

Design of Frequency Domain Induced Polarization Equipment having Optimized Frequency of Signal Transmission

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Abstract

Soil resistivity is measured by resistivity or induced polarization methods. In induced polarization techniques, time domain or frequency domain methods are used. The frequency range of operation is 1-10 Hz. In this paper we have designed a frequency domain induced polarization equipment for 55 v/110 V/220 v range in dc and ac. Frequency selection is done as some cardinal parts 0.1, 1.0, 0.3 and 3.0... up to 10 Hz. The collected data for each of the frequency is used to compute the percentage of frequency effect. The values are to be obtained in different kinds of soil for optimization of frequency. This instrument has wide application in demarcating types of soil/rock for pollution and disaster management studies.

Keywords: Frequency Domain, Induced Polarization, Optimized Frequency, Percent Frequency Effect, Resistivity, Time Domain

1. Introduction

IP is a current stimulated electrical occurrence observed as delayed voltage response in earth materials. The name 'induced polarization' has its origin in translation of the Schlumberger papers. IP refers to the induced electrical polarization of more or less conductive rocks. Wait proposed in the year 1959 entitled Overvoltage Research and Geophysical Applications¹. The most important reason of IP within mineralized rocks is a current-induced electron transfer reaction between electrolyte ions and metallic-luster minerals. When metallic minerals block or are next to electrolyte-filled pore paths and electric current flows through the rock, an electrochemical overpotential (overvoltage) builds up at the interface between the electron-conducting mineral² and the pore solution. These electrochemical forces that oppose current flow are described as polarizing the interface, and the increase in voltage required to drive current through the interface is

called the overvoltage². IP is a dimensionless quantity, but in practice it is measured as a changing voltage with time or frequency. IP and resistivity are the surveys, normal utilized in mineral exploration and have large ranging functions in groundwater and mineral exploration, civil and geotechnical engineering tasks.

2. Types of Soils

It is of paramount importance that the signal frequency applied is optimized with the soil conditions. For example in Maharashtra, Black cotton soil consists of Montmorillonite clay particles. Montmorillonite swells with the addition of water. Nevertheless, some Montmorillonite broaden radically more than other clays due to water penetrating the interlayer molecular spaces³. The quantity of expansion depends upon the type of exchangeable cation contained within the sample. The presence of sodium can result in the clay swelling

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to several times its original volume. The frequency of operation is around 4Hz so that the water content is electrolyzed by the frequency.

3. Geoelectrical Methods

Whereas soil resistivity is managed often by electrical conduction inside the pore fluid in IP survey, both resistive and capacitive properties of the soil are measured. IP measurements are made in the field using a four electrodes arrangement. It is a main aspect in design of techniques that depend on passing present through the Earth's surface. An understanding of the soil resistivity⁵ and how it varies with depth is very useful in to designing the grounding procedure in an electrical substation, or for lightning conductors. Electrical conduction in soil is truly electrolytic and consequently the soil resistivity depends upon moisture content, salt content and temperature. The gradual decrease in measured voltage is a complex conduction within the pore fluid along the grain boundaries. In FD mode, a phase – shifted voltage relative to an injected alternating current is measured .The percent frequency effect (PFE) has been used as an IP measure in FD Reynolds et.al in 1998.

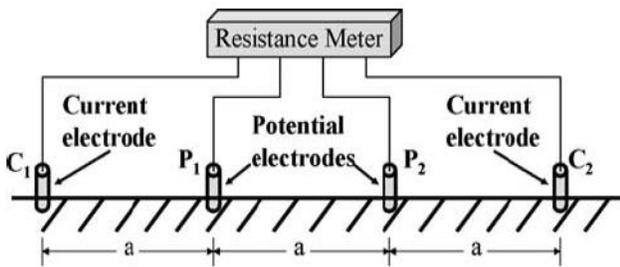


Figure 1. Representing the electricity resistivity method.

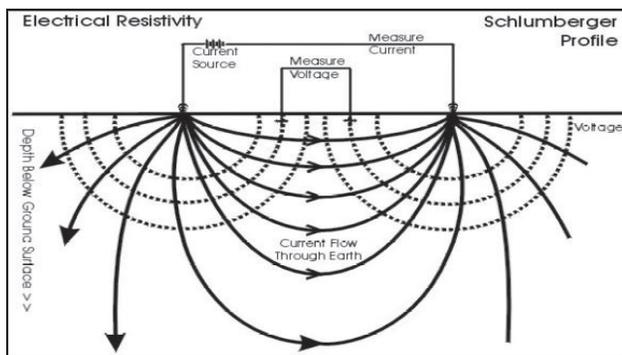


Figure 2. Representing the distribution of electric field in the soil.

4. Induced Polarization

A significant amount of the current above 1000 Hz is carried through the interfacial layer in a non-faradic way. As the frequency is lowered, more current transmits through faradic way. The induced polarization^{6,7} effect is mostly seen between the frequencies of 0.1 and 20 Hz. Higher frequencies are not preferred because of their high electromagnetic induction effect. Moreover, the High-Frequency signal running in the current lead induces a noise voltage in the potential leads, which cannot be wholly filtered out. This noise becomes larger than the measured signal as the soil resistivity diminishes and the pin spacing increases. By and large, measurements realized in the frequency environment are below 10 Hz.

In practice, the value of one frequency is ten times higher than the value of other frequency, such as $f_1=0.1\text{Hz}$, $f_2 = 1\text{Hz}$. The current is held at constant peak amplitude while the regularity is varied. The apparent resistivity at low frequency (ρ_l) is greater than the apparent resistivity at a higher frequency (ρ_h) for the reason the resistivity of rocks reduces as the frequency of the alternating currents is increased. The two apparent resistivity are therefore used to find out the Frequency Effect (FE) (unit less) which may also be expressed, as the Percentage Frequency Effect (PFE).

5. Percent Frequency Effect

The IP represents the ability of the medium to store electrical energy.

- PFE 0 : reference value of water and air
- PFE decreases : highly fractured rocks or coarse soil
- PFE increases : large or not fractured rocks

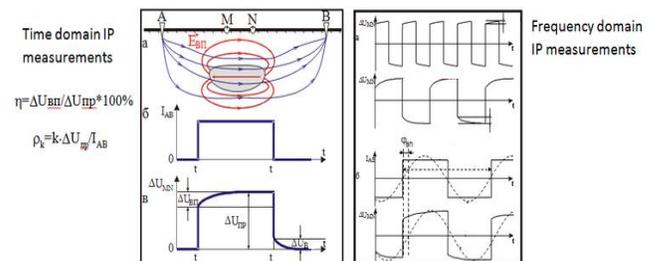


Figure 3. Represents the time and frequency domain waveforms.

PFE⁸ is sensitive to porosity/permeability. The PFE represents the change in amplitude spectrum with frequency and low values indicate insensitivity of the amplitude to changes in frequency. PFE increases exponentially with increase in fines content.

Percentage frequency affect

$$PFE = \frac{(\rho_o - \rho_{hi})}{\rho_{hi}} \times 100 = 100 FE \tag{1}$$

5.1 Frequency-Domain Measurements

Frequency effect^{9, 10}

$$FE = \frac{(V_{lo} - V_{hi})}{V_{hi}} \text{ or } FE = \frac{(\rho_{lo} - \rho_{hi})}{\rho_{hi}} \text{ (unit less)} \tag{2}$$

ρ_{lo} : Apparent resistivity at low frequencies (0.05 – 0.5 Hz)

ρ_{hi} : Apparent resistivity at high frequencies (1-10Hz)

Where ($\rho_{lo} > \rho_{hi}$)

Percentage frequency affect

$$PFE = \frac{(\rho_{lo} - \rho_{hi})}{\rho_{hi}} \times 100 = 100 FE \tag{3}$$

Block/schematic/circuit diagram of IP transmitter

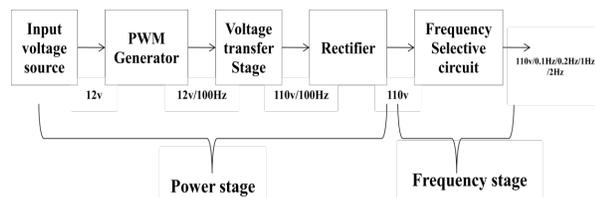


Figure 4. Represents the Block/schematic diagram of IP transmitter.

This circuit is designed and developed which increases the 12 volt current applied from points A1 and A2 of the transmitted unit to 55 volts, 110 volts, or 220 volts and converts the current into accurate direct current through filtering. In the circuit, a 100 Hz square wave signal is produced and is applied to the primary windings of the T1 transformer through Q1 and Q2 power MOSFETs^{11,12}.

The MOSFETs used in the circuit are resistant up to a 50 ampere current. In order to prevent the MOSFETs from being destroyed in the case that they overheat when a high current is drawn, MOSFETs are looped to heat sinks. A 12 volt voltage applied from the primary

winding of the T1 transformer is converted to 55 volt, 110 volt, and 220 volt at the secondary winding. The R1 relay is responsible for selecting the transformed voltages. A 100 Hz voltage alternating current chosen by the R1 relay is transformed into a direct current through diodes D1, D2, D3, and D4 and sent to points B1 and B2.

5.2 Power Stage

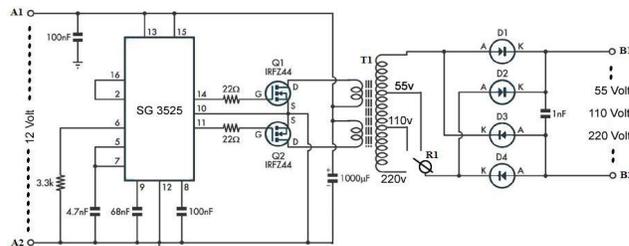


Figure 5. Represents the circuit diagram of power stage of IP transmitter.

5.3 Frequency Stage

The 0.1 Hz, 0.3 Hz, 1 Hz, frequency signal is generated by using the CCS C programming language in the 8051 microcontroller and inverter circuit, as shown in Figure 6. When point F1 of the inverter circuit is logic-1, the Q3 and Q6 MOSFETs are switched; when point F2 is logic-1, the Q4 and Q5 MOSFETs are switched. The direct current derived from the power stage, which is looped to points K1 and K2, is transformed into the square wave form at the C1 and C2 collector points through the double cross switching of the MOSFETs. The waveforms in Figure 7 are the square wave forms, which are observed through the oscilloscope at the C1 and C2 collector points.

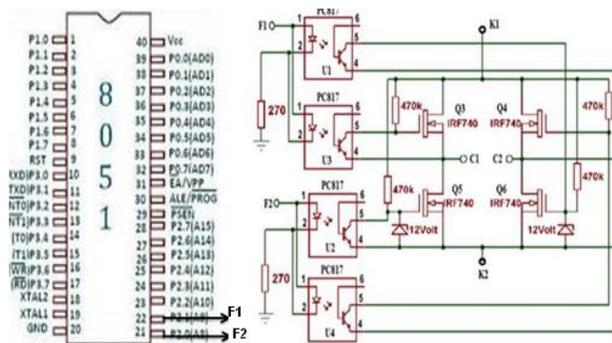


Figure 6. Represents the circuit diagram of frequency stage of IP transmitter.

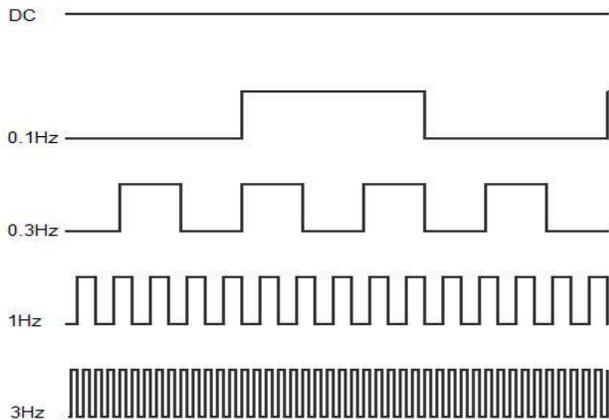


Figure 7. Represents the Wave forms of C1-C2 collectors in the transmitter unit.

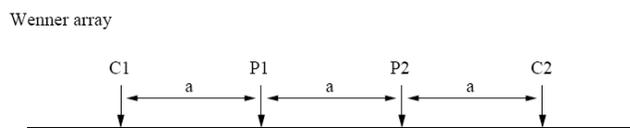


Figure 8. Represents the four electrodes arrangement for measurement.

6. Results Analysis and Discussion

A test setup is arranged for collection of data. A circuit that is sensitive to different frequencies was designed. The square wave signal at 1Hz frequency is generated and transmitted into the soil using vertical bar electrodes spaced equidistantly as shown above. The receiver unit used is an oscilloscope for monitoring the voltage value on the soil. The voltage value received from the soil is received by the vertical bar electrodes inserted into the soil and is measured by oscilloscope. The values are measured and the waveform is recorded and displayed for further observation.

In equation ρ_{lo} is the resistivity at 1.0 Hz and ρ_{hi} is the resistivity at 10.0 Hz. They represent respectively the “dc” and the “ac” electrical resistivity. The value of the high (“ac”) frequency is ten times the value of the low (“dc”) frequency. The PFE value obtained for the set of readings is 30%. The data is obtained and compared with the theoretical value and is roughly similar.

Figure 8 shows the variation of PFE with fines content ($PFE = 2.88 \exp [0.06Fc]$, $R^2 = 0.53$, $Se = 5.7$). The samples prepared corresponded to fines content of 10, 20 and 30. It shows an exponential pattern as predicted by Frederick Owusu-Nimo, department of Civil

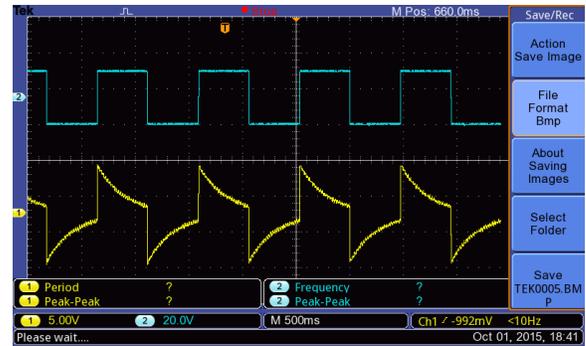


Figure 9. Represents the output voltage waveforms at 1.0 Hz.

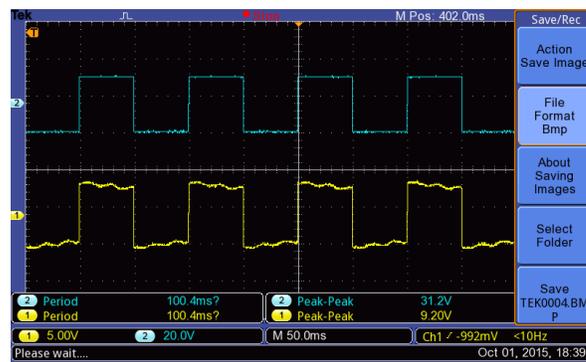


Figure 10. Represents the output voltage waveforms at 10.0 Hz.

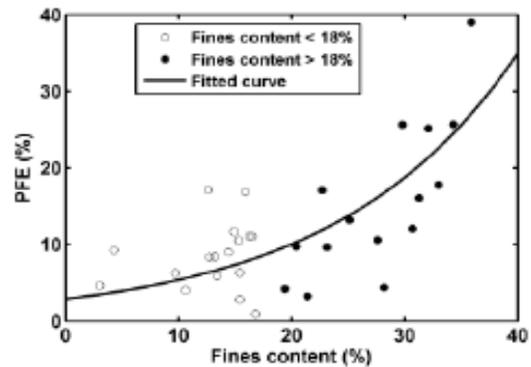


Figure 11. Represents the plot of the variation of percent frequency effect with fines content.

and Environmental Engineering, Duke University. It is found to be true.

7. Conclusions

In this study, in order to identify the physical and chemical features of the soil, a device that sends direct

or alternating current underground into the soil was designed and implemented. In an attempt to identify the nature of the soil underground, the current sent from the power stage of the system should be strong as it affects the accuracy of the results to a large extent. A system was designed using 8051 microcontroller and C# programming language, which enables to generate square waves at different frequencies very accurately. We hope that this study will serve as a basis for the use of more advanced microprocessors and computers within the study system, which will ensure creation of systems that provide more accurate data.

8. References

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