR	R(in ohm)
Tolerable	Calculated	Tolerable	Calculated		
702.6	525.4	2339.5	2322.6	12575.1	0.34

Resistance as per site test

The resistance value for all substations had been tested at site and achieved less than one ohm resistance value

CONCLUSION

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. For earthing conductor and vertical earth electrode, Stainless-clad Steel rod type are used. LT side fault current is considered for earth mat design. Resistance value for all substations has been tested at site and achieved as less than 1 ohm.

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