# CYMGRID Based Effective Earthing Design Model for Substation

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*Abstract* - The main objective of this paper is to develop an effective substation earthing system model to ensure that step and touch potentials are within the acceptable levels using effective design implementation steps with real time data based on the IEEE 80-2000. In this proposed method measurement of soil resistibility has been achieved using four probe wenner methods. The two layer soil resistivity model has been developed and CYMGRD based soil resistivity computations has been implemented. Overall impedance to earth has been calculated and grid potential rise limits has been obtained. Step and Touch potentials has been obtained and identified that the values are lower than allowable step and touch potentials, hence satisfies the design requirements of the substation.

***Keywords* – Soil resistivity, Earth fault current, Wenner method, touch voltage, grid potential.**

## I. Introduction

Earthing in a substation is essential for personnel safety and for reliable power system operation. Earthing is the total set of measures used to connect an electrically conductive part to earth. It is an essential part of power networks at both high- and low-voltage levels. A good earthing system is required to, adhere safety of human and animal life by limiting touch and step voltages to safe values, enable protective system operation, ensures that no thermal or mechanical damage occurs on the equipment within the substation, electromagnetic compatibility, and proper function of the electricity supply network and to ensure good power quality

## II. Identification of Electrical Soil Resistivity

The earthing system for 132/11 kV substation is designed to withstand an earth fault on the 132kV system of 40kA with a maximum fault clearance time of 3 sec and on the 11kV system of 40kA with a maximum fault clearance time of 5ec.

### A. *Measurement of Soil Resistivity using 4-probe Wenner method: [2]*

The earth resistance to any electrode is influenced by the resistivity of the surrounding soil. This will depend to a large extent on the nature of the soil and it's moisture content. Resistivity may change with depth, temperature, moisture content and can vary from place to place depending on the strata of the soil and rock formation. The soil resistivity figure will have a direct impact on the overall substation resistance and how much electrode is required to achieve the desired values. It will also influence separation distances between two adjacent earth systems (e.g. HV and LV earths at hot distribution sites). The lower the resistivity, the less electrodes is required to achieve the desired earth resistance value. It is an advantage to know the resistivity value at the planning stage as this gives a good indication of how much electrode is required The Wenner (four terminal) test is the common method for determining soil resistivity at Primary/Grid sites. The soil resistivity data can influence the chosen site location as well as the decision on the best type of earthing electrode system to be installed.

For example, it helps to decide if it's an advantage to drive rods to a greater depth or whether to increase the surface area by installing more buried tape. The survey can produce considerable savings in electrode and installation costs when trying to achieve the required resistance.

If the results gained from the soil resistivity survey are unclear then soil modeling can be undertaken. With up-to-date techniques a fairly good and accurate soil model can be produced.

Also core drilling usually associated with a Geo-Technical survey will give an accurate soil model and can be used to check measured soil resistivity results.

1) Two Layer Soil Resistivity Model:

One of the main objectives of an earthing study is to obtain a realistic estimation of the soil characteristics in the vicinity of the concerned substation. Multiple soil layers of widely varying resistivity are involved in the ground current return paths. The complex stratification patterns often encountered, dictate that a realistic soil model should involve more than one layer for properly representing the conductivity profile of the ground.

Today, generally accepted model is a two-layer model, one of the finite depth from the ground surface and second of infinite depth but of different resistivity.

Field measurement of soil resistivity is normally carried out which are then used to obtain an equivalent two layer model as shown in fig 1.

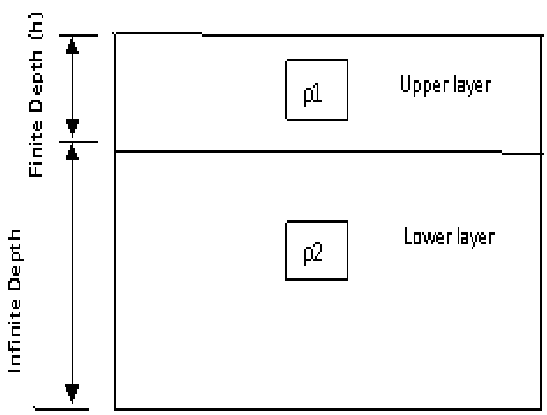


Fig.1 - Two Layer model for Resistivity calculation

For the interpretation of the measurement of soil resistivity CYME software is used.

Program is associated with one input file (data from field measurements) and two output files (Calculations results and resistivity curve).

Based on the field measurements the following is calculated.

ρ1 - Resistivity in upper layer
ρ2 - Resistivity in lower layer
h - Thickness of upper layer.

Table 1:
MEASUREMENT AND CALCULATED VALUES OF ELECTRICAL SOIL RESISTIVITY USING TWO LAYER SOIL RESISTIVITY MODEL

| **Measured Values** | | **Calculated values** | | |
|---|---|---|---|---|
| **Electrode Spacing (m)** | **Soil Resistivity ρ(Ω m)** | **H (m)** | **P1(Ωm)- Upper layer** | **P2 (Ωm)- Lower layer** |
| 1 | 41.42 | 01.80 | 50.08 | 02.96 |
| 2 | 31.30 | | | |
| 3 | 23.00 | | | |
| 4 | 22.12 | | | |
| 5 | 21.99 | | | |
| 6 | 03.77 | | | |
| 12 | 04.52 | | | |

*B.* Calculation of Electrical soil Resistivity using software tool CYMGRD [4]

CYMGRD is the software used for calculating the earth resistivity. CYME'S substation grounding grid design which is exclusively designed to help for the formation of new grids and reinforce the existing grids of any shape .The program conforms to IEEE standard 80-2000, 81-1983 and 837-2002. The use of this software allows us to analyse various design alternatives to select an economical solution for a particular installation. CYMGRD software has user friendly data entry, efficient analysis, and powerful graphical facilities. It also helps us to arrive at technically sound and economical designs.

In this software, data from the field measurement will be the input and the output will be resistivity curves, calculation and of soil resistivity.

The resistivity curve shows the relationship between the distance of probes and the resistivity as shown in fig 2. As the distance and depth of probe increases the resistivity decreases because the moisture content of soil increases with increase in depth.

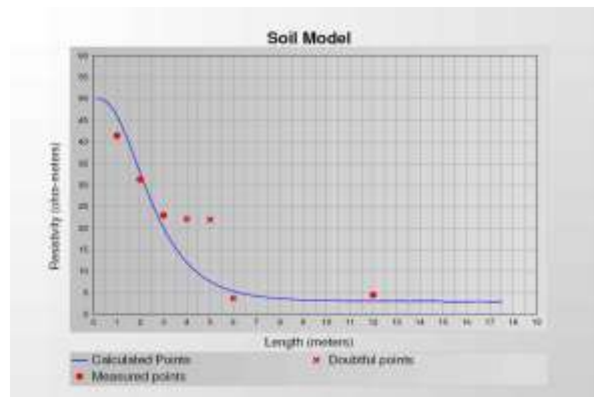


Fig.2 – Resistivity Curve

## III. SELECTION OF CONDUCTORS AND JOINTS

### *A. Conductors: [5]*

The most common metallic conductors include copper and aluminium. Of the metals copper is commonly used as conductors because it has high conductivity. Aluminium is also used as a conductor in housing applications, it is more conductive than copper but it has problems related to heat and thermal expansion which ultimately tends to loose connections. Still copper is the most common choice due to its ease connection by soldering or clamping.

Conductors shall be of high conductivity copper in the form of circular conductors trapped to solid bars. The conductor sheath can be of yellow-green coloured PVC (Polyvinyl Chloride) to meet the requirements with the minimum thickness of 1.5 mm.

Buried conductors which are not part of earth electrode system will be PVC sheathed circular stranded cable. Bare strip conductors will be used for earth electrodes or voltage control meshes.

*B. Joints: [5]*

Permanent joints are made up of Brazing, Exothermic Welding or by Crimping. When the reinforcing in concrete is used as a part of the earthing system the fittings used to provide a connection point at the surface of the concrete should be exothermically welded to a reinforcing bar. This fitting shall be provided with a bolted connection for an earthing conductor. The main bars in the reinforcing shall be welded together at intervals to ensure electrical continuity throughout the reinforcing.

Fig.3 - Overlap joint between conductors at 90 degree [2]

Fig.4 - Joint welding process [2]

## IV. Conductor Size

The conductor size for the earthing system shall be determined by conductor cross section which can be calculated from the formula given below and Table 1 of IEEE 80-2000: [1]

$$A = I \sqrt{((T c.\rho r.\alpha r.10^4/TCAP) / \ln [Tm-Ta/K + Ta])} \text{---} \quad (1)$$

TABLE II

Selection of copper to attain the pvc conductor size [6]

| **A conductor cross section in mm^2 I rms Current in KA Division factor Grid current of the specified fault current** | **11kV Buried copper conductor (PVC) insulated** | **132kV Buried copper conductor (PVC) insulated** | **11kV Riser copper conductor (PVC) insulated** | **132kV Riser copper conductor (PVC) insulated** |
|---|---|---|---|---|
| | 15kA | 24kA | 25kA | 40KA |
| **tc time of current flow in seconds** | 5sec | 3sec | 5sec | 3sec |
| **αo thermal coefficient of resistivity at 0 degree C K1/ αo** | 242 | 242 | 242 | 242 |
| **Ar thermal coefficient of resistivity at reference temperature Tr** | 0.00381 | 0.00381 | 0.00381 | 0.00381 |
| **ρr the resistivity of the ground conductor at reference temperature Tr in μΩ/cm3** | 1.78 | 1.78 | 1.78 | 1.78 |
| **TCAP thermal capacity factor in J/cm3/C** | 3.42 | 3.42 | 3.42 | 3.42 |
| **Tm Maximum allowable temperature in C** | 250C | 250C | 160C | 160C |
| **Ta ambient temperature in C** | 35C | 35C | 50C | 50C |
| **Calculated Conductor Size, A=** | 197 mm2 | 244 mm2 | 195 mm2 | 241 mm2 |
| **Selected copper conductor size as per contract specification A=** | 1x300 mm2 | 1x300 mm2 | 1x300 mm2 | 1x300 mm2 |

The above is the minimum cross section of the copper conductor required and therefore the next available standard of 300mm^2 are adapted for the earthing conductors.

## V. Resistance Calculations

### *A. General: [1]*

A good grounding system offers low resistance to remote earth in order to minimize the GPR (Ground Potential Rise). For large substations as we have considered the ground resistance is usually about 1 Ω or less. This resistance calculation include,

- Mesh resistance
- Resistance of Earth Rods
- Grid Resistance
- Impedance of neighbouring Substations
- Overall Impedance to Earth

### *B. Mesh Resistance: [1]*

The Mesh Resistance of horizontal earth electrode and shallow buried copper earth rod is calculated from IEEE80-2000 equation given below,

$$R_m = \rho \left[ (1/L_t) + \left( 1/\sqrt{20 * A} \right) \left[ 1 + \left( 1/(1 + h\sqrt{20 * A}) \right) \right] \right] \quad –(2)$$

$R_m = 0.449\ \Omega$

### *C. Resistance of Earth Rod: [1]*

The Resistance of each rod is given by IEEE80-2000 equation as shown below,

$$R_{rod} = \rho / 2 \prod L_r \left[ \ln(8 * L_r/d) - 1 \right] \quad \text{-------} (3)$$

We use 12 deep copper earth rods. In order to find the resistance for these rods

$R_{rod} = 19.019\ \Omega$

For 12 rods = 1.585 Ω

### *D. Grid resistance [1]*

Grid Resistance is obtained from the Mesh resistance and Earth Rod resistance which are in parallel,

$$R_g = \left[ (1/R_m) + (1/R_r) \right]^{-1} \quad \text{---------} (4)$$

$R_g = 0.349\ \Omega$

### *E. Impedance [1]*

The earthing system of the main substation is connected with the earthing system of the neighboring substations. So the total parallel Impedance of the main substation is,

$$Z_c = Z_1 Z_2 / Z_1 + Z_2 \quad \text{------------} (5)$$

$$Z_1 = (R_c * l_1/n) + R_1 \quad \text{------------} (6)$$

$$Z_2 = (R_c * l_2 / n) + R_2 \quad \text{------------} (7)$$

R1&R2= 0.125 Ω (assumed values for safety calculation)

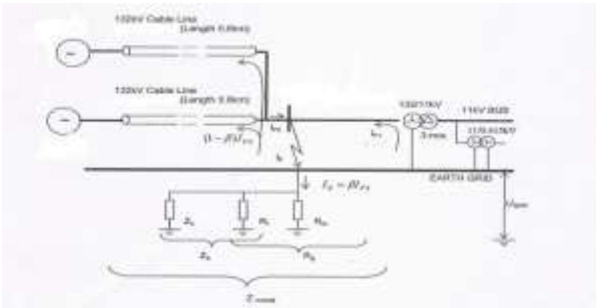


Fig.5 – Earth Fault Current Distribution

$Z1 = 0.13\ \Omega$
$Z2 = 0.22\ \Omega$
$Zc = 0.08\ \Omega$

### *F. Overall impedance to earth [1]*

The overall Impedance to Earth is given by IEEE80 – 2000 – equation as shown below,

$Z_{overall} = [\ (1/R_m) + (1/R_r) + (1/Z_c)\ ]^{-1}$ -------- (8)

$Z_{overall} = 0.065\ \Omega$

## VI. Distribution of Earth Fault Current

Fault current is an abnormal current in a substation due to a short circuit or low impedance path .If the substation is to be protected properly; the fault current must able to operate the protective device within a short period of time as possible. The protective device must also be able to withstand the fault current and extinguish the resulting arcs without any significant length of time [5].

The total earth fault current is given by,

$I_f = I_{f1} + I_{f2}$ --------- (9)

The Earth Fault currents which has been referred from the safety calculations is as follows,

$I_f = 36.2$ kA – Maximum earth fault current

$I_{f1} = 0.3$ kA – Current runs through substation neutral

$I_{f2} = 35.9$ kA – Current runs through network system neutrals

The Earth Fault current through the Earthing system is

$I_e = D_f * \beta * I_{f2}$ ---------- (10)

$I_e = 17787$ A

## VII. Grid Potential Rise

The Grid Potential Rise occurs when the current flows to earth through earth grid impedance. The potential on the earth is highest at the point where current enters the ground and declines when it is away from the source. The ground potential is concern in the substation because of high potential which may cause hazardous to people or equipment [6].

$U_{gpr} = Z_{overall} * I_e$ --------- (11)

$U_{gpr} = 1156.155$ V

## VIII. Safety Assessment

### *A. Step and touch potential [2]*

The risk of serious injury caused by electric shock to persons who may come into contact with metalwork, fittings and structures during times of system earth fault is guarded against by compliance with the relevant sections of IEEE 80-2000.

When an earth fault occurs, the substation earth will rise in voltage above that of the gentle mass of earth for the duration of the fault, and a person who happens at that time to be standing in the vicinity of the substation, may experience a difference in potential between his feet. This is said to be step potential.

During the period of the fault, a person whose feet are at some potential determined by his position on the site, touches some exposed metal work which is directly connected to the substation 'earth', he may experience a difference in potential hands and feet.

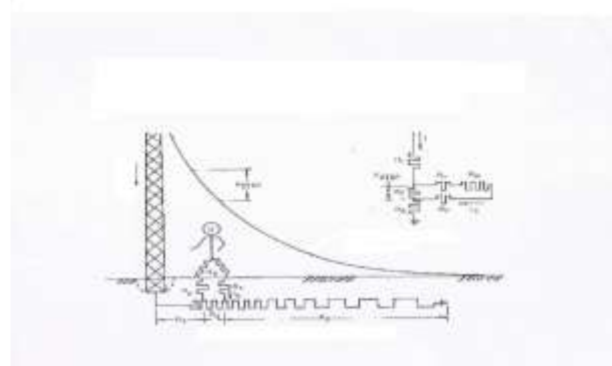

Fig 6 - Step voltage at a Grounded structure [1]

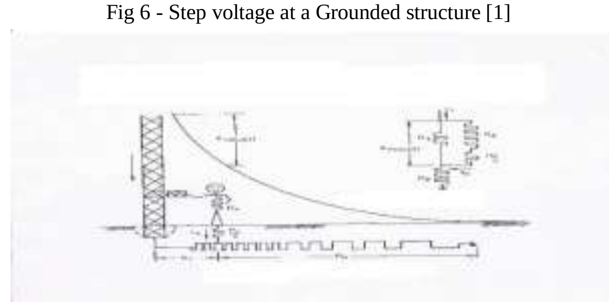

Fig 7 - Touch voltage at a Grounded structure **[1]**

This difference in potential is known as touch potential. Potential rise above remote earth is shown in Fig 6 & 7 for step and touch voltage cases respectively.

### *B. Allowable Step and Touch Potential [2]*

Allowable values of touch and step voltages inside substation for persons weighing 50kg are given by IEEE80 equation as given below,

$E_{step} = [(1000+6C_s* \rho_s)\ 0.157/\sqrt{t_s}]$ ------ (12)

$E_{touch} = [(1000+1.5C_s*\rho_s)\ 0.157/\sqrt{t_s}\ ]$ ------ (13)

$E_{step} = 1649.128$ V

Etouch= 530.032 V

TABLE 3 SURFACE LAYER FACTORS

| **S.No** | **Surface Layer** | **Surface layer resistivity ρs (Ωm)** | **Thickness H (mm)** | **Reduction Factor Cs** |
|---|---|---|---|---|
| 1 | Interlock tiles | 3000 | 100 | 0.528 |
| 2 | Concrete | 100000 | 300 | 0.8514 |

C. Actual Step and Touch Potential [2]

1) Step Potentials:

$E_{step} = (\rho K_s K_i I_e / L_s)$ -------- (14)
$n = n_a \times n_b \times n_c$ -------- (15)
$n_a = 2L_c/L_p$ -------- (16)
$n_b = \sqrt{L_p}/4\sqrt{A}$ -------- (17)
$K_i = 0.644+0.148n$ -------- (18)
Estep=157.80V

2) Touch Potential

$E_{touch} = \rho K_m K_i I_e/L_m$ --------- (19)
$L_m = L_c+[1.55+1.22*L_r/\sqrt{L_x2+L_y2}]L_R$ ------ (20)
E touch=48.86*0.8*0.652*17787/988.47
=462.96V.

TABLE 4 TOUCH VOLTAGE VALUES

| | **Allowable Values** | **Actual Values** |
|---|---|---|
| **E Step** | 1649.128 V | 157.8 V |
| **E Touch** | 530.032 V | 462.96 V |

It is found that Actual calculated step and touch potentials are found to be lower than Allowable step and touch potentials which satisfy the design requirement of the substation.

## IX. CONCLUSION

The safe and reliable earthing system for 132/11 KV substation has been obtained with use of IEEE Standard 80 – 2000, the main parameters of the earthing system such as the soil resistivity has been obtained from the CYMGRD software.

Earthing conductors has been selected according to IEEE standards. The type and size of conductors has been identified from table 01 of IEEE 80-2000. Overall impedance to earth has been calculated by using mesh resistances, resistance of earth rods, grid resistance, impedance of neighbouring substations and overall impedance to earth, which is found to be within the limits.

The earth fault current through the earthing system has been calculated according to the IEEE standards, we have to make sure that the protective device is designed to withstand the fault current of 17KA. Grid potential rise has been identified to verify the potential rise in the ground is below the danger level.

All resistance are found satisfactory and no danger potentials identified with in the Substation. With the help of IEEE equations Step and Touch potentials has been obtained and identified that the values are lower than allowable step and touch potentials, hence satisfies the design requirements of the substation.

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