Chapter 1
Introduction

1.1 Background

Earth resistivity surveying is commonly conducted to interpret the subsurface conditions (soil structure) for engineering applications. Soil structure investigation is very important in many Engineering applications such as Electrical Engineering, Civil Engineering and Earth Resource Engineering applications. For instance Civil Engineers investigate the soil structure for pile foundation constructions. Earth Resource and Mines Engineers apply them in mineral and groundwater exploration, Sand Gravel prospecting and oil exploration; and Electrical Engineers use soil structure knowledge for designing of grounding systems and for lighting protection design. Nowadays they are also extensively used to monitor groundwater contamination, locate subsurface cavities and fissure for various other engineering applications.

Sub soil structure investigations can be done by indirect methods and by direct methods. The latter includes the direct drilling of the earth which is time consuming and costly. Limitations do arise in physical excavations on subsurface study due to digging.

Indirect methods come under Geophysics, where, among other methods, they use electrical energy to gain knowledge of the interior of the earth. These methods are based on sound principles of physical science, which is Geophysics, and involves the application of physical theories and measurements to discover the properties of the earth or the soil structure.

Geophysics can be divided into two broad categories: Whole earth geophysics and applied geophysics. Whole earth geophysics involves the study of physical processes that span the whole earth, such as those associated with plate tectonics, earthquakes and the earth's magnetic field.

Applied geophysics is the use methods such as seismic, gravity, magnetic, electrical, and electromagnetic, in the search for oil, gas, metallic mineral deposits, and water. It also includes the investigation of subsurface structures and materials that have engineering implications, the study of near-surface processes that impact the environment and society, and more, with the objective of economic exploitation. The variation in electrical conductivity and natural currents in the earth, rates of decay of artificial potential differences introduced into the ground, local changes of gravity, magnetism and radioactivity- all these provide information about the nature of structure below the surface, thus permitting geophysicists to determine the most favorable places to search for the mineral deposits etc., that they seek. In short, geophysical exploration intends to create an image of the subsurface of the earth in terms of its physical properties. Unlike solid earth geophysics, exploration geophysics generally concentrates on finding lateral heterogeneities in a relatively small part of the earth's crust.

Applied Geophysics in the search for minerals, oil and gas may be divided into the methods of Exploration as given in Table 1.1.

<table>
<tr><th colspan="2">Geophysical Method</th><th>Quantitative Measure
(Experimental or observational data)</th></tr>
<tr><td colspan="2">Gravity Method</td><td>Measures the variation in gravitational field of the earth</td></tr>
<tr><td colspan="2">Magnetic Method</td><td>measures the earth's ambient magnetic field</td></tr>
<tr><td colspan="2">Seismic Methods (reflection and refraction)</td><td>measures the response of seismic (sound) waves that are input into the earth</td></tr>
<tr><td rowspan="4">Electrical Methods</td><td>Spontaneous Potential</td><td>measures naturally occurring DC currents</td></tr>
<tr><td>Electromagnetic Method</td><td>measure apparent resistance of ground to induced alternating current (AC) flow</td></tr>
<tr><td>Field resistivity measurements</td><td>Measures apparent resistance/resistivity of ground to direct current flow.</td></tr>
<tr><td>Induced Polarization</td><td>measures effect on current flow of charge storage in ground</td></tr>
<tr><td colspan="2">Ground-penetrating radar</td><td>Measures changes in dielectric properties</td></tr>
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Table 1.1 – Applied Geophysical Methods

It should be pointed out that geophysics techniques can detect only a discontinuity, that is, where one region differs sufficiently from another in some property. This, however, is a universal limitation, for we cannot perceive that which is homogeneous in nature; we can discern only that which has some variation in time and/or space [1]. The choice of techniques to locate a certain mineral depends on the nature of the mineral and of the surrounding rocks. Sometimes a method may give a direct indication of the presence of the mineral being sought, for instance, the magnetic method when used to find magnetic ores of iron or nickel; at other times the method may indicate only whether or not conditions are favorable to the occurrence of the mineral sought. For instance, the magnetic method is used in petroleum exploration as a reconnaissance tool to determine the depth to the basement rocks and thus determine the sediments are thick enough to warrant exploration.

1.2 Electrical Geophysical Methods and their applications

Electrical exploration methods may be subdivided into two main groups. One group is concerned with measurement of resistivity, or conductivity, of rocks, while the other group is concerned with measurement of their capacitance. The resistivity, induction and magneto-telluric methods belong to the first group, and the induced polarization methods belong to the second group.

1.2.1 Spontaneous Potential Method

The Spontaneous Potential or Self Potential method measures the natural variation of the ground voltage between two electrodes. The voltage variation is caused by electrochemical reactions at a conductive body.

Natural oxidation-reduction processes generate small electrical potentials that can be measured and mapped. Oxidation of a mineral such as pyrite, transforms iron sulfide into iron oxide; that liberates electrons, which produce a negatively charged electrical current that is normally under one volt. Spontaneous Potential methods take advantage of this phenomenon that contrasts zones with higher concentration of sulfides in oxidation which produce negative potential anomalies that stand out well below the local base level.

To measure small currents on the ground one needs special electrodes that do not polarize as they are introduced in the soil. Spontaneous potential (SP) is measured by an electrode in a borehole relative to a fixed reference electrode on the surface. In the field one probe of a voltmeter is placed at the Earth's surface (called surface electrode) and the other probe in the borehole (called down hole electrode), where the SP is to be measured. In fact, logging tools employ exactly this method. Since this measurement is relatively simple, usually the SP down-hole electrode is built into other logging tools.

1.2.2 Electromagnetic induction Method

The electromagnetic induction (EM) method measures the response of an induced alternating current. A current is induced into the ground by a transmitting coil. A receiving coil is placed a short distance away to measure the induced earth current. The size of the induced current depends on the geologic material (lithology) beneath the transmitter and receiver. By mapping changes in the induced current, it is possible to map out changes in lithology, in order to determine the potential presence of an aquifer. A map of subsurface conductivity can be produced from the data obtained in an electromagnetic induction survey. The map shows areas of disturbed soil, buried metallic objects, and changes in soil conductivity that may be related to disposal of highly conductive substances.

The EM method is also very sensitive to metal. Thus, the location of buried metal objects, such as drums or pipes, can be mapped with this technique.

1.2.3 Resistivity Method

All resistivity methods employ an artificial source of current, which is introduced to the ground through point electrodes. In practice, the current is introduced into the ground through one pair of electrodes. Current flow between these electrodes span out through the ground in a pattern and intensity that depends on the conductivity of the ground and any stratification or obstacles that lie in the vicinity of the electrodes. A second pair of electrodes is then used to quantitatively measure the voltage pattern on the surface resulting from the current flow pattern of the first set of electrodes. Finally an effective or apparent resistivity of the subsurface is determined.

Search for geothermal reservoirs normally involves resistivity surveying and is also employed routinely in groundwater exploration and in civil engineering.

The chief drawback of the method is its high sensitivity to minor variations in conductivity near the surface; in electronic parlance the noise level is high. This limitation added to the practical difficulties involved in dragging several electrodes and long wires through rough areas and due to cultural problems causing interference, e.g., power lines, pipelines, buried casings, fences has made the electromagnetic method popular than resistivity in mineral exploration. The resistivity method is not particularly suitable for oil prospecting.

The rapid development of the induced polarization technique, which includes resistivity data, has guaranteed the resistivity method's continuous use in spite of its limitations.

1.2.4.4 Induced Polarization Method

Induced Polarization (IP) is an Electrical method of geophysical surveying employing an electrical current to determine indications of mineralization. The induced polarization method has been developed for detecting small concentrations of disseminated mineralization in base metal exploration. With the IP surveys subsurface materials, such as ore's can be easily identified. This method has also found limited use for detecting other exploration targets, e.g., in groundwater exploration, geotechnical and environmental applications.

The method is similar to electrical resistivity surveys, in that an electric current is induced into the subsurface through two electrodes, and voltage is monitored through two other electrodes. In the Time domain IP method the slow decay of voltage or chargeability over a specified time interval after the induced voltage is removed. The integrated voltage is used as the measurement, when the injected current is stopped. The IP method therefore measures the bulk electrical chargeability of the rocks.

Frequency domain IP methods use alternating currents (AC) to induce electric charges in the subsurface, and the apparent resistivity is measured at different AC frequencies.

The induced polarization (IP) method was developed originally for ore exploration. The transition from electronic to electrolytic conduction causes strong polarization effects in ores. However, other porous materials also exhibit polarization effects. They are caused by electrochemical processes at the internal interface between the pore fluid and the mineral grains. Although these effects are one to two orders smaller in size, modern IP equipment is able to resolve.

1.3 Resistivity Method – The Inverse Problem

The inversion of field dc resistivity measurements to interpret the actual sub soil structure is presently a popular geophysical method. The scientific procedure for the study of such a physical system can be divided into the following three steps [2].

- *Parameterization of the system*:

  The discovery of a minimal set of model parameters whose values completely characterize the system.

- *Forward modeling*

  The discovery of the physical laws, which allows us to make predictions on the results of measurements on some observable parameters, when the model parameters are given.

- *Inverse modeling*

  The use of the actual results of some measurements of the observable parameters to infer the actual values of the model parameters.

Strong feedback exists between these steps, and a dramatic advance in one of them is usually followed by advances in the other two. While the first two steps are mainly inductive, the third step is deductive. Inverse modeling of the Geophysical Resistivity Method constitute to the determination of the actual variation of the Soil resistivity from the collected apparent resistivity (discussed in section 2.8.1) data from the field. The field data contain apparent resistivity values together with the geometry information.

In Sub surface interpretations, three main topographies are used, namely One Dimensional (1D) interpretation, Two Dimensional (2D) interpretation and Three Dimensional (3D) interpretation. In each of these interpretations the amount of sub soil conditions revealed is different. In the present study in the context of Electrical Engineering we are interested mainly in 1D and 2D interpretations to achieve successful earthing of a system.

In a 1D study the vertical variation beneath a point of interest is obtained. The field apparent resistivity values are inverted to produce a one dimensional plot of resistivity values (Figure 1.1) i.e. thickness and earth resistivity of each layer in a horizontally stratified multilayer earth structure. Early practitioners used several quantitative graphical representation methods such as Curve matching, Ohm-meter method, Moore-cumulative method and Barnes layer method [3]. Other conventional 1D DC resistivity inversion techniques include graphical methods requiring interpolation and judgment and computer based iterative calculation methods [4], [5], [6], [7]. Recently Artificial Intelligence approaches such as Genetic Algorithms [8] and Artificial Neural Networks [9], [10], [11] have been used.

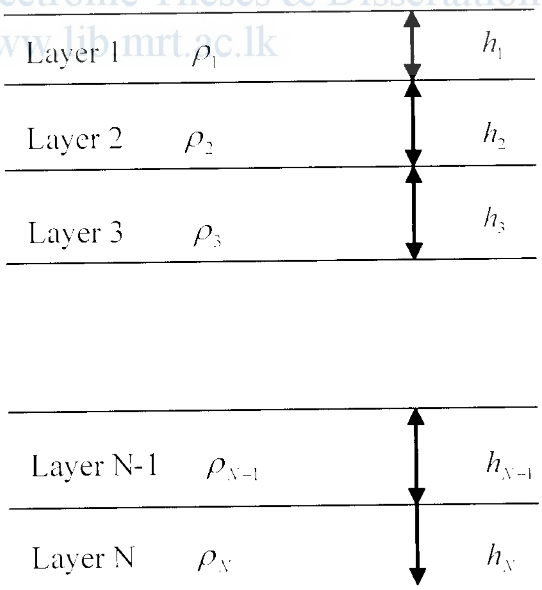

Figure 1.1 - One Dimensional Interpretation of a N-layer horizontally stratified soil structure

But a 1D interpretation will not generally reveal the actual sub soil structure of a complex earth model. However 1D inversion results are very useful in constructing initial models for multidimensional interpretations. Then presently, two-dimensional (2D) interpretations are also widely used. In order to adequately resolve complex soil structures with arbitrary resistivity distributions, the regularized least squares optimization is frequently used [12] in the 2D inversion of electrical imaging data. Simulated annealing [13], Maximum entropy [14], Conjugate Gradient [15] and Neural Networks [11], [16] are other techniques used in the complex structure 2D inversions of geophysical data.

In areas where the geological structures are approximately two-dimensional (2D), conventional 2D electrical imaging surveys have been successfully used. The main limitation of such surveys is probably the assumption of a 2D structure. In areas with complex structures, there is no substitute for a full 3D survey. Researchers have observed that 2D and 3D resistivity surveys at the same location produced very different images on the same cross section. This discrepancy causes much confusion among practitioners about effectiveness of resistivity imaging methods.

Neural Networks are capable of solving several types of problems, including parameter estimation, parameter prediction, pattern recognition, classification and optimization. Also recently the use of Neural Networks in the Geophysics parameter estimation problems has shown strong results [10]. In the past decade and even earlier, there has been research done on the application of Neural Networks in the area of geophysics. Examples of such research are, Electromagnetic [17], Seismic data processing [18], Seismic velocity estimation [19], and 3D resistivity interpretation of controlled-source audio-magnetotelluric (CSAMT) data [20], inversions of magneto telluric (MT) data [21].

With these research showing a great potential in Neural Networks as a inversion tool for geophysics applications lately Neural Networks were applied for 1D and 2D inversion of resistivity data [9][10][11][16].

In the present study Neural Networks is proposed as the inversion tool for parameter estimation in the resistivity problem (discussed in Chapter 3).

1.4 Objectives of the Present Study

The objective of this study is to address the inverse problem of the geophysical resistivity method to implement the one dimensional (1D), two dimensional (2D) and three dimensional (3D) earth structures from a set of field resistivity measurements. This is proposed to be achieved by developing a user friendly software tool with fast response, at low cost to suit current requirements using Artificial Intelligent concepts.

Soil Resistivity is a major factor influencing the performance of an earthing system. In the present study special attention is given to evaluate this with the use of the resistivity method.

Preliminary a study on the resistivity methods Forward Modeling problem was carried out to study how the currents flowing in the different earth structures give rise to the measurable potentials on the earth's surface, that is, how the current flow inside different earth structures behaves. Secondly, the inverse problem for 1D, 2D and 3D cases is implemented with the application of Neural Networks.

1.5 Organization of the Chapters

The rest of the thesis is divided in to eight chapters.

Chapter 2 deals with the Resistivity Method's Forward Modeling equations and the general theories/terminologies in acquiring field measurements.

Chapter 3 deals with a general discussion on Neural Network architecture, algorithms and training.

Chapter 4 discusses the One Dimensional Interpretation of the resistivity problem. A literature survey of the one dimensional problem and Neural Network programs and optimizations together with the interpretation results are given.

Chapter 5 discusses the practical importance (for Earthing) of the resistivity interpretation.

Chapter 6 gives the Two Dimensional resistivity data inversion is presented. The chapter outlines practical field measurement techniques and existing forward modeling approaches and inversion strategies.

Chapters 7 discuss the capability of Neural Networks for Three Dimensional resistivity inversions with the use of synthetic examples. Practical field measurement techniques and existing forward modeling approaches and inversion strategies are outlined.

Chapter 8 presents the results of the NN optimization and theoretical and practical results obtained with NN Inversion.

Chapter 9 gives the conclusion of the study and further recommendations to be added in future work.