Int. J. Econ. Environ. Geol. Vol. 10 (3) 35-39, 2019

Journal home page: www.econ-environ-geol.org

Open Access

ISSN: 2223-957X

Low-Cost Resistivity Meter for Groundwater Exploration Using High Voltage Experimentations

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***Received:** 26 March, 2018* ***Accepted:** 17 September, 2019*

Abstract: Resistivity survey is very well known for the exploration of groundwater and to determine the depth of bedrock. Generally, in Pakistan local drillers rarely use resistivity meter due to high cost of commercially available equipment. Therefore, most of the wells for groundwater are drilled without any feasibility survey, which causes economic and time loss. An inexpensive resistivity meter has been developed that can help the local community to conduct a survey for groundwater. This designed equipment is handy, portable, easy to operate and can be manufactured locally. This equipment costs 500 US Dollars (USD), whereas commercially available equipment costs 2500 to 50000 USD. The designed portable device comprises of a 12V DC battery, an inverter, multiplier circuit, DPDT switch and electrodes. A 12V DC battery is fed to an inverter to achieve AC supply of 220V. The achieved AC voltage is rectified to DC-voltage which is further enhanced up-to 1300 volts using voltage multiplier circuit. This high DC voltage is called High Voltage Direct Current (HVDC). HVDC is switched at very low frequency of 1Hz. Automatic switching is being accomplished by means of DPDT relay and its control circuitry. HVDC at low frequency is applied to the earth through electrodes to determine resistivity for different materials lying inside the ground with a penetration depth of 100 meters. This portable instrument would be useful to map surface lithological layers, determine quality of groundwater and bedrock level in accurate and inexpensive way.

Keywords: Groundwater geophysics and structure, inexpensive, resistivity, high voltage direct current, low frequency.

Introduction

Pakistan is water scarce country, where contaminated and poor quality of water is major issue in Pakistan. Groundwater carries different sorts of dissolved salts which allows it to conduct electricity into the ground (Kurien 'et al', 2013). Presence of water can be determined by evaluating the resistivity of ground layers. Geologists have employed various kinds of methods for geophysical exploration including gravity, seismic, and detailed geological mapping but these methods are costly and time consuming. The most important method among all geophysical methods in ground exploration is electrical method. The point of interest in this method is resistivity of rocks and other materials inside the ground layers. Due to electrical resistivity and other geophysical methods, different features such as current, voltage, and electromagnetic field of forces, which may happen naturally or artificially can be evaluated. Additionally, different ways of measurements can be used to get results (Wightman et al, 2003). For Geophysical exploration, the concept of Electrical Resistivity Meter (ERM) was used to manufactured the device which provides detailed characteristics of depth, location and resistivity of water and various underground layers. Resistivity technique utilizes an artificial source of supply instead of natural fields of lines as in the case of gravity survey etc. This device is developed by utilizing components which are easily available, inexpensive, and portable and which can be purchased from electronics and hardware stores. This is comparatively a cheaper, accurate and portable device. Total cost of this device is 70,000PKR. Generally, by using ERM, current is inserted into the ground by two outer electrodes and resulting potential difference is measured between two inner electrodes on the earth surface. The basic relationship for this method is vector form of Ohm’s law (Field Strength = Resistivity × Current Density). The main aim of the present study is the use of electrical geophysical method (Resistivity method) to elaborate geological structures briefly at a quicker rate and construct a device that is less in price than commercial devices (Mahipaul, 2013).

Materials and Methods

Electrodes (two outer electrodes “A, B” for current penetration and two inner electrodes “M, N” for measurement of induced voltages) are fabricated by metal of good conductivity and low ductile materials i.e. silver, aluminum, stainless steel or cast iron (Arshad et al, 2007). These electrodes are inserted into the ground in the way that a firm contact is confirmed. Water can be used for better contacts between ground and electrodes. Contact resistance between electrodes and ground should be as small as possible (Clark and Page, 2011). Lithium ion battery (12V, 7Ah) can be used as power bank, which provides power supply to the main system while taking measurements. Four wires are used one end of four wire is connected to electrodes via banana plug and other end is connected to the respective terminal of resistivity device.

The size of the capacitors used in voltage multiplier circuit is directly proportional to the frequency of the signal applied. Supply frequency used in this multiplier circuit is 50 Hz and capacitors used have capacity of 100micro-farads with voltage rating of 460 volts. Selection of these capacitors is to develop a constant voltage level of about 1.2KV required for measurement in this device. Diodes used in multiplier circuit must be chosen in such a way that it must carry the current, which passes through them to charge the capacitor. For this purpose, power diodes are used in this multiplier circuit (Herman, 2001). Battery, inverter, multiplier and meters are properly enclosed in a case of plastic to make this device portable and to avoid moisture and mechanical hazards.

Both of the resistivity methods, either Wenner or Schlumberger are used in field survey. As explained earlier that these are four probe methods that is why ohmic and stray losses are negligible. Both methods are almost of same type but in this device Schlumberger configuration is being used. All four electrodes are inserted into the ground and current is introduced through two outer electrodes, while due to this supply current induced potential difference is measured across two inner electrodes. By increasing the spacing between the current electrodes, penetration can be increased. These supply current and induced voltage are utilized to calculate apparent resistivity using Schlumberger equation. In this method, two inner electrodes remain fixed while only outer electrodes are moved up to a certain limit. Calculated value of resistivity is compared with standard resistivity table to check for the presence of water and other ground materials such as clay, sand and bedrock etc. (Table 1).

Table 1. Typical Geophysical Properties (Clark and Page, 2011).

Geological Material	Resistivity (Ohm-m)
Soil	20 - 300
Clay (Wet)	1 - 50
Clay (Dry)	10 - 100
Sand (Dry)	1000 - 10,000
Sand (Wet)	50 - 500
Sandstone	50 - 1000
Shale/Siltstone	10 - 400
Granite	1000 - 10,000
Air	Very Large
Water (fresh)	50 - 100
Water (salty)	0.2

Electrical Resistivity Design

Design goal was to build a device, which is inexpensive, accurate, handy and portable so that a plumber or a common man in Pakistan can purchase it. The most economical list of components for this project is in Table 2. There are four electrodes, two outer electrodes “A and B” for current penetration and remaining two are inner electrodes “M and N” for the measurement of induced voltage.

Table 2. Prerequisites for inexpensive resistivity meter.

Component	Specifications	Quantity
DC Battery	12V, 7Ah	1
Inverter	12V DC to 220V AC, 500Watt	1
Voltage Multiplier Circuit	Multiplier Circuit	1
Voltmeter	Digital Meter	1
Ammeter	Digital Meter	1
Timer Circuit	50% duty cycle	1
Electrodes	Steel	4

High voltages across the current electrodes are desired at larger spacing hence the depth of current penetration in the ground is limited by the voltage magnitude across the current electrodes “A and B” (Clark and Page, 2011).
All resistivity methods such as Wenner method or Schlumberger method employ an artificial source of current which is inserted into the ground via electrodes. The potential is measured across inner electrodes and current is measured at outer electrodes; thus, it is possible to determine apparent resistivity of various sub surfaces of ground using equation. In this regard the resistivity technique is superior, at least theoretically. To all other electrical methods because quantitative results are obtained by using a controlled source of specific value. Experimentally, as in all other geophysical methods, maximum potency of resistivity is never realized (Arshad et al, 2007; Clark and Page, 2011). Schematic diagram of this device is shown in Figure 3 in which, a 12V, 7Ah battery can be used as power source to supply this device. A small 500watt inverter that produces “modified sine wave” of 220V from a 12V DC source, taken as input then further it is enhanced at next stage using voltage multiplier circuit to the required value of several hundred volts.

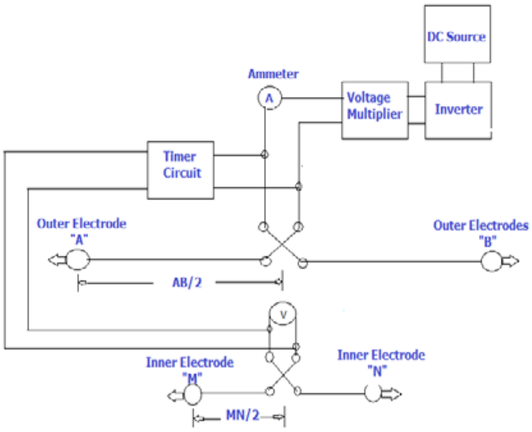

Fig. 1 Circuit diagram for resistivity meter.

Voltage multipliers are used where high-level voltages and lower current are required. This device describes the basic concept to utilize HVDC from single phase AC which is employed with four stages of voltage multiplier to step up voltages up to 1.2KV approximately. In DC system, transformer method to step up the voltages cannot be used due to the constant flux of DC. This flux cannot be linked from primary to the secondary of the transformer. Also, the weight of transformer is more than voltage multiplier circuit. The voltage multiplier circuits are usually used to step up the voltage level of 230V, 50Hz to higher DC voltage levels. This voltage multiplication is also known as Cockcroft-Walton voltage multiplier method**.** The output of voltage multiplier is equal to V_{in}*N where, N is the number of the stages of voltage multiplier circuit. Cockcroft-Walton circuit for voltage multiplier circuit is shown in Figure 2 (Tijare et al, 2015; Waghamare and Argelwar, 2015).

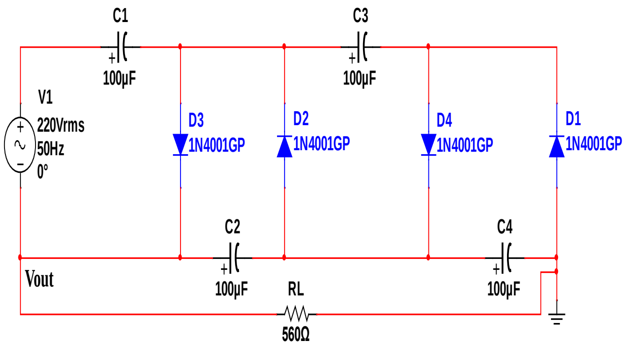

Fig. 2 Cockcroft-Walton multiplier circuit (4 stages).

A rectifier module was being used previously for devices based on this same concept. But in this device rectifier circuit is not necessary at inverter output because in this circuit voltage multiplier performs dual action, stepping up the voltage level as well as rectification. An ammeter is connected in series with the output of multiplier circuit and DPDT switch, while a voltmeter is connected in between two inner electrodes for the measurement of induced voltages as shown in Fig 1.

In all electrical methods, apparent resistivity, $\mathbf{R_{app}}$ of the ground is defined by the relation $\mathbf{R_{app} = F \times V_{MN} / I_{AB}}$, where I_{AB} is supply current to outer electrode and V_{MN} is induced voltages across inner electrodes while, **F** is a geometrical coefficient that depends upon separation between four electrodes **(**Clark and Page, 2011).

In Pakistan, resistivity at depths exceeding 30m were yarely detected and for deeper penetration, this inexpensive device can be utilized which is sufficient up to 100m penetration depth. So, to gain our goal, Schlumberger electrode array is used because in this method current is directly proportional to the difference of squares of electrode spacing, also it is relatively easy to implement due to fixed inner electrodes. An identical device was built in Tanzania based on the same concept to find the resistivity up to 30m depth (Clark and Page, 2011). It is an extended version of that device (Fig. 3), which includes two reversing switches, double-pole double-through (DPDT), one for inner and second for outer electrodes.

To measure current and voltage two small inexpensive digital multimeters can work well. Cost for basic components of this inexpensive device is given in Table 3, which is well within the design budget of 70000PKR. Most of the materials are easily available at electronic supply and hardware stores in local market. Inverter and digital multimeters are also available easily, while voltage multiplier can be designed with simple combination of diodes and capacitors as explained earlier (Herman, 2001; Tijare et al, 2015; Waghamare and Argelwar, 2015).

Table 3. Feasibility report for basic components of inexpensive resistivity meter.

Quantity	Items	Price (PKR)
2	DPDT Relay	500
2	Digital Multimeter	4000
1	100m Tape Measure	1000
1	500W Inverter	3000
1	DC Battery	2000
1	Voltage Multiplier	3000
4	Electrodes	3000

Table 4. Readings for cricket ground (University of Sargodha, Sargodha)

Sr#	AB/2 (m)	MN/2 (m)	V_m (mV)	I (mA)	ρ_a (Ω-m)
1)	5	1	12.3	33	14
2)	5	2	47.5	32.9	23.8
3)	10	2	13.0	32.7	30.0
4)	10	5	45.2	32.6	32.7
5)	15	5	19.5	33.2	36.9
6)	20	5	10.7	33.1	38.0
7)	25	5	6.80	32.9	38.1
8)	25	10	17.0	34.5	40.1
9)	30	10	12.3	33.1	46.7
10)	35	10	8.80	32.3	48.1
11)	40	10	7.70	32.8	55.3
12)	45	10	6.00	33.0	55.0
13)	50	10	4.00	32.4	46.5
14)	50	20	8.60	32.6	43.0

Results and Discussion

Resistivity technique is organized at different locations. This informs about the thickness and depth of water layer and provides complete data about different materials present in ground. Data and results describe about the resistivity of underground layers. Measurements and calculations are examined in a straight line of about 200 meters. These measurements are taken to get the current and voltage values required to calculate the apparent resistivity using Schlumberger equation. This survey is performed on different locations effectively. Date is provided for that survey which was carried out in University of Sargodha's cricket ground (Table 4). Graph between resistivity and outer electrode spacing is shown in Figure 3, which shows the variation in resistivity values at various depths due to different earth lithological layers. These values are showing that after 35m depth, in drinkable water is available. There is more certainty about availability of clean water and aquifer depth. Graph also gives us a pattern and variations being followed by the resistivity inside the ground layers.

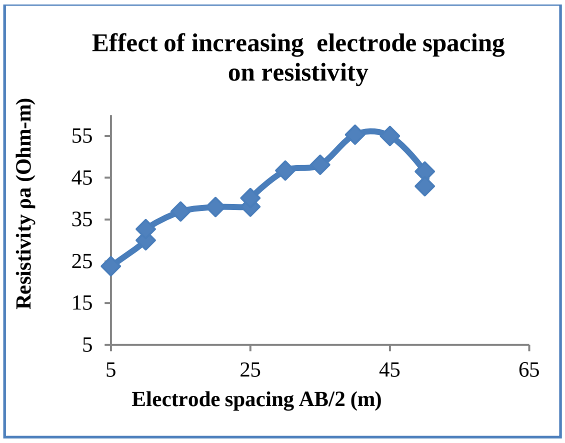

Fig. 3 Resistivity vs. electrode spacing curve.

This survey gave us various values of resistivity for different ground lithological layers including soil, wet clay, dry clay and water. Data for that survey is provided in Table 5 and respective resistivity versus depth of penetration graph is shown in Figure 4. From this survey, fresh water was available at the depth of 30m inside the ground, which was very close to the exact depth of water bore drilled for "P12 water turbine" of 27m. This survey was performed up to 100m (claimed depth of penetration for this resistivity device) and data are provided up to that depth of penetration.

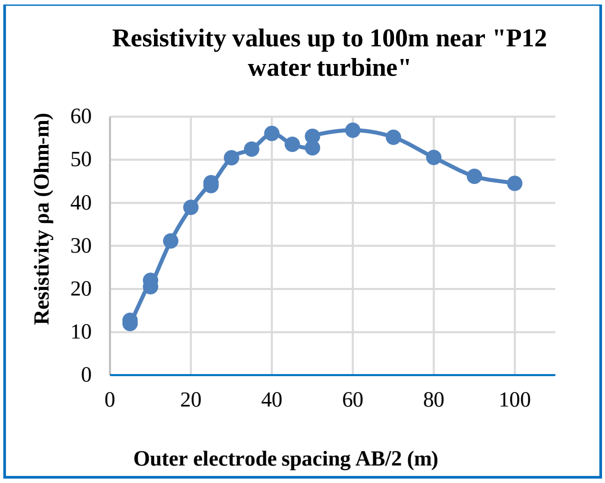

Fig. 4 Resistivity vs. depth of penetration (up to 100m).

In Figure 5, resistivity comparison is provided in the form of two curves on same graph to check for the accuracy of this Inexpensive device with commercial device "ABEM SAS 4000".

In this graph, results are provided for the land near Kirana hills in Pakistan. Curve 1 shows the trend of resistivity obtained using our inexpensive device while Curve 2 shows the results obtained using above mentioned commercial device. Here, the accuracy of inexpensive device can be analyzed by comparing the trends of both resistivity curves. By analyzing these trends, it is obvious that this inexpensive device is following the same resistivity trend which is provided by that commercially available device. These results show the comparable accuracy and precision of this inexpensive resistivity meter.

Table 5. Resistivity values near "P12 water turbine.

Sr#	AB/2 (m)	MN/2 (m)	V_m (mV)	I (mA)	ρ_a (Ω-m)
1)	5	1	35.5	105	12.7
2)	5	2	78.5	108	11.98
3)	10	2	31.5	108	21.98
4)	10	5	91.6	105	20.5
5)	15	5	52	105	31.1
6)	20	5	34.7	105	38.9
7)	25	5	24.9	105	44.68
8)	25	10	56	105	43.96
9)	30	10	42.2	105	50.48
10)	35	10	31.2	105	52.48
11)	40	10	25	105	56.07
12)	45	10	19.5	110	53.58
13)	50	10	15.4	110	52.75
14)	50	20	37	110	55.45
15)	60	20	24.9	110	56.86
16	70	20	17.2	110	55.24
17)	80	20	11.8	110	50.53
18)	90	20	8.4	110	46.16
19)	100	20	6.5	110	44.5

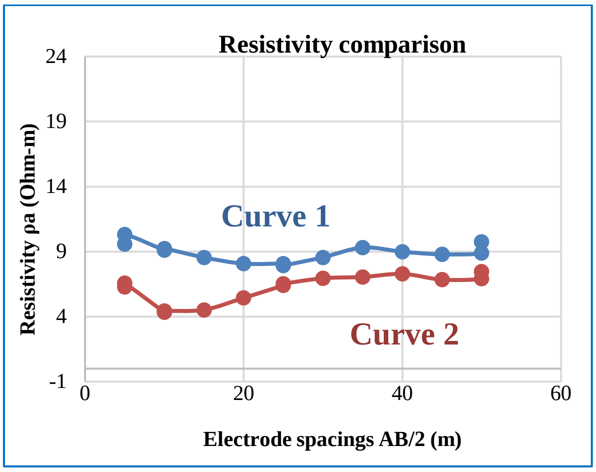

Fig. 5 Apparent resistivity comparison graph between commercial "ABEM SAS 4000" and newly developed device.

Schlumberger configuration is well organized than Wenner configuration in field survey. Field time is halved by using this method. Data assembling requires much time. Maximum spacing of outer electrode is kept at 200m and maximum depth achieved is 100m by using 12V battery and 500watt inverter. In case of Schlumberger, inner electrodes (MN) are closer which yield low potential drop so greater voltage input is required which can be achieved by using voltage multiplier (Clark and Page, 2011). Different types of errors can occur established during these surveys. Firstly, A minor mistake leads to distraction from main task and plenty of time is required to resolve it. Secondly Due to the impact of low battery voltages, readings may change erratically. Electrical grounds, cables and metal pipes can cause more difficulties during the experiment. The most common error is yielding of negative values of resistance due to negative voltage or current readings; two main sources can provide such types of reading errors 1) problem in instrument 2) problem in field mechanism. Sometimes, abnormally high and low readings or unstable readings may occur. To overcome different errors, exact technique must be implemented, device must be operated with specified methodology, readings must be noted with proper care, calculations should be done with correct formulations and most importantly safety measurements must be done effectively and efficiently. Survey should be done at that place where no power cable or high voltage lines are passing. Otherwise they may affect the readings due to the grounding of various electrical equipment such as transformers, high voltage lines and poles supporting the cables (Diaz Fatahillah et al, *2019*).

Conclusion

This device is handy, accurate and inexpensive (500 USD) and made for local use. Small, common and light weight components used in the assembly of this device makes this device portable, efficient and effective. Results of hammering (seismic refraction) for the exploration of ground water provide more confirmation about resistivity surveys.

Acknowledgement

We wish to pay our deep gratitude to College of Engineering and Technology, University of Sargodha (CET, UOS) and its entire labs management for their support and help during the development of this inexpensive device. We are thankful to the management of Nusrat Jahan College, Chenab Nagar for their exceptional support during survey near Kirana hills. We are highly thankful to Engr. Hasnain Shahid Hashmi for his kind guidance during the construction of this device.

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