CHAPTER 1

INTRODUCTION & LITERATURE REVIEW

1.1 Introduction

Power system in our country is growing in leaps and bounds. Due to economic development there is a huge requirement of power and more need for making transmission & distribution substations. The numbers of Gas Insulated Substation (GIS) substations are increasing due to scarcity of space especially in metropolitan cities. The GIS substation occupies minimum space, meets all the requirements of power system and is also environment friendly.

There is need to provide low resistance path for the discharge of short circuit fault current to ensure safety to working personnel and costly installed equipments in the substation. This in turn helps to keep the ground potential rise, and touch and step voltages within permissible limit.

Design of the grounding system of GIS is a challenging task because of limited space and rise in the short circuit level of power system.

1.2 Relevance for Designing with Multi-Layered Soil Model in India

India is passing through the phase of development. A number of new GIS substations are being developed in India and technology of GIS has touched new height [1-5]. So the price of GIS has come down drastically. The aim of grounding design is to control the values of step and touch potentials below their tolerable levels. These designs are possible for the conventional Air Insulated outdoor substations that are constructed in very large areas. However in case of gas insulated substations (GIS), which usually covers an area of approximately 1/10th of the area covered by Air

Insulated Substation (AIS), it is very challenging to reduce resistance of grounding grid. The problem of reducing resistance of grounding grid becomes more difficult for area where the soil resistivity is quite high.

1.3 Literature Review

In the last two decades the designing of grounding system of HV substation using different computer software [1,6,7,8] have gained a lot of research interest as the fault level of substations are increasing drastically due to load growth. The complete design of grounding system mainly focus on soil modeling, calculation of safety parameters using two or more soil resistivity model & parametric analysis of grounding mat design for optimal results. Many researchers have done research on grounding system design of GIS and AIS. Few of most related research have been discussed below.

IEEE-80 guide for safety in AC substation grounding [1] serves as a Bible for grounding system designers. It helps the electrical engineers for safe AC substation grounding grid design. This guide deals the issues of safe grounding procedures and methodology of AC network working in the range of 50- 60 Hz. This standard provides information on safe accidental current, different dangerous potentials in the substation, selection of conductor for grounding system, tolerable potentials, fault and maximum grid current, calculation of resistance of the grounding system, actual potential calculation, parametric analysis of grounding system, soil modeling of substation etc.

IEEE-81 guide for measuring earth resistivity, ground impedance and earth surface potentials of a grounding system [2].Actual measurement of soil resistivity and its accurate interpretation for soil modeling is very crucial in the design of the grounding system. This guide provides the accurate method for measurement of ground resistivity of the substation's soil using 4 pin methods. Further with the help of testing output data, soil model can derived using finite or infinite series methods. The optimal design of grounding system depends upon the accurate measurement and soil resistivity model of substation.

Also Manual "Grounding of AC Power Systems" Publication No 302, C.B.I.P. [3] and I.S.3043-1987, Indian Standard Code of Practice for Grounding [4] are usually followed by all the design engineers in India. It covers all the spheres of grounding system i.e. measurement , interpretation of measurement, safety potentials, designing of grounding system for AIS as well as for GIS substations, grounding of equipment etc. This code deals the issues concerned with safe grounding practices for power system operating with frequency of 50 Hz. This guide provides grounding design help for both industry and substations.

Besides above guidelines of IEEE 142-2007 - IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems [5] are also followed by design engineer of commercial and industrial system worldwide. It gives guidance on types of grounding system, neutral grounding, connections to ground, designing of grounding system. It helps the electrical engineers in designing of safe grounding system. This provides guidance and information for safe grounding practices in industrial and commercial power systems.

The design of grounding system starts with the soil modeling of substation and to perform this task, paper written by Hans R. Seedher & J. K. Arora [6] proposed an efficient method of obtaining an optimal two layer soil model using soil resistivity measurement data obtained by wenner method. A computer program Soil Parameter Estimation using Finite Expression (SPEF) developed using the finite expressions described in the paper and some case studies of soil resistivity data are discussed. The accuracy of above method was tested by obtaining the two soil model for various data available and comparing the results with the results of other established software 'RESIST'. Similarly, Gary Gilbert [7] illustrated the importance of providing to a suitably low resistance connection to the grounding grid to limit the potential rise of the substation with respect to the potential of the surrounding ground. The potential rise must be controlled to keep touch and step potential under control. This paper further provided an insight of the various soils resistivity testing methods and soil modeling techniques. The paper also examined the model construction of the single and two layer soil resistivity structures.

Further paper of M. Nassereddine et.al [8] and Rodney Urban, Karl Mardira [9] emphasized that High voltage (HV) grounding design is of prime importance for safety of both men and machinery. High voltage system creates unsafe conditions for working staff in the substation. The soil model plays a crucial role in deciding the tolerable and actual step/touch potentials. These paper presented important information for two-layer soil model and suggested that soil resistivity data and its accuracy is important to achieve good design of grounding system. The data of many soil resistivity measurements in the Sydney area for rail system grounding design was presented in the paper [9]. A comparison of the results suggested the possible deviation of soil resistivity results at various depths over small distances and further suggested the application of this finding in the grounding system design.

The computer program which can provide the soil model of the resistivity measurement data were proposed by Ioannis F. Gonos et.al [10] and Adeitan I. Aderibigbe, Fakolujo A. Olaosebikan [11]. A methodology with which different parameters of soil resistivity structure with two layers from the data of resistivity measurement can be computed was discussed and described. The paper discussed different optimization functions and suggested that relative error is the most appropriate optimization function that gives the best fitting curve to the field data. The processing involved the setting soil resistivity data as inputs to an optimization function for optimization. This paper proposed an algorithm in which the square error is used as an optimization function. The accuracy of the new algorithm developed was tested by comparing the results from previous works.

The authors of the paper J. Ma, F.P. Dawalibi & R.D. Southey [12] gave an insight on the major changes incorporated in the 2000 version of IEEE guide for Safety in AC substation grounding with respect to the IEEE-1986 version. Comparisons were made for various sections of two versions of the IEEE guide where significant changes occurred. In this paper examples were also given to show the impacts of the changes on the design of substation grounding. Further, authors, R.D. Southey & F.P. Dawalibi [13] suggested the accurate method of resistivity measurement using Wenner 4-pin method especially this paper emphasized on the probe spacing to get accurate results. This paper discussed the degree of error that may occur in the calculated grid resistance, touch potential and step potential as a function of maximum probe spacing for different soil models. Many problems of grounding system design involving two or more soil resistivity models were discussed by researchers [14-20].

Research paper [21] provides complete analysis of the performance of a grounding system made of copper conductors. The grounding performance was computed in respect of ground potential rise (GPR), touch potential and step potential caused by flow of large currents in the grounding system and finally dissipated in the soil. In this paper modeling and simulation were done on the 'CDEGS' software. The grounding design was illustrated by a case study for the 69/12-24 kV, outdoor-type substation. The factors affecting the apparent soil resistivity of multilayer soil were investigated. Such these factors are:-

1. The number of layers of soil structure (double and three layers are considered in this paper) and their arrangement.

2. The thickness of each layer.

3. The reflection factor between each layer.

The research papers [22-25] presented an experimental work using scale model for different grounding system configuration such as vertical rods with different shapes and different grounding grids to measure the Earth Surface Potential (ESP) in uniform and two layer soil resistivity model. The scale models representing uniform as well as two layer soil model were used for analysis of grounding system. The results derived from the scale models were compared with those given by computer software simulation. These paper also provide information on the analytical methods to calculate the earth surface potential. Three methods charge simulation, current simulation and boundary element methods were used to compute (R_g) and (ESP). Further comparison between the three methods results and IEEE Standard formulas [1] was presented [22, 25].

The paper of P. Hajebi et al [26] recommended that finite element method (FEM) are the most accurate methods for calculation of resistance of grounding grid. In this paper, many grounding grids in two-layer soil with different dimensions and soil resistivity values were simulated using FEM. The FEM results were used to optimize the expressions for estimating the grounding resistance. The expressions were optimized by introducing an objective function and using genetic algorithm (GA). Simulations showed that the proposed expressions give accurate results that match well with those obtained by complete FEM modeling of the grounding grids.

The next step in the designing of grounding system is to find the empirical formula which can use the soil modeling results. In this regard, the research paper of Hatim Ghazi Zaini [27] suggested some empirical resistivity formulas to present the apparent resistivity of the two layer model soil. In this paper current simulation method was used for calculating the resistance of grounding grid (Rg) and Earth Surface Potential (ESP) of the grounding grid in two-layer soil resistivity model.

The papers of Nevil Jose [28] and M.G. Unde & B.E. Kushare [29] described the design of an grounding system for a GIS substation using 'CYMGRD' and SES Auto grid softwares. The buried earth grid design was based on the soil resistivity of the substation site and the design was verified through simulations to make sure that the attainable potentials were within the permissible limits ensuring safety of personnel as well as equipments. The design confirmed to the IEEE standard 80-2000 [1]. A case study of 33/11kV indoor GIS substation with a 33kV fault level of 40kA was discussed [28]. The dessert soil conditions were taken with poor resistivity and measurement was done using Wenner 4 point method. The measured soil values were then analyzed using the Soil Analysis module of CYMGRD software. The conductor spacing and the ground rod quantity was arrived based on various simulations. The paper [28] also threw light into methods to improve the grounding system when the soil resistivity found to be high. Further performance assessment was done for grounding grid with two layer soil resistivity model. The analysis was done for positive as well as negative reflection factor (K) respectively. The simulation was done with the help of SES AutoAutogrid .

The papers of F.P. Dawalibi, J. Ma & R.D. Southey [29] and Kaustubh A. Vyas and J.G. Jamnani of the paper [30,31] provided an exhaustive parametric analysis of grounding grid in multilayer soil resistivity structures. Various practical cases were studied for various parameters affecting the design of the grounding system. The results presented in the papers [30,31] may be used as a benchmark for future work in this domain. A software which designs the ground grids of various shapes as per IEEE standard 80-2000 [1] was developed with the help of MATLAB. To test the performance of the software the results were compared with ETAP-GGS module.

The paper of Soni M., Dr. Abraham George [33] emphasized that a well-designed grounding system is very much essential as far as the safety of the crew and the substation equipments are concerned. Optimal design of grounding system for a substation is complex due to the involvement of numerous parameters. In this paper grounding system was cost optimized by MATLAB simulation and the results were analyzed. Variation in touch and step voltages for different values of fault currents with variations in conductors spacing, depth of burial and number of ground rods were also plotted. The grid design parameters such as ground resistance, ground potential rise, step and mesh voltages, total length of grid and ground rods were calculated as per formulas given in IEEE std. 80-2000 [1].

In the paper of S. Ghoneim et al [34] the Earth Surface Potential (ESP) was computed using new practical method i.e. Charge Simulation Method (CSM). This paper further suggested that the optimal design of the grounding grid depends upon ground resistance (Rg), the ground potential rise (GPR), touch and step voltages and the design cost. The above mentioned parameters depend on the grid parameters as well as grid geometric factors. The effect of number of point charges on the grounding grids, the profile location, and the vertical rod length on ESP was studied. A case study was discussed to elaborate the performance of this method.

Many researchers [35-43] suggested the importance of accurate measurement of the grounding resistance of grounding grid for proper safety in the substation. It was also suggested that the substation ground should have low ground resistance, adequate current carrying capacity. This low resistance helps to control ESP and dangerous potential in the substation. For power system network and substation the efforts need to be made to bring the ground resistance as low as possible. These papers also discussed about optimization of the grounding grid design using a new application of charge simulation method (CSM). The case study of 400 /220 kV substation [39] was also presented to elaborate the various aspects of the design of the grounding grid of the substation. Successful operation of entire power system depends on grounding of 400/220 kV substation. A poor grounding system may result in non-operation or non-operation of protective relays. Also grounding system has to be safe as it is directly concerned with safety of persons working within the substation. Grounding design of substation with non uniform soil resistivity was also discussed. This paper [39] discussed the method of calculation of parameters for 400 kV substations with the help of MATLAB program.

The paper presented by Ersan Senturk et al [44], provided an insight on numerical calculation of potential distribution around a grounding rod using 3D method. The problem was modeled in the cylindrical coordinates and solved using finite difference method.

The paper by A.Raghu Ram, K. Santhosh Kumar [45] emphasized on the problems like VFTO (very fast transient over voltages) which need to be studied thoroughly for insulation coordination, especially, in the case of EHV & UHV substations. Effect of TEV (Transient Enclosure Voltages) was also discussed and it was simulated by modeling which represent the exact replication for the behavior of the enclosure surface of the GIS. The simulation was carried out by using MATLAB Simulink.

The paper written by Premalathaz Potta, R. Balakrishnan [46] suggested that designing of grounding grid is very necessary for protection of working staff and costly equipments installed in the substation. This paper presented the design of grounding systems of 66KV substation using ETAP (Electrical Transient Analyzer Program) software. Simulation of power system analysis using computer software was carried out to get accurate design especially for large substation.

1.4 Inferences drawn from Literature

There are many areas which need more attention or investigation so far the optimal grounding design of high voltage substation are concerned, some of them are:

i. Accurate estimation of ground resistivity for multi layered soil model of GIS needs further investigation.
ii. More research efforts are required for investigating a design for multi layered soil model.
iii. Parametric analysis of different parameters of designing like resistivity, fault current, area of substation, cross sectional area of grounding conductors, total length of mesh conductors, height of gravel, depth of burial of grounding conductors etc for multi layered soil model need more investigation.
iv. Trend of potential on the surface of substation at the time of short circuit fault condition can be done separately using scale model.
v. Some empirical formulas are required for making design calculation easy and fast for design engineers.

1.5 Objectives of the Research

1. The main aim of this research is to get a relatively accurate soil resistivity structure model with two different layers of soil instead of uniform soil model.

2. To map the different parameters that will influence the performance of the grounding system & to compute the effect of each parameter on the design.

3. To develop a software program for designing of grounding system for two layer soil resistivity model of GIS substation.

4. To estimate the surface potential on different parts of substation and division of fault current in the grounding mat using the scale model.

5. To develop empirical formulas for designing of grounding system with two layer soil model.

6. To optimize the design of grounding grid design of the substation using MATLAB GUI.

1.6 Methodology

The work has been carried out in the following steps:

1.6.1 **Identification of Most Influential Parameters**.

In our study the most influential parameters shall be

a) Resistivity of soil (ohm- metre).

b) Short circuit current / fault level (kA).

c) Duration of fault current (time of isolation of faulty part) in millisecond.

1.6.2 Development of Computer Program for Designing of Grounding System of GIS with Multi Layered Soil Model

On the basics of various influential parameters a computer program named **RPDGS** has been developed for designing of grounding system of GIS with uniform and two layer soil model, parametric analysis has also been done.

1.6.3 Techniques Used

MATLAB GUI has been used for designing and analysis of grounding system of GIS with two layered soil model.

1.7 Flow Chart of Designing of Grounding system

The algorithm [1] of the steps involved in the designing of the EHV substation is given below in the figure 1.1 :

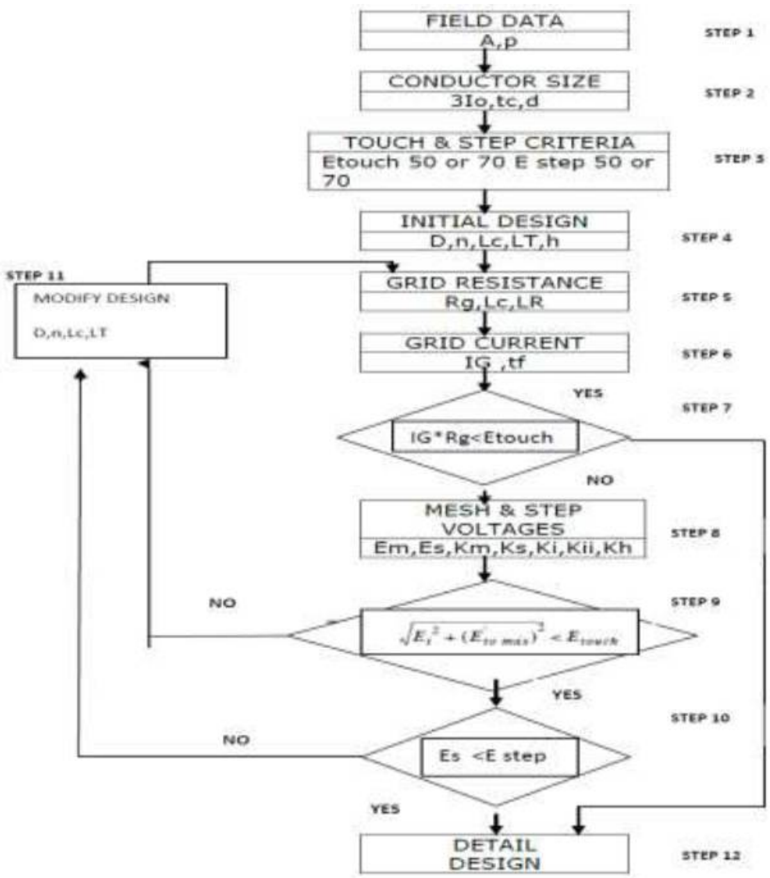

Fig 1.1 Flow Chart of Designing of Grounding System

1.8 Method and Procedure of Resistivity Measurement

There are many methods being used worldwide for measurement of resistivity. Among them four point method of resistivity measurement is most referred by researchers and design engineers.

1.8.1 Four-point method [2]

Out of many methods available for soil resistivity measurement for substation soil, four point method is assumed to be accurate and reliable. In this method four auxiliary electrodes are driven into the soil, at depth *b* and usually placed (in a straight line) with spacing of electrodes equal to *a*. A test current *I* is made to pass through the two outer electrodes, and the potential *V between* the two inner electrodes is measured with a potentiometer or high-impedance voltmeter as shown in figure 1.2. Then, the *V/I* ratio gives the resistance *R* in ohms.

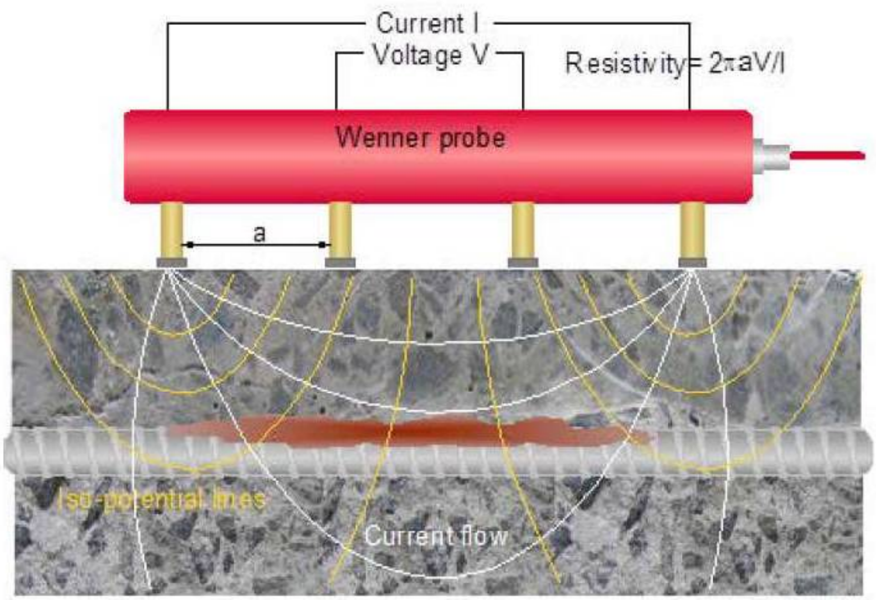

Fig 1.2 Four Point Method of Resistivity Measurement

Two different variations of the four-point method are often used, as follows:

1.8.1.1 Equally Spaced or Wenner Arrangement. In this method of resistivity measurement the measuring probes or electrodes are placed at equal distance, as shown in figure 1.3(a). Let *a* is the spacing between two adjacent measuring electrodes. Then, the apparent resistivity is given as follows:

$$\rho = \frac{4\pi a R}{1+\frac{2a}{\sqrt{a^2+4b^2}}-\frac{a}{\sqrt{a^2+b^2}}}. \qquad \textbf{(1.1)}$$

Theoretically, the electrodes are made of point contacts or these electrodes may be of hemispherical shape with radius *b*. However, in practice, all four electrodes are placed in a straight line with spacing between them is *a* and these electrodes are driven into soil at a depth not exceeding 0.1 *a*. Then, the value of *b* may be taken as zero which makes the above equation as follows:

$$\boldsymbol{\rho = 2\pi a R} \qquad \textbf{(1.2)}$$

Equation (1.1) may be used to find the apparent resistivity of soil in the field for soil depth of "a" meter.

A set of readings are measured with different probe or electrode spacing. These values are plotted against spacing of the electrode which in turn helps to derive the desired two layer soil model with the help of developed software RPDGS.

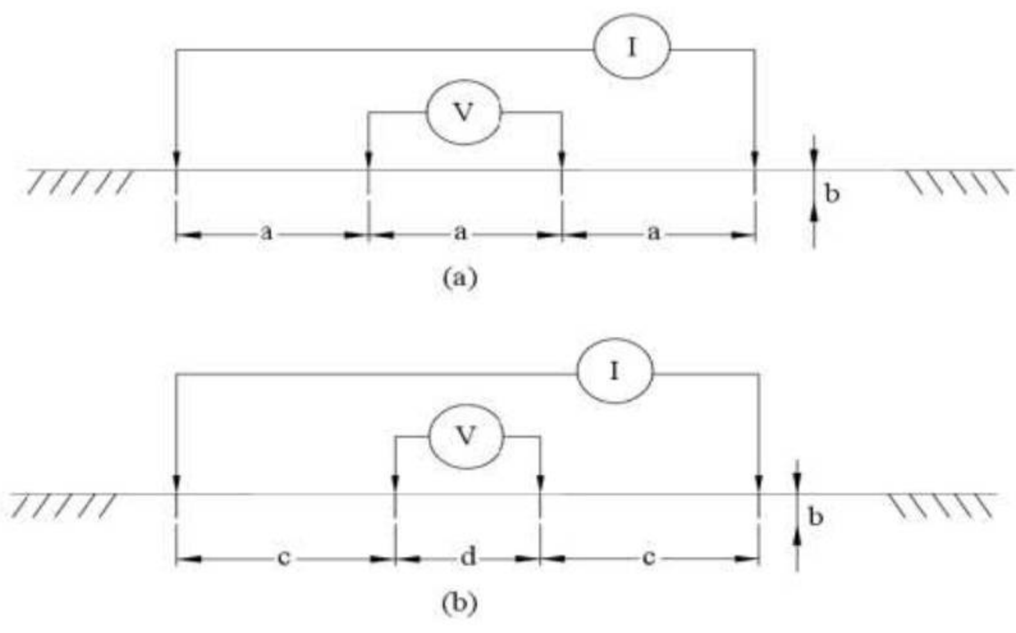

Fig 1.3 Wenner Method and Schlumberger-Palmer Method

1.8.1.2 Unequally Spaced or Schlumberger–Palmer Arrangement. One shortcoming of the Wenner method is the rapid decrease in magnitude of potential between the two inner probes when their spacing is increased to relatively large values. Historically, instruments were inadequate for measuring such low potential values, although improved sensitivity in modern testers mitigates this disadvantage to some extent. Another disadvantage with the Wenner 4 point measurement method is the requirement to reposition all four probes of the instrument for each depth to be computed. The arrangement shown in Figure 1.3(b) can be used to measure soil resistivity to expedite testing for multiple current probe locations. With the Schlumberger method, the inner two probes / electrodes are placed closer together and the outer probes are placed farther apart. Unlike the Wenner 4 pin method, which requires all probes to be moved for calculation of soil resistivity at different depths, the Schlumberger method only required the outer probes to be repositioned for subsequent measurements. Reducing the number of probes to be repositioned for each test makes the Schlumberger method a faster choice for testing at different depths. The equation to be used in this case can be easily determined. If the depth of burial of the probes *b* is small compared to their separation *d* and *c*, and $c > 2d$, then the measured soil resistivity can be computed as follows:

$$\rho = \frac{\pi(c+d)R}{d} \qquad \textbf{(1.2)}$$

Where

d= Spacing between potential terminals (P1 and P2)

c= Spacing between current and potential terminals (C1 and P1, C2 and P2)

R= Resistance Measured

1.8.1.3 Field Measurement : The resistivity measurement using four point Wenner method for new developed part of 220 kV substation Shalimar Bagh, Delhi is depicted in figure 1.4 below.

Fig 1.4 Resistivity Measurement in the Field (220 kV SMB)

Fig 1.5 Resistivity Measurement in the Field (220 kV Narela)

The resistivity measurement using four point Wenner method for existing substation i.e. 220 kV substation Narela, Delhi is depicted in figure 1.5 above.

The readings / results of resistivity measurement by earth meters for 220 kV SMB is depicted in the figure 1.6 below.

Fig 1.6 Resistance value shown by Earth Tester (WACO-MAKE)

The readings / results of resistivity measurement by earth meters for 220 kV Narela is depicted in the figure 1.7 below.

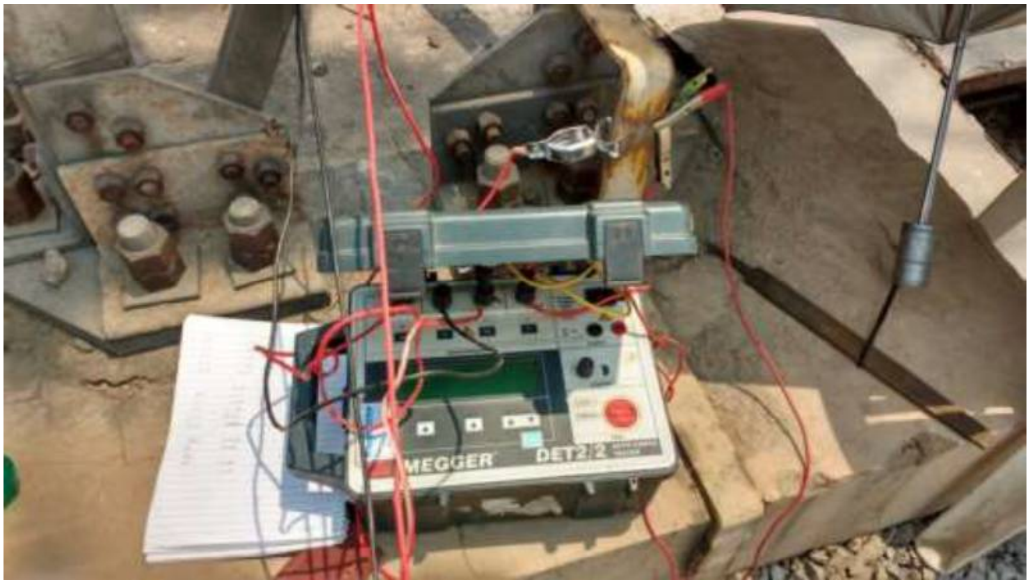

Fig 1.7 Resistance value shown by Earth Tester (MEGGAR-MAKE)

As shown above the earth testers at two different sites were of different makes. In this four points method we use all the four terminals C1, C2, P1 & P4. Readings are taken in all the direction to get accurate soil resistivity model of the substation by gradually increasing the spacing between the four electrodes.

1.9 Thesis Organization

Thesis of the PhD study entitled "**Designing & Parametric Analysis of Grounding System of Gas Insulated Substation (GIS) for Multi Layered Soil Model**" is organized in six chapters and one appendix to describe the theory of soil layer resistivity modeling and designing of grounding mat of HV GIS substation with the help of MATLAB GUI.

Chp.1: Introduction and Literature Review

The chapter presents the introduction and background of grounding at the substation with relevance of designing with multilayer soil resistivity model. It provides the findings of many researchers on the topic of two layer soil modeling, grounding design factors, scale model study of grounding system, optimal design of grounding system etc. Finally, the inference drawn from the literature is given which provides a road map for presented research work.

It further explains the objectives of the research and methodology to be adopted to achieve the objectives. Next the flow chart for designing of grounding system is given. Also, the actual method of soil resistivity measurement in the field with 4 point Wenner method is explained.

Chp.2: Basics of Grounding and Grounding Design

This chapter starts with the basics of grounding and its objectives. It further explains the accidental ground current and equivalent circuit for the accident in the substation. Next, the concept of GPR and different dangerous potential which may occur in the substation are explained. Besides above, the role of fault current and grid current for designing of the grounding grid, importance of step and touch potential and different parts of the grounding system of substation are described in detail.

This chapter further describes the need of GIS, difference of grounding design in AIS and GIS. It further explains the concept of enclosure and circulating currents in GIS. It also elaborates the grounding method of enclosures of GIS, foundation of GIS building .It suggests the areas of special concern of GIS.

Chp.3: Soil Resistivity and Soil Modeling

This chapter introduces the concept of soil resistivity and different soil models of soil resistivity in the substation. It also explains the nature of an earth electrode and components of its resistance. The numerical equations which are used to derive two layer soil resistivity model are explained.

Also the example of design of grounding system for 220/33 kV GIS substation is explained step by step. Also the example of two layer soil modeling from the data of soil resistivity measurement with the help of MATLAB GUI is explained.

Many case studies of two layer soil modeling are carried out and the results obtained are compared with the result of previous research papers to validate the outcome of the developed software RPDGS.

Chp.4: Empirical Formulas for Two Layer Soil Model and Scale Model

This chapter explains the empirical formulas which may be used to compute the different parameters of the grounding mat design of substation with two layer soil resistivity model. These empirical formulas are useful for the complete grounding design of substation using two layer soil model. Different cases studies for two layer soil model are undertaken and results obtained are compared with SES Autogrid software to validate the use of these empirical formulas with MATLAB GUI.

This chapter also explains the method of experiments carried out for both uniform and two layer soil resistivity model of the substation. The factors which affect the potential distribution and earth surface potential in the substation during fault are explained. The experiments are done with and without earth electrodes.

Chp.5: Parametric Analysis

This chapter provides the parametric analysis of all the parameters which may change or affect the design for the grounding system in the substation. All the parameters are discussed one by one and its impact on the design of the grounding system is studied. Also the analysis of grounding system for two layer soil resistivity model is explained.

Chp.6: Conclusion

This chapter discusses the findings of the study carried out for grounding mat or grid design for substation with two layer soil resistivity model.