Geophysical Research Abstracts
Vol. 13, EGU2011-4008-1, 2011
EGU General Assembly 2011

The preliminary study on considering IP effect for CSAMT data

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The CSAMT responses of geoelectric media are actually the accumulation of electromagnetic response and induced polarization (IP) under the stimulation of controlled source. Traditionally, the resistivity is generally considered as a real number parameter unrelated with frequency when people do inversion of field data. But in fact, the resistivity of polarized layer is a plural number related with frequencies due to Induced Polarization (IP) effect. Due to the induced polarization of underground layers, using only real resistivity will lead an inaccurate result.

Large number of published papers in recognizing and extracting IP effect from electromagnetic field data of Magnetotellurics (MT) and Transient Electromagnetic (TEM) methods were documented in recent years. The possibility of acquiring the IP information from MT data is discussed based on the analysis of magnitude of MT signal and the circumstances of IP effect generating from rocks (Wu and Wang, 1978). Separating IP effect from field data of TEM method which stimulated by the magnetic transmitter such as central loops and overlapping loops is also discussed (Sun, 1998). Li and D. W. Oldenburg (2000) presented a preliminary 3-D inversion result of induced polarization data acquired in a 3-D environment. Chen (2001) made the detailed researches on the theory of IP with natural source in his doctoral thesis and drawn several interesting forward computational results. Erika and Morrison (2001) studied the same research as Chen and come up with the significant conclusion as well. The MT anomaly led by geoelectric inhomogeneity is much larger in magnitude than that of IP effect so it is inaccessible to get the IP information from data of prominent induction and electromagnetic effect, which means the application is not available (Luo, 2003). Theoretical MT studies have shown that the result of conducting MT survey with natural source is significant, which is validated by the experiment finished in some lead and zinc mine area (Li and Chen, 2003). Cao (2006) studied the MT forward and inversion research for field data based on Cole-Cole model. Yue et al (2007, 2009) studied the similar research of MT data with Dias model and they achieved a good progress in extracting induced polarization.

As an effective EM method, Controlled Source Audio Magnetotellurics (CSAMT) is an important approach which has many advantages than MT and been widely used in the exploration of mineral resource, underground water, oil and gas, geothermal as well as civil engineering in recent years. In this paper, take a three-layer model as an example, we will carry out a forward simulation and analysis the different SCAMT responses when IP effect is considered when we do CSAMT data inversion.

The rock's IP effect is a complex process involved electro-chemical contents, which is affected by some factors and is not easily described by a simple model. By considering the theory of IP effect, it is possible to express this process approximately in some kind of simplified model. A Lot of models are proposed through many cases for the description of IP effects, such as Cole-Cole model, Dias model (Pelton, 1977) and Complex Cole-Cole model. The Cole-Cole model, which is the most widely adopted and used, was originally developed by Cole and Cole (1941) and we'll choose this model in this paper.

In field survey, the CSAMT method always measure two EM components—electric field **E** and the corresponding magnetic field **H**. According to Maxwell Equations, we can decompose **E** and **H** into three components separately or two different polarization modes TE and TM. Through the ratio of horizontal electric field E_x and its coupling horizontal magnetic field H_y, or E_y and H_x, which is called impendence tensor, the Cagniard apparent resistivity can be calculated. The electric field and the magnetic field are expressed as follows:

$$E_x = \frac{I \cdot AB \cdot \rho_1}{2\pi r^3}\left(3\cos^2\theta - 2\right) \tag{1}$$

$$E_y = \frac{3 \cdot I \cdot AB \cdot \rho_1}{4\pi r^3}\sin 2\theta \tag{2}$$

$$E_z = (i-1)\,\frac{I \cdot AB \cdot \rho_1}{2\pi r^2}\sqrt{\frac{\mu_0\omega}{2\rho_1}}\cos\theta \tag{3}$$

$$H_x = -(1+i)\frac{3 \cdot I \cdot AB}{4\pi r^3}\sqrt{\frac{2\rho_1}{\mu_0\omega}}\cos\theta\sin\theta \tag{4}$$

$$H_y = (1+i)\frac{I \cdot AB}{4\pi r^3}\sqrt{\frac{2\rho_1}{\mu_0\omega}}\left(3\cos^2\theta - 2\right) \tag{5}$$

$$H_z = i\frac{3I \cdot AB \cdot \rho_1}{2\pi\mu_0\omega r^4}\sin\theta \tag{6}$$

Where θ is the angle of dipole source AB and random spot M, and r is the distance between the mid-point of AB and M. μ_0 is the magnetic permeability. Once the electric fields E in formula (1) and magnetic fields H in formula (5) are calculated, the TM mode of the Cagniard apparent resistivity can be estimated by,

$$\rho_s = \frac{1}{\mu_0\omega}\left|\frac{E_x}{H_y}\right|^2 \tag{7}$$

Or, by substituting the permeability in free space, as,

$$\rho_s \approx \frac{1}{5f}\frac{|E_x|^2}{|H_y|^2} \tag{8}$$

We calculated the forward responses of CSAMT with the horizontal electric dipole source which is most commonly used in the field survey. The data is received at the equator direction with the source-receiver offset of 7000m. We choose five different type of Cagniard apparent resistivities in formula (8) which include O, A, Q , K and H type for forward modeling of three-layer earth model. The layer resistivities were replaced by complex resistivity with the value of time constant τ 1 and frequency dependence c 0.5. We studied the CSAMT responses when the middle layer has or has not induced polarization effect, respectively. Furthermore, if the middle layer had IP effect, we calculated two situations with changing the value of chargeability $m$as 0.2 and 0.4 respectively and qualitatively analysis the relationship between m and apparent resistivity.

We can see that all the curves are overlapped in the same shape at high-frequency band which illustrates that the IP effect is highly suppressed. However, when the frequency is getting lower, IP effect turns to be gradually obvious that curves will separate from each other. On the other hand, different type of electric property has different sensitivity of IP effect. From pictures below, H type is the most sensitive to IP effect and then are A, Q and O types. The K-type curve is the most insensitive one to IP effect.

From our results, we can see that the bigger the value of m, the much influence of IP effect to CSAMT data. We can know that IP effect will deviate the inversion result from medium to low frequency band if the IP effect is not accounted for.

ACKNOWLEDGEMENT

This work is sponsored by Chinese National Science Foundation (40774073, 40774074) and Chinese National Programs for Fundamental Research and Development (2007CB209607).

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