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DESIGN AND IMPLEMENTATION OF A PROTOTYPE TO PERFORM GEOPHYSICAL PROSPECTING BY APPLYING THE VES METHOD

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ABSTRACT

In this paper the procedure of the design and the implementation of an electrical equipment to realize geophysical prospecting by means of the method of electrical tomography is exposed. The equipment is of medium power, which guarantees exploration depths quite suitable for commercial and geotechnical applications and studies. The equipment is essentially a DC voltage source of 500 volts which is capable of providing a maximum current intensity of 1 ampere. It also consists of a small current source which counteracts the electric currents that are naturally in the subsoil and which manifest as a potential difference in the surface. A general explanation of the geophysical method in question, allows to understand the basic principles of operation of the equipment and the functions that it has to fulfill. Once the construction of the equipment was completed, a data acquisition was carried out in the field near the municipality of Gachancipa (Cundinamarca). The data obtained with the equipment is processed with specialized software. The images obtained with the software present the distributions of the subsoil resistivities that can be associated to the possible structures and geology of the study area.

Keywords: apparent resistivity, electrical tomography, geophysical prospecting, vertical electrical sounding (VES).

1. INTRODUCTION

The study of the electrical behavior of rocks and sediments in relation to the electric current is called geoelectric. The geoelectric in is a geophysical method that allows to delimit the layers of the subsoil obtaining the thicknesses and electrical resistivities of the characteristic layers.

Geoelectric methods consist of introducing an electric current into the ground and measuring voltage drops produced by this current at different points on the surface. This procedure allows obtaining apparent resistivity values to differentiate subsoil zones by means of current values and voltage drops. Each type of material or structure in the subsoil presents a characteristic range of resistivities, whose value serves as the basis for the interpretation of the results.

The resistivity measurements give an image of the resistivity distribution of the subsoil. To convert this image into a geological structure, it is very important and necessary to know how this parameter varies in the different types of materials that constitute the subsoil and in the geological structures of the study area.

In this work, electrical equipment is designed and implemented that serves as a tool for the acquisition of geophysical data of electrical resistivity, applying the technique of electrical tomography. An equipment of approximately 500w of power is conceived, since with this capacity general studies of geological and geotechnical interest can be realized [1].

The equipment allows investigations in the subsoil to depths no greater than 300 meters, although this effective depth of investigation is dependent on the local characteristics of the subsoil. The equipment allows obtaining voltage and current measurements, which allow the calculation of the apparent resistivity at different points in the subsoil.

In order to obtain a tomographic image of the subsoil it is necessary to feed specialized software with the data obtained with the equipment. The equipment for performing electrical tomography allows the carrying out of studies whose results are of particular interest in hydrogeology, since it allows determining groundwater levels or the presence of aquifer reservoirs. Therefore, these studies can be done at a low cost, compared to the cost of using other equipment or mechanical means (perforations).

In the elements required for the complete application of the geoelectric method, the acquisition equipment, the field tools, the processing software, and finally the interpretation of the obtained results are counted. Regarding the acquisition equipment, there are different electrode configurations that can be adopted by the equipment. With respect to the parts of the equipment stands out the so-called central unit which is the central object and of interest in this paper.

2. MATERIALS AND METHODS

2.1 Principles of the Geoelectric Method

Figure-1 illustrates the fundamental principle of the resistivity measurement of the subsoil, which consists in injecting a continuous electric current through the electrodes A and B, determining the potential difference between the pair of electrodes M and N.

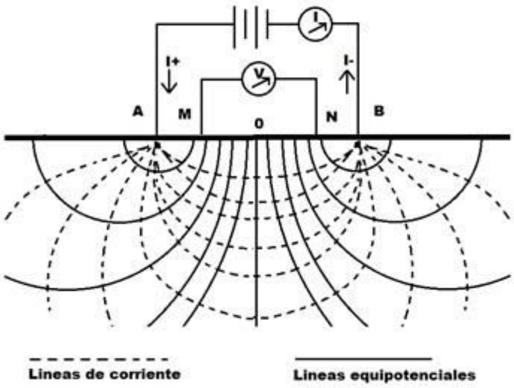

Figure-1. Basic scheme of a device to determine the electrical resistivity of the subsoil.

The current injection electrodes A and B and the measurement electrodes M and N are aligned, according to the configurations proposed by Schlumberger and Wenner [2]. For a medium with homogeneous resistivity, the potential difference is:

$$\Delta V = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{AN} - \frac{1}{BM} + \frac{1}{BN}\right)$$

Where AM, AN, BM, BN are the distances between the electrodes. The resistivity is given by the following equation:

$$\rho = g\frac{\Delta V}{I}$$

where

$$g = 2\pi\left(\frac{1}{AM} - \frac{1}{AN} - \frac{1}{BM} + \frac{1}{BN}\right)^{-1}$$

As can be seen, g is a geometric factor that depends on the arrangement of the electrodes.

The electrical tomography technique uses the apparent resistivity values measured with the geoelectric devices on the surface of the ground to generate images of the subsoil where the values of the true resistivity of the different subsoil zones are represented. The relationship between apparent resistivity and true resistivity is a complex relationship. To determine the true resistivity of the subsurface from the values of the apparent resistivity, the "inversion" technique is applied [3].

2.2 Acquisition equipment

The equipment that is designed and constructed is essentially conformed by the following parts:

Central unit which is responsible for providing the voltage and current to be introduced into the subsoil. It has meters that provide the value of the magnitudes of the current introduced in the subsoil, and of the potential difference measured in the same.

Electrodes that are metal bars that are inserted into the ground, their length should be enough to be able to fix firmly in any terrain, their function is to provide electrical contact between the equipment and the ground.

Cables or copper conductors whose length depends on the maximum distance that could be between the equipment and any of the electrodes, its function is to transport the electrical current from the equipment to the electrodes and/or vice versa. The connectors that are at the ends of the cables and that can be clamps of sufficient size to be able to be attached to the electrodes, or suitable connectors to make a firm connection between the cables and the equipment.

A **battery** that is the power supply that provides power to the entire system, must meet the condition of being portable, rechargeable and easy to replace.

3. RESULTS AND DISCUSSIONS

3.1 Overview of the central unit

The central unit of the acquisition equipment can be divided into two general circuits, these are an emission circuit and a receiving circuit.

3.1.1. Emission circuit

Its purpose is to circulate an electric current of constant value *I* through the ground, introducing it through two electrodes A and B. This circuit is formed by a power supply, a stage of adequacy of current and voltage, two electrodes A and B, an amperemeter for the measurement of I, the necessary cables and connection elements, and finally the ground as electric charge.

The equipment is able to deliver a maximum voltage difference of 500 volts DC at its output terminals A and B, for this the emitting circuit takes the input voltage of 12 volts DC delivered by the power supply or battery and converts it in an alternating voltage. This alternating voltage is used to power an elevator transformer that converts the 12-volt peak-to-peak into an output signal of 500 volts AC. This output signal is rectified so that an output of 500 volts DC is obtained between the terminals A and B. The block diagram of the transmitter circuit is illustrated in Figure-2.

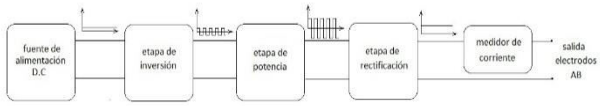

Figure-2. Bloc diagram of the emission circuit.

The inverter circuit is essentially a power converter that is powered by a DC voltage of 12 volts and delivers an output voltage of 500 volts DC and 1 ampere; that is with a power of 500 watts.

In this circuit the integrated CD4047 which is a low power monostable/a stable CMOS multivibrator, it is used to generate a square wave signal of 60 Hz. This could be considered a step to convert the input signal from DC to AC.

After the signal is inverted, each of the negative and positive pulses is pre-amplified by an LM358 operational amplifier. The LM358 contains two independent operational amplifiers with high gain and internal compensation.

The output signal of the LM358 is amplified by 2N2222 NPN transistors which are capable of dissipating a maximum power of 25 watts.

The power stage consists of two sets of four NPN transistors of the series 2N3055, controlled by the output of the 2N2222. These transistors have been designed for general purpose amplification applications and for switching applications, so they are easy to acquire and replace. Each of these sets is connected to the primary central winding of an elevator transformer that receives a voltage of 12 volts AC and is capable of delivering an output voltage of 500 volts AC.

Finally the voltage that is delivered by the secondary winding of the transformer is rectified and converted to a voltage of about 500 volts DC.

3.1.2. Receiving circuit

The purpose of this circuit is to provide the measure of potential difference provided by the ground excited with the emission circuit. This is done through the electrodes M and N and a voltmeter that measures that potential difference. Also connecting cables are needed between them [4].

In addition to this, this equipment has a small current source isolated from the emission circuit, which serves to inject a small direct current to the ground through the electrodes M and N, in order to cancel out the telluric currents that are found in the area of these electrodes and thus to eliminate the spontaneous potential that exists, before injecting some current through the electrodes A and B.

In summary the receiver circuit is basically a voltmeter connected to the electrodes M and N, but in addition, in parallel to this there is a current generating circuit intended to compensate the spontaneous potentials. For this it has a DC voltage source of 6 volts, which is a small rechargeable battery independent of the 12 volts DC. This battery is connected in parallel to a six-position selector which is responsible for inverting the output polarity of the circuit and selecting resistors of different values to adjust the output current. In order to provide a fine adjustment for this current a potentiometer in series with the 6 volt source is connected.

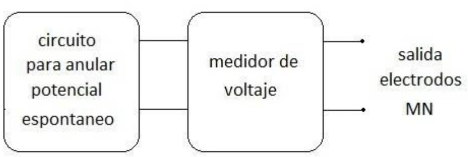

Figure-3. Block diagram of the receiving circuit

3.1.3. Description of the front panel

The front panel of the central unit of the acquisition equipment contains the indicators and controls of the equipment, the switches on and off, in addition to the connection ports to the electrodes A and B, the electrodes M and N and the power supply.

The indicators are digital multimeters UT33C; these multimeters are very reliable and relatively easy to get on the market, so in case of failure they can be replaced quickly and easily. The multimeter located at the left edge of the front panel is responsible for measuring the current flowing through the electrodes A and B. This is done by measuring the voltage drop that is generated in a resistance of 1Ω that is in series with the generator circuit. The second multimeter is responsible for recording the voltage drop between the electrodes M and N and the value of the spontaneous potential present between them at a given time.

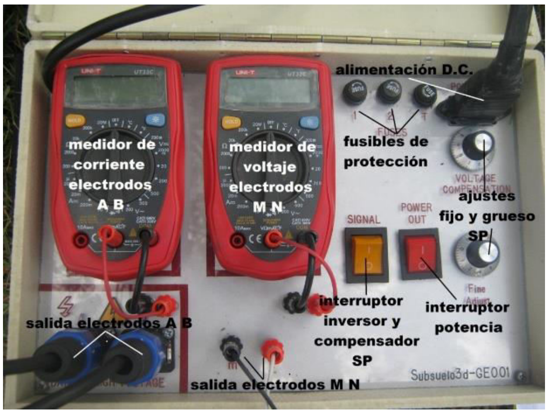

Figure-4. Front panel of the equipment.

The front panel has the output ports of the electrodes M and N, and the electrodes A and B. Care must be taken with the latter, because when the equipment is active, through these electrodes there is a difference of potential close to 500 volts DC with a maximum current of one ampere. Therefore, there is a high risk of injury or fatal electric shock if improperly handled.

The front panel contains the connector for the power supply, which is outside the central unit, this is done to allow the equipment to be more portable, and in case of failure of the power supply, this can be Replaced easily. The power switches for the emitter and receiver circuits, in addition to the fine and coarse adjustment controls to achieve a suitable cancelation of the spontaneous potential, can also be observed.

3.1.4. Power supply

The power supply used to deliver power to the system is an external 12 volts rechargeable battery that can deliver a current of 50 or 100 amperes per hour. This type of battery is commonly used in cars, which allows it to be easily exchanged and have a good amount of energy, necessary in long days of acquisition.

This power supply is connected to the central unit by means of a pair of conductive wires with strong

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connectors at their ends. These conductors are able to withstand a maximum DC current of 40 amps, this current would be the maximum in case of subjecting the equipment to conditions of resistivity of the very low terrain.

3.2 Field tests

Once the acquisition equipment was built, it was used to perform a geoelectric data acquisition in the northern part of the municipality of Gachancipa (Cundinamarca). The line of acquisition was raised near the salt dome on which the municipality of Nemocon (Cundinamarca) is located. The objective of the study was to identify the intrusion of the dome below the acquisition line.

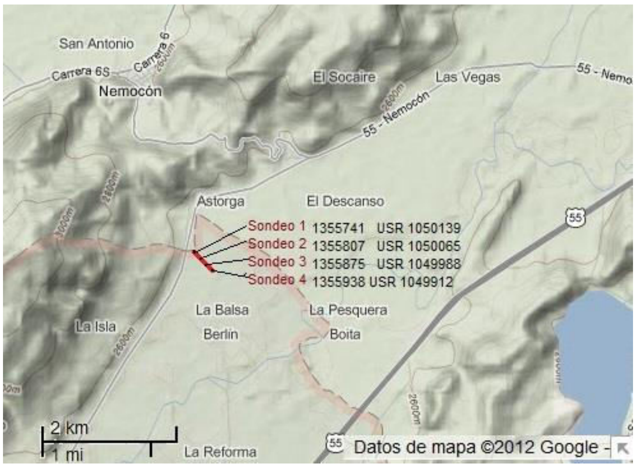

Figure-5. Location of the geographical line of tests performed.

The field results obtained with the acquisition equipment, that is, the voltage values in millivolts and the current values in mili-amperes obtained for each point of each probe are shown. The values AB/2 and MN/2 correspond to the mean values of the distances between the pairs of electrodes A and B, and M and N respectively. The value K corresponds to the geometric constant of the arrangement, and this depends on the type of arrangement and the values of the electrode distances. The value ρ_a corresponds to the value of the apparent resistivity for the point being measured at that moment.

3.2.1. Results of the first VES

The voltage and current values obtained in the field during the acquisition of the first VES were processed in the IPI2Win software [5] and the results of such processing are illustrated in Figure-6.

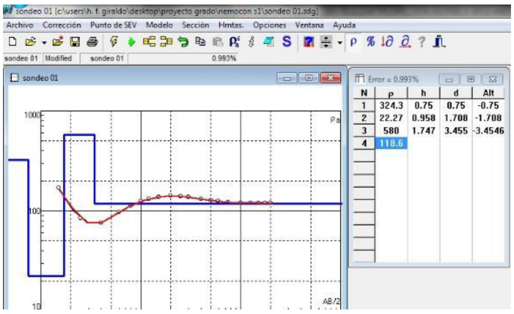

Figure-6. Inversion of the data of the first VES.

The graph to the left in Figure-6 shows the apparent resistivity values on the red line and the real resistivity values in the blue graph. This graph shows the values of resistivity with respect to the average distance between electrodes A and B.

The table on the right in Figure-6 shows the values of the resistivities (shown in blue on the graph) and the depth of the same. This allows to generate a model in one dimension of the resistivities of the subsoil layers in depth, in the central point of the line where the survey was carried out.

Here it is observed that there is a first layer with a resistivity of 324.3 Ω/m and with a thickness of 0.75 m. The model also proposes a second layer with a 22.27 Ω/m and a thickness of 0.96 m. The third layer in depth exhibits a resistivity of 580 Ω/m and a thickness of 1.75 m. Below these three layers underlies a fourth of undefined thickness having a resistivity of 118.6 Ω/m. These values are in line with what is expected to be found in the field, which are resistivity values corresponding to limestones and sandstones.

3.2.2. Results of the second VES

The voltage and current values obtained in the field during the acquisition of the second VES were processed in the IPI2Win software and the results of such processing are illustrated in Figure-7.

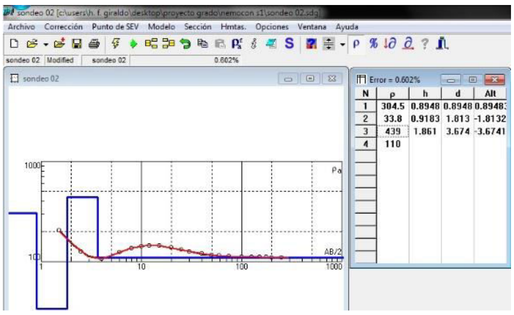

Figure-7. Inversion of the data of the second VES.

The graph to the left of Figure-7 shows the apparent resistivity values on the red line, and the real resistivity values on the blue graph. This graph shows the values of resistivity with respect to the average distance between electrodes A and B.

The table on the right in Figure-7 shows the values of the resistivities and the depth of the same. Here it is observed that there is a first layer with a resistivity of 304.5 Ω/m and with a thickness of 0.89 m. The model also proposes a second layer with a 33.8 Ω/m and a thickness of 0.92 m. The third layer in depth exhibits a resistivity of 439 Ω/m and a thickness of 1.86 m. Below these three layers underlies a fourth of undefined thickness having a resistivity of 110 Ω/m. These values are in line with what is expected to be found in the field, which are resistivity values corresponding to limestones and sandstones.

3.2.3. Results of the third VES

The voltage and current values obtained in the field during the acquisition of the first VES were processed in the IPI2Win software and the results of such processing are illustrated in Figure-8.

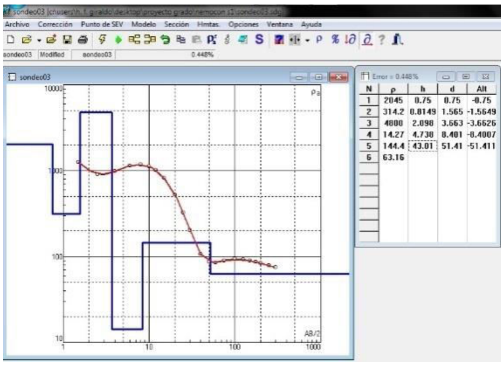

Figure-8. Inversion of the data of the third VES.

For this test a 6-layer model was generated where the first layer presents a resistivity of2045 Ω/m to a depth of 0.75 m. A second layer with a resistivity of 314.2 Ω/m with a thickness of 0.81 m.A third layer with a resistivity of 4800 Ω/m and a thickness of 2.09 m, followed by a layer of 14.27 Ω/m and a thickness of 4.73 m. The next layer has a resistivity of 144.4 Ω/m and a thickness of 43 meters. The final layer exhibits a resistivity of 63.16 Ω/m to an indeterminate depth.

3.2.4. Results of the fourth VES

The voltage and current values obtained in the field during the acquisition of the first VES were processed in the IPI2Win software and the results of such processing are illustrated in Figure-9.

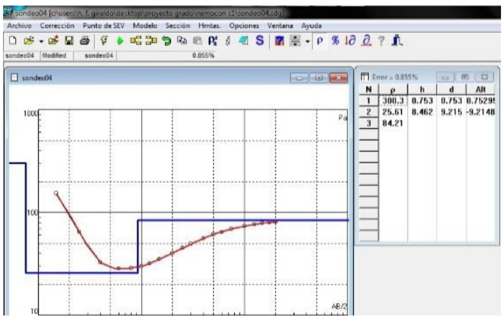

Figure-9. Inversion of the data of the fourth VES.

The inversion of the data of the fourth test yielded a 3-layer model with the following characteristics, a first layer with a resistivity of 300.1 Ω/m that can be found up to a depth of 0.75 m. A second layer is identified with a resistivity of 25.61 Ω/m with a thickness of 8.46m. Below the second layer lies a third layer with a resistivity of 84.21 Ω/m and has an indefinite thickness.

3.2.5. Geoelectric profile obtained

The results of the four Vertical Electrical Sounding-VES performed are used to create a pseudo 2D profile of the line on which the tests were performed. Figure-10 shows the apparent resistivity profile generated. The horizontal scale located at the bottom of the figure indicates the distance in meters between tests which are identified as s1, s2, s3 and s4. The vertical scale indicates the depth in meters. On the right side the color scale is observed for the resistivity values.

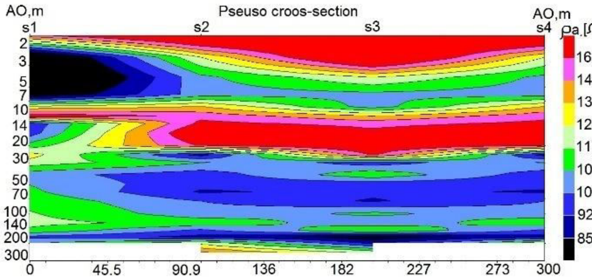

Figure-10. Geoelectric profile obtained from VES.

4. CONCLUSIONS

This equipment, built and designed for geoelectric prospecting, proved to be capable of performing geoelectric tomography studies at depths of at least 250 meters. This depth of investigation is dependent on the length of the separation between the electrodes A and B and the conditions of the terrain studied.

There is no detailed and detailed mathematical analysis of the system, due to its eminently practical development. It is equipment based on a simple electronics, easy to understand and repair.

This is a team built with the aim of being practical and functional, so it has been designed with easy-to-access electronic components in any local market, which is a plus in case the equipment could suffer any type of failure, because delaying too much or totally suspending a data acquisition campaign in the field entails costs that would not be recovered if the objective of the same is not achieved.

The portability, strength and robustness thought in the design of the equipment for the work in the open field, have fulfilled the desired objective when it has been requested.

It was possible to obtain a resistivity profile of the studied area, and the results obtained were in agreement with the expected, according to the field geology previously performed.

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