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Design of Earth Grid for a 33/11kV GIS Substation at a High Soil Resistivity Site using CYMGRD Software

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***Abstract*—Thispaper describes the design ofan earthing system for aGas Insulated Switchgear (GIS) substation using CYMGRD software.The buried earth grid design is based on the soil resistivity of the substation site and the design is verified through simulationsto make sure that the attainable potentials are within the permissible limits ensuring safety of personnel as well as equipments.The design confirms to the IEEE standard80-2000. A 33/11kV indoor GIS substation with a 33kV fault level of 40kA is considered. The soil conditions considered are desert conditions and hence with poor resistivity. Soil resistivity measurement is done using Wenner 4 point method. The measured soil values are then analyzed using the Soil Analysis module of CYMGRD software. The conductor spacing and the ground rod quantity is arrived based on various simulations. This paper also throws light into methods to improve the earthing system when the soil resistivity is high.**

Keywords—Soil Electrical Resistivity; Substation Earth Grid;Touch Potential; Step Potential;CYMGRD; Ground Potential Rise.

I. INTRODUCTION

Substations form an integral part of electric power distribution systems. An efficient earthing system ensures safe and reliable operation of substations. It ensures the safety of personnel inside or in the immediate vicinity of the station. The earthing system provides a low impedance path for electric current to the earth without exceeding the operating limits of equipment.Furthermore, it ensures that in the event of a fault,the current is easily dissipated into the earth without damaging the equipments or exposing personnel on site to dangerous touch and step voltages[2].Since the various factors to be considered while designing an earthing system such as soil electrical resistivity, system fault level, fault clearing time, area occupied by the substation plot, etc. varies from substation to substation, it is not possible to have a common design.

An earthing system for substation mainly consists of a buried grid comprising of interconnected horizontal conductors and vertical earth/ground rods forming an earth mat. All the power equipments and metallic parts on site are earthed by connecting them to this buried earth mat. An efficient earthing design should be able to clearly decide profile of the buried earthmat and the earth rods. Being a critical part of the system, the earthmat design should be in a way such that it is efficient and cost-effective.

Earth mat design can be done by manual calculations as well as with the help of computer software. Though manual calculation is a good, software tools ensure a detailed design so that the earth mat is neither under-designed hence safe nor overdesigned hence cost effective.

This paper presents the complete design of earth mat for a 33/11kV indoor GIS (Gas Insulated Switchgear) Substationusing CYMGRD software. Soil resistivity measurement is done using Wenner four point Method and the measured values are then analyzed and verified.

II. BASICS OF EARTH GRID DESIGN

While deigning an earthing system for any substation, the prime focus should be on the fact that the actual touch and step voltages should not exceed the tolerable values. [1].Ground potential rise (GPR) is the maximum voltage that the earthing system may achieve relative to a remote point assumed to be at the potential of earth [2]. Touch voltage is the potential difference between the ground potential rise on a structure and the surface potential at the point where a person is standing while touching the structure. Step voltage is the surface potential difference experienced between the feet of a person standing on the surface [2].

The primary data required to design an effective earthing system are grid area, soil resistivity, grid fault clearing time and the maximum grid current. In general the design process of an effective earthing systeminvolves Soil resistivity measurement and its analysis, Estimation of permissible touch and step voltages, Estimation of maximum grid current, Buried earth grid design and Safety evaluation of the designed earthing system to ensure potentials are within limits.

In this paper, the focus is on According to IEEE 80-2000, the area of the grid is the single most important geometric factor in determining the grid resistance and they are inversely related. With a larger grid area, a lower grid resistance and hence lower GPR can be expected.

III. SOIL ELECTRICAL RESISTIVITY

Soil resistivity is one of the key factors in the earthing system design. Soil resistivity depends on various factors such as the soil type, depth, presence of moisture, electrolyte contents, temperature, etc and could vary seasonally [5].

Soil resistivity value has direct effect on the overall substation earth resistance and hence on the amount of conductors/ground rods required to achieve a safe earthing design [5]. Consequently, more accurate the measured soil resistivity values are, more accurate thedesign is. Soil resistivity report gives an idea of how deep the ground rods are to be driven or how close the conductors shall be spaced. Hence, when the design is based on this report, considerable savings in material and installation cost shall be expected.

There are various methods by which soil resistivity can be measured like the Wenner four point method, Schlumberger array method, Driven rod (three pin) method, etc. The four point wenner method is the most efficient and widely used. This method adopts multiple depth testing along various axes of the proposed substation site and an overall soil resistivity profile of the site is developed. A detailed description of this method is available in [1].

IV. EARTH GRID DESIGN

Once the soil resistivity is measured, the earth grid can be designed. CYMGRD software confirms to IEEE standard 80-2000, 81-1983 and 837-2002 [3]. It makes use of Finite Element Methods (FEM) for calculating grounding indices. This software helps to design and analyze different profiles of the earthing grid and hence the most economic and technically safe design can be chosen.

A. Soil Resistivity Measurement

Soil resistivity measurement is done using Wenner 4 point method. The average soil resistivity values observed are tabulated in Table 1.

TABLE I. SOIL RESISTIVITY REPORT

Sl No.	*Probe Distance (meters)*	*Resistivity (Ohm-m)*
1	1	1158.98
2	2	743.96
3	4	455.46
4	6	343.65
5	8	245.07
6	10	185.443
7	12.5	121.229
8	15	84.378
9	17.5	51.83
10	20	31.06

B. Input Parameters

In order to start with the design, other inputs required apart from soil resistivity values are described below:

1) Fault current and shock Duration - The fault current is the current that would pass through the earth grid in the event of a fault. The fault duration is the time for which the fault current will flow through the grid before protective devices operate and interrupt the fault. Here, a falut current of 40kA is considered and fault duration of 3 seconds is cosidered for conductor sizing whereas 1 second is used to estimate the permissibe step and touch potential values.

2) Grid Dimension - This is the dimension of the area which the buried earth grid will cover. As mentioned earlier, area of the grid has a direct impact on the grid resistance. This design is for a 77m X 77m grid. Eventhough the substation plot is 75m X 75m, the grid is extended 1m beyond the boundary on all sides of the plot to take care of the high potentials that may occur along the plot boundary as suggested in IEEE 80-2000.

3) Surface Layer - It is suggested that the use of a high resistivity surface layer is capable of improving the safety while designing substation earthing grid in high resistivity soil [1]. When there is a surface layer that provides high resistance between the ground grid and a person on surface, only a smaller amount of grid current will flow to the surface layer. Furthermore, amount of current that may flow through the person to ground is reduced because of the layer of higher resistivity between the person and ground [6]. In this design, a 0.2m thick surface layer of river gravel whose resistivity is 5000Ω.m is considered [1].

4) Grid Conductors and Ground Rods - Both Copper and Aluminium can be used, however,copper is chosen for its better characteristics.

5) Split Factor - In actual case, the whole fault current may not pass through the earth grid due to the presence of overhead lines or ground wires. A part of the fault current may flow to the source through overhead wires. This is possible where there is an overhead neutral connected to the substation from a remote end. Split factor takes care of this current division phenomenon and avoids overdesigning the grid. In this study, a split factor of 0.7 is used.

6) Rod Encaement – In cases where the soil resistivity is high, an improvement in soil property can be obtained by encasing the ground rods in a low resistivity material. Bentonite is an excellent material forn this purpose and is widely used. The resistivity of bentonite is found to be 2.5 Ohm-m [1]. CYMGRD has an option that allows the user to encase the rods with any material of any diameter. The encasement diameter and material resistivity has to be fed to the program.

7) Depth of burial- IEEE 80-2000 suggests that the earth grid be buried at a depth from 0.5m to 1.5m below the surface.

C. Soil Analysis

Soil generally has non-uniform soil resistivity profile.CYMRGD offers choice between “uniform” and “two layer” soil models. In order to obtain a simpler yet more realistic characteristic of the soil resistivity of the site under study, a two-layer soil model is used. It contains a top layer of finite depth and bottom layer of infinite depth. CYMGRD also suggests any possible error in the measured data by pointing out the data as a doubtful value. It can be decided whether to use or neglect this data based on the value of RMS error. A resistivity curve is plotted which shows the relationship between resistivity and depth. This throws a light on how deep the ground rods need to be driven to achieve lower resistivity in case of poor soil conditions. The soil resistivity curve obtained is shown in Fig.1. The RMS error is also calculated, based on thisthe doubtful value may or may not be neglected. If to be neglected, the soil analysis shall be repeated after removing the doubtful value.

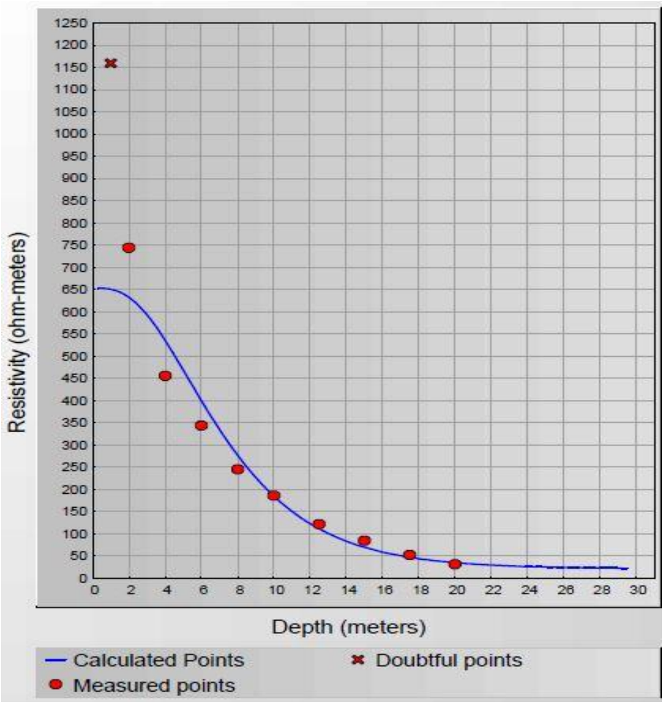


Fig 1 Soil Resistivity Curve

This curve shows that beyond a depth of 12 meters, the soil resistivity is very low. Hence it can be inferred that, if ground rods of depth 12m or more is employed, better design can be achieved. The soil analysis results are tabulated in Table II.

TABLE II. SOIL ANALYSIS REPORT

Sl No.	Calculated Results		
	Description	*Output Value*	*Unit*
1	Upper Layer Thickness	5.17	Meters
2	Upper Layer Resistivity	653.46	Ohm-m
3	Lower Layer Resistivity	20.14	Ohm-m
4	Reduction Factor	0.84	
5	Max. Permissible Touch Voltage	847.09	Volts
6	Max. Permissible Touch Voltage	3040.35	Volts
7	RMS Error	18.74	%

D. Conductor Sizing

The minimum required conductor size can be determined. By enabling the required type of conductor, CYMGRD calculates the minimum required conductor cross section. Inthis project the minimum conductor size was found to be 269 mm^2 and hence copper conductors of 300 mm^2 cross section will be used. The conductor size can also be calculated using the formulae given in Table 1 of IEEE 80-2000 which is given below:

$$A = \sqrt{\frac{1}{\left(\frac{TCAP*10^{-4}}{t_c \alpha_r \rho_r}\right) ln\left(\frac{K_0+T_m}{K_0+T_a}\right)}} \qquad (1)$$

where,

- Ais the minimum cross sectional area of conductor required.
- TCAP is the thermal capacity factor of conductor material,
- $t_c$is the time of current flow,
- $\alpha_{r\ is}$ thermal co-efficient of resistivity of the material at reference temperature.
- $\rho_r$is the resistivity of the conductor,
- K_0 is the inverse of thermal coefficient of resistivity at 0^oC,
- T_m is the maximum allowable temperature in ^0C,
- T_a is the ambient temperature in ^0C.

E. Earth Grid Analysis

Once the horizontal conductor spacing is decided, the gird can be developed. The number of conductors along X and Y axis of the grid shall be calculated and entered into the program. A 2-D as well as 3-D visualization of the grid is available. Once the conductors are placed, the ground rods can be placed. It is always beneficial to place the minimum required ground rods such as transformer earthing rods, lightning protection rods, etc as per the technical requirement of the specific project initially. A trial grid analysis shall be done which gives an idea about the attainable touch and step potentials. This gives an idea about how to proceed further to reduce the resistivity and bring down the potential to the permissible limits. Earthing grid of any shape can be modelled and simulated in CYMGRD.

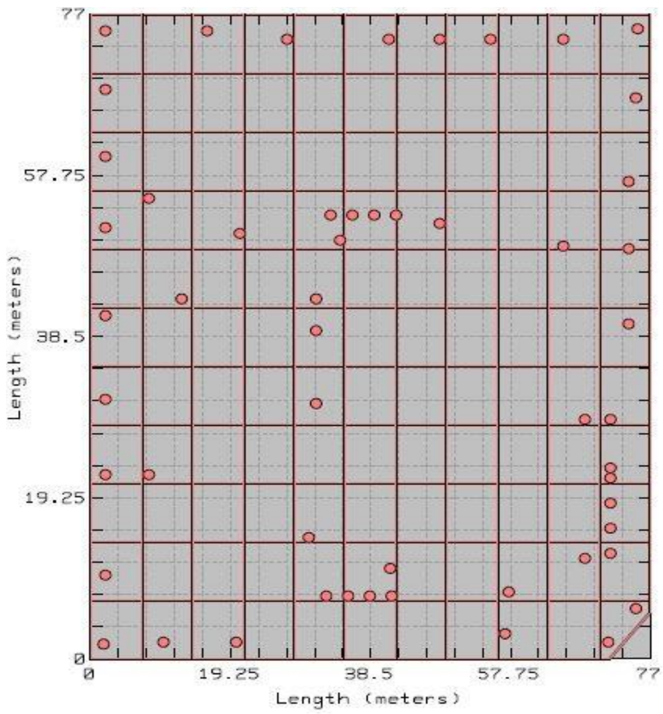


Fig 2 Earth Grid Plan

The earth mat in this study is designed with 7m horizontal conductor spacing resulting in 12 conductors each, along X and Y axes. The grid is buried at a depth of 1m below the ground. In Fig 2, the lines represent the horizontal conductors and the red dots are the ground rods. The ground rods are driven to a maximum depth of 12m. Some are of lesser depth. This is adjusted based on contour plots from different simulations. Rods along the grid periphery are encased with bentonite of 150mm diameter. The designed grid is analysed for grid fault. CYMGRD simulates the application of fault on to the grid for the specified shock duration. Th grid analysis results are tabulated in Table III.

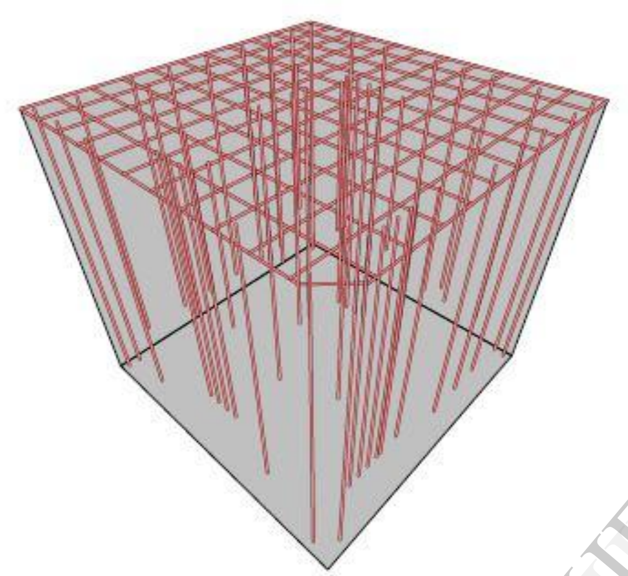


Fig 3 Earth Grid 3D View

TABLE III. GRID ANALYSIS REPORT

Sl No.	Results		
	Description	*Output Value*	*Unit*
1	Ground Potential Rise	3798.09	Ohms
2	Parallel Impedance	0.313	Ohms
3	Decrement Factor	1.0099	
4	Calculated Ground Resistance	0.1343	Ohms
5	Equivalent Impedance	0.09402	Ohms
6	Total Length of Grid Conductors	1848	Meters
7	Total Length of ground rods	525	Meters

F. Potential Profile

This plot gives the maximum touch, step and surface potentials attainable by the overall earth grid in the event of a fault. The profile of the voltages along the grid can be identified from this plot. This profile plot helps in improving the design by checking the effectiveness of the addition of a conductor or rod to the grid and finally an efficient design can be achieved. The potential profile plot achieved after final design is illustrated in Fig 4 and the output results are tabulated in Table IV.

TABLE IV. POTENTIAL PROFILE REPORT

Sl No.	Results		
	Description	*Maximum Attainable*	*Permissible*
1	Surface Potential	3556.79 Volts	3798.09 Volts
2	Touch Potential	816.455 Volts	847.09 Volts
3	Step Potential	296.8 Volts	3040.35 Volts

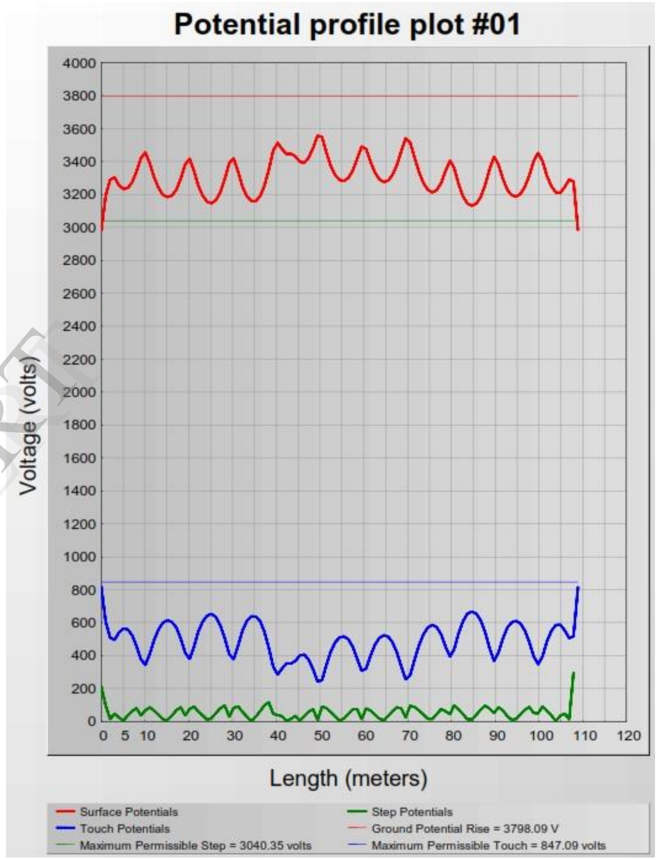


Fig 4Potential Profile Plot

G. Potential Contour

The potential contour plot shows the distribution of surface potential, touch voltage and step voltage along the entire earth grid designed. This gives an idea about the point by point potential levels along the substation. This is very useful in analyzing the grid area by area so that safety can be improved in all areas around the substation. In some situations, even though the overall maximum attainable voltages are within the limits, some areas may still be exposed to dangerous voltages. Potential contour plot is an excellent tool to tackle this situation. The grid can be redesigned based on this plot. Consequently, it can be ensured that ground rods are inserted at critical areas rather than randomly distributing them. This assures overall safety and cost saving. The potential contour plot is shown in Fig 5.

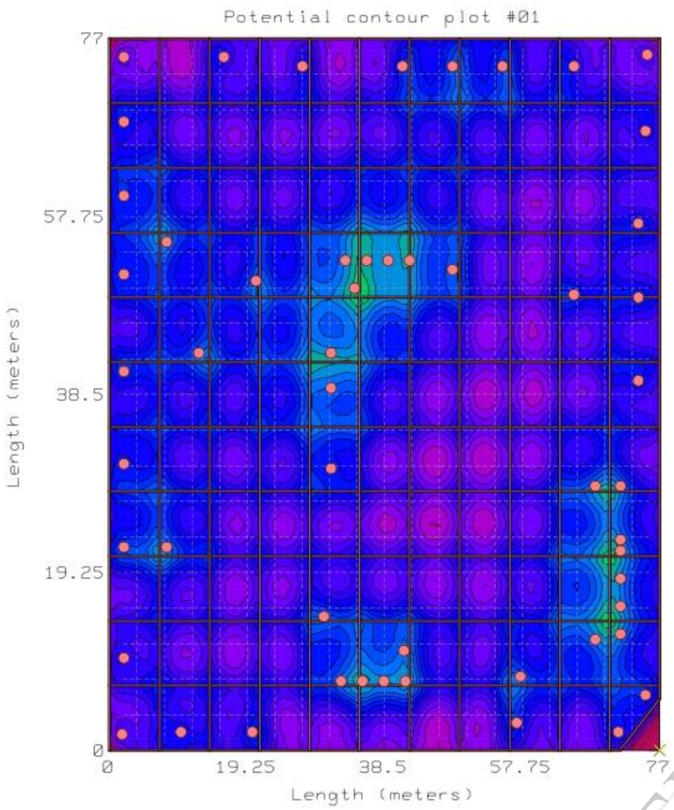
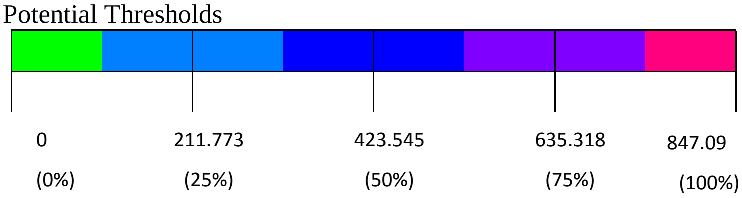


Fig 5Potential Contour Plot

The colours in the above plot indicate the following potential thresholds

Potential Thresholds



V. CONCLUSION

A safe and reliable earthing system for a 33/11kV substation has been designed using measured soil resistivity data and with the help of CYMGRD software. The design confirms to IEEE standard 80-2000. The designed grid has been analyzed and confirmed to be safe for operation. With the help of potential contour plot, it has been reaffirmed that the touch and step voltages at any part of the substation are within the permissible safe limits.

The importance of soil resistivity data for an efficient earth mat design has been clearly described. Design improvement techniques such as use of surface layer and ground rod encasement have been discussed. Hence, it can be inferred that with proper soil resistivity data and design software, safe and cost effective earthing design for substations at sites of very poor resistivity can be carried out.

VI. ACKNOWLEDGMENT

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