A Review of Electromagnetic Geophysics

Frijia Mortuza

Abstract— Different aspects of electromagnetic geophysics research are shortly reviewed. Since the discovery of electromagnetic geophysics in 19th century the main attention was the structure of the earth later It is known that it helps to explore ground exploration, dynamic internal structures and surface expressions. As the field is now far advanced to express in a short review, thus here are some important notes are presented.

Index Terms— Electromagnetic Geophysics, Ground Exploration, Active EM method, Passive EM method, Subsurface Resistivity.

1. Introduction:

It is not possible to explain long historical background of geophysics in a short note. As it is important to emphasize earth and ground (included in geophysics) in terms of electromagnetic field so this article has only represented historical background in that perspective. Electromagnetic geophysics helps us to know earth structure and substructure by the help of conductivity [1]. Later it was known that it also enables us to investigate ground exploration, gravitation, magnetic field, internal composition dynamics and surface expression, ground structures [2].

The word geophysics was used by Julius Frobel in 1834. In 1962 a scientist named Jean Richer made a geophysical observation and found a perfect pendulum but it contained large errors as it was losing time. Fifteen years later Isaac Newton explained it by the laws of gravitation and motion as we all know Isaac Newton is famous for his theory of mechanics [5]. He also explained that, the shape of a rotating earth is oblate ellipsoid [5]. By using his theory of mechanics' equipment were developed to measure earth's shape gravity field and density.

Rotation of the earth is a quantity characterized by both magnitude and direction so it a vector and it behaves like an elastic body and deforms in response to the forces generated by its rotation. For explaining wide exploration of the solid Earth and the ocean and also for ground level exploration, geophysical methods and instruments were developed in 20th century. Scientists were always concerned about dynamic condition of the earth. For this mechanisms they always tried to make some hypothesizes.

Electromagnetic geophysics has become modern technology from basic resistivity in the last century [6]. Resistivity is a simple property to understand in physics but how does resistivity can be investigated on the surface which reflects on the object that is important in geophysics. In 1920 industrial applications of geophysics and groundwater geophysics were improved. In 1990 new applications of geophysics were invented like Earthquakes issues for minimization of hazards.

2. Mathematical Representation

It is known that, Earth's magnetic field has three components:

-The main field originates the Earth's inner space and changes are slow

-A small field changes rapidly and originates outside of the Earth.

-Spatial variations of the main field are smaller than the main field and usually same with the respect of time and place. [14]

Only one electric and one magnetic vector is needed for describing EM field when all the magnetizations and electric polarizations are known for a specific medium. As the EM field is a function of the distribution of electric charge, the equation of this electric charge is the Coulomb Law is

$$\nabla . \varepsilon E = Q$$

Magnetic field circulates around J according to Ampere's law.

$$\nabla . J = -dQ/dt$$

As a result,

$$J = \sigma E$$

Where the proportionality constant σ is a property of the material known as the electrical conductivity [3].
For macroscopic EM fields,

$$\nabla . \varepsilon E = -\nabla . P$$
$$\nabla . H = -\nabla . M$$

Where electric and magnetic polarization vectors are P and M.
Coupling between the E and H fields are described by Ampere's law and Faraday's Laws.

$$\nabla \times E = - dB/dt \quad \text{and}$$
$$\nabla \times H = dD/dt + J$$

These all are the fundamental equation for EM field for microscopic level and macroscopic level based on coulombs law, Amperes Law and Faradays law [3]. These are also known as fundamental Maxwell's equation. Electromagnetic induction follows the principle of induction to measure the electrical conductivity of the subsurface.
Later It was much needed to introduce some advanced model and mathematical representations apart from all these fundamental theories and expressions for practical applications. Around 1950 Tikhnov and Cagniard showed a concept of magneto telluric method to measure the dependence of magnetic field on the electrical properties of the ground as,

$$Z_{xy} = E_X / H_y$$
$$Z_{xy} = -E_Y / H_x,$$

Dimensions of volts per ampere or ohms. [4]
The time–frequency electromagnetic method (TFEM) is another advanced model to detect deep targets for controlled source EM methods [13]
For Time domain electromagnetic method, $H\_Z^\delta\ (t) \approx \rho y/\tau^5\ 8\pi(2\pi)^(1/2)/\mu$

Where, Time domain parameter is T. [4]
For the selected frequencies apparent resistivity and phase data can be derived from the measured electric and magnetic field,

$$\emptyset(f) = \mathrm{T}(E_X/H_Y)/\mathrm{R}(E_X/H_Y)^1$$

3. How Electromagnetic Geophysics make sense?

Geophysics has become an individual branch in 19th century. Electromagnetic geophysics is an important part of geophysics. Electromagnetic (EM) method helps to use of the ground response of the propagation of the electromagnetic field. It is composed of alternating electric field and magnetic field. As assumptions of electromagnetic methods are tough, most geophysicists can sketch accurately mechanical and magnetic methods by the help of susceptibility or density distribution. An electromagnetic field can be accelerated by going through an AC by a small core made up of loop wire.
For geophysical applications, frequencies of the primary AC current are usually less than a few thousand Hertz. In geophysical technique electromagnetic method is powerful tool. For shallow targets from low frequency to higher frequency techniques developed for deeper applications, such as mining, geothermal and crustal studies [12].
EM method can active or passive. Active method is for natural ground signal and passive signal is where artificial transmitter is used. As Geophysics does not need direct access to subsurface it evaluates vast volumes of earth at less cost, still there is exception like borehole methods where access is direct. As we see electromagnetic geophysics has been widely useful for past half decades and procedures are simple and cost is low so in present it's a very important phenomenon as a broad range of earth technology is covered by geophysics and it has lots of options.
Earth's physical properties from a limited set of measurements of a related physical field made on the earth's surface is the ultimate intension of geophysics. In recent years applied electromagnetic geophysics is widely used. For understanding applied geophysics, it is necessary to have a good knowledge of math and physics theories, geology, computer skills and experience of using instruments.

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Applied geophysics is useful for making advanced instruments and this tools enable us to have a better understanding of EM method in real earth [17].

Ground Penetrating Radar (GPR) is now a well-established tool that combines high sensitivity and spatial resolution [19]. Surface geophysical methods can reduce risk and unnecessary costs as it has successful history for decades.

4. Appication

Long time ago it was established that investigation of earth structure in terms of electrical conductivity is possible by electromagnetic geophysics [1]. But in 20 century applications of electromagnetic geophysics is wide and more useful.

Geological mapping plays an important role for investigating of landfills, bridges, tunnels and dam [8,9,10]. For mapping subsidence areas Resistivity is also possible with the help of this method. [11]. Such as time domain EM field is used for characterization of ground water and subsurface resistivity [12].

There is an instrument named conducting meter for shallow monitoring of ground water pollution with the help of its two receiver coils, one coil is for susceptibility another is for conductivity.

For measuring groundwater exploration electromagnetic conducting meter is used. Geophysics helps us to investigate the formation factor, bulk density, porosity, permeability, moisture content, and specific yield of water-bearing rocks. It can also define dynamics, origin and chemical and physical characteristics of ground water [15].

Calibration and standardization, radius of investigation, and extraneous effects are also possible to determine by using geophysical activities. Exploration geophysics also enables to find out the information of surface of the earth [16].

Landmine detection, interferometry, airborne unexploded ordnance (UXO) discrimination are introduced by using many advanced and new techniques [18]. Airborne Electromagnetic data is gathered by transmitting an electromagnetic signal from a system of a helicopter. This system is made by electromagnetic geophysics also.

5. Conclusion

The main theme of this article was how electromagnetic geophysics has been used in different sectors from the past to present. As this branch has become wide so only some important notes are shown here like how this phenomenon has improved day by day. The main intension of this article was to provide general outline of the term electromagnetic geophysics as lots of people are still new with this term. In this article at first a short overview of historical background is explained. After that, some important theoretical representations, purposes and applications are summarized.

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