Optimization of galvanic TEM-system geometry to decrease induced polarization effect on transient electromagnetic data

Alexander N Shein, Eugene Yu Antonov
Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia

SUMMARY

Behavior of a transient electromagnetic field for the galvanic measuring system (transmitter and receiver are arranged in a horizontal electric line) is considered in the work. The choice of such a measuring system was preceded by modeling of areal measurements of all components of both electrical and magnetic fields generated in a horizontally-layered polarizable medium. Based on investigations performed earlier, the method for configuration of galvanic TEM-system is proposed for discrimination of polarization and induction components of TEM characteristic of a layered polarizable medium. It has been found by means of mathematical modeling that there exist such positions of the receiving line for which the IP effect is essentially reduced. The results of mathematical modeling have been supported by field experiments.

Keywords: induced polarization (IP), transient electromagnetic method (TEM), mathematical modeling

INTRODUCTION

When a medium is sounded by galvanic tools, an effect of induced polarization (IP) is often revealed in the signal being recorded. The IP phenomenon constitutes complex processes of electrophysical and electrochemical nature that arise when electric current flows through a medium. In solving electrodynamic problems, account for the IP effect is implemented by introduction of the frequency-dependent resistivity, for which purpose the Cole-Cole formula is often used [Pelton et al., 1978]:

$$\rho(\omega)=\rho_0\left[1-m\left(1-\frac{1}{1+(i\omega\tau)^c}\right)\right].$$

Here ρ_0 is dc resistivity, ω is the angular frequency, m is the stationary polarizability, τ is the time constant, and c is the frequency-dependent parameter. Introduction of complex resistivity leads to increase in the number of parameters defining solution of a forward problem (from two (ρ, h) to five (ρ, h, m, τ, c)). This causes extension of the equivalence area of solutions obtained. Possibility for "independent" search of a nonpolarizable model (ρ, h) and subsequent determination of IP parameters (m, τ, c) can essentially enhance the interpretation quality. Thus, discrimination of transient processes and IP effect allows the inverse problem to be reduced to two problems with the lesser number of sought parameters. The present work presents a way for solving the stated problem with the help of the special position of sounding tool elements.

BEHAVIOR OF RESPONSE DEPENDING ON AZIMUTH ANGLE φ

Coming immediately to the investigation, it should be noted that a transient electrical field in a homogenous nonpolarizable isotropic half-space is independent of angles φ and ψ (Fig. 1). This is not the case in a polarizable half-space. Field components in the frequency domain $E_{\parallel}(\omega)$ and $E_{\perp}(\omega)$ are described by the following expressions [Veshev A.V., 1980]:

$$E_{\parallel}(\omega)=\frac{I_x dl}{2\pi r^3}\rho(\omega)\left[\left(3\cos^2\varphi-2\right)+\left(1+kr\right)e^{-kr}\right]$$

$$E_{\perp}(\omega)=\frac{3I_x dl}{2\pi r^3}\rho(\omega)\cos\varphi\sin\varphi ,$$

where $k^2=-i\omega\mu_0/\rho(\omega)=-i\omega\mu_0\sigma(\omega)$. In order to investigate effect of angles φ and ψ on sensitivity of the galvanic system to IP, the low-frequency expansion was considered for the imaginary part of the expression $E(\omega)=E_{\parallel}(\omega)\cos\psi+E_{\perp}(\omega)\sin\psi$ from which was derived the following equation:

$$\left(3\cos^2\varphi-1\right)\cos\psi+3\sin\varphi\cos\varphi\sin\psi=0 .$$

Having found its particular solution, one can determine a combination of angles of the galvanic sounding system whereby the IP effect is minimal. In particular, for the parallel array (for $\psi=0$), $\varphi=\arccos\frac{1}{\sqrt{3}}\approx 54.736°$. For the azimuth angle $\varphi=45°$ often used in a practice, we get $\psi=-arctg\frac{1}{3}=-18,435°$.

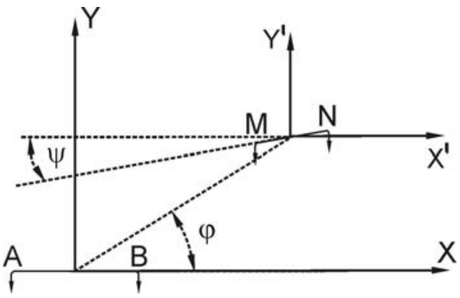

Fig. 1 Scheme of galvanic measuring system

Calculations of fields in various models of polarizable horizontally-layered media show that signals measured with the parallel system $AB-MN,\ \psi=0$ possess the characteristic feature. On isolines for late transient periods, two areas corresponding to positive and negative values of signals are always present (Fig. 2).

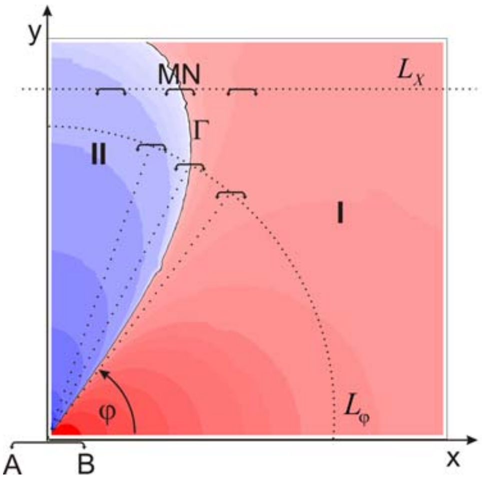

Fig. 2. Isolines of galvanic system (transmitter and receiver are horizontal electric line 100 m and 50m; the spacing is 50 m) for the given time delay: areas of monotonic (I) and sign-reversal (II) signal behavior (Γ is boundary between areas) for the model of a polarizable half-space $\rho=100.\ Ohm\cdot m,\ m=0.05,\ \ \tau=0.1\ s,\ c=0.5$.

It is also ascertained that the important feature such that the boundary Γ between positive and negative values of a signal passes through points of a space (Fig. 3) where the IP effect is weakened. Signals above and below the Γ boundary differ qualitatively. This circumstance can be used for data acquisition by which the structure of conducting nonpolarizable section is recovered with the high accuracy. Search of boundaries Γ can be implemented effectively by two ways. By the first way, the spacing is given and the azimuth angle that specifies the direction from the axis of a transmitter line to the center of a receiver line is varied (Fig. 2). The center of the receiver line is moved in an arc L_φ.

By the second way, the receiver line is moved in parallel with the transmitter one for the given ordinate value, the line L_X (Fig. 2). Searching the Γ line depends on a particular case of field measurements, but naturally, it can be implemented much more simply moving the receiver line along a profile.

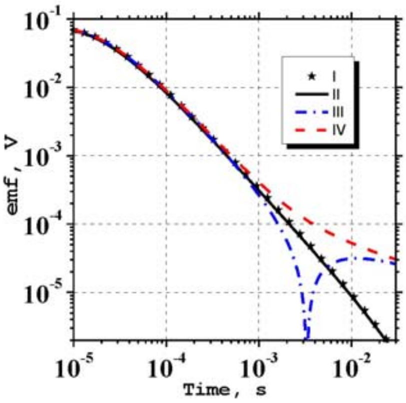

Рис. 3. Soundings at the point on boundary: I - IP, II – without IP, soundings for azimuthal deviations with respect to position on the boundary Γ: III- ($+0.5°$), IV - ($-0.5°$).

The modeling results have been supported by field measurements. The first experiment was carried out in the clay open pit (10 km from the outlying districts of Novosibirsk). The array consisted of transmitter (horizontal electric line 100 m long) and receiver (horizontal electric line 50m long), the distance between centers was 80 m. Measurements were performed for the given spacing, and three positions of receivers (20° and 45°), the transmitter and receiver were arranged in parallel. The second field experiment was carried out on the bank of the Ob' water basin 5 km from the settlement Verkh-Irmen' (Novosibirsk region, Ordynsk district) using the system consisting of transmitter (horizontal electric line 100 m long) and receiver (horizontal electric line 50m long) arranged in parallel with transmitter, the distance between centers was 75 m. Measurements were carried out for the given spacing with the polar angles within the range from 25° to 45°. Fig. 4 presents the field curves. The measurements showed that in this place the equipment demonstrated the least sensitivity to IP within the range between 28° and 29°. After the conducting model was chosen, it has been ascertained that the section included two polarizable layers. Thus, it has been found that for the parallel $(\psi = 0)$ galvanic system, there exist certain positions of a receiver line (spacing and azimuth angle φ) that are characterized by a weakened IP effect.

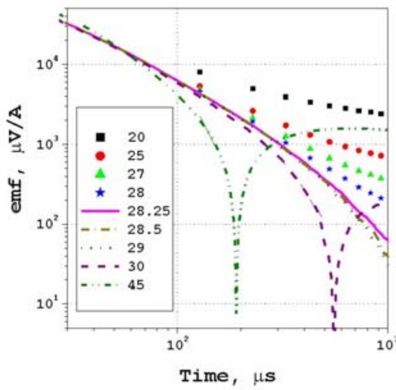

Fig. 4. Field measurements on test area (settlement Verkh-Irmen', Novosibirsk region)

BEHAVIOR OF RESPONSE DEPENDING ON THE ANGLE BETWEEN LINES ψ

Study of an effect of the angle between lines ψ on the measured signal is a logical continuation for search of a special position of galvanic system elements (Fig. 1).

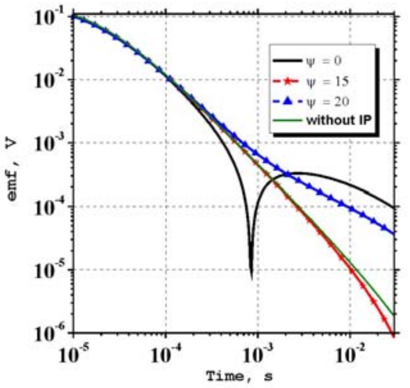

Fig. 5 Change in signal measured as receiver line is rotated

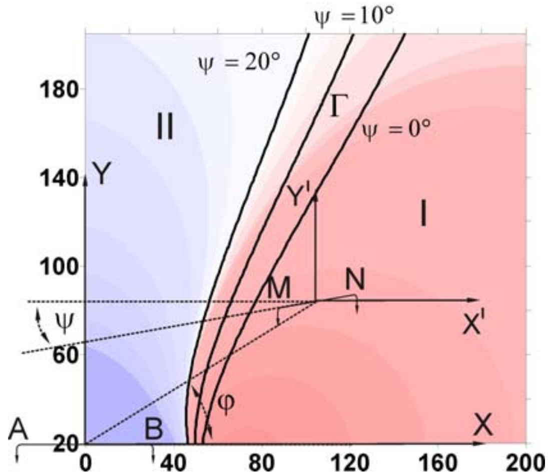

Fig. 6 Isolines of galvanic system and boundary between areas (Γ) for the angle between lines $\psi = 0°, 10°, 20°$. I – sign-reversal and II –areas of monotonic signal behavior for the model of a polarizable half-space: $\rho = 100.\ Ohm \cdot m$, $m = 0.05$, $\tau = 0.1\ s$, $c = 0.5$.

For the modeling, the following dipole system $AB = 100\,m$, $MN = 50\,m$, and $r = 72\,м$, $\varphi = 45°$ has been chosen. When modeling nonparallel systems, an interesting feature was observed above the polarizable half-space: there is angle ψ for which the IP effect weakened (Fig. 5). This can be explained by the fact that when a receiver line is rotated position of curve Γ changes (Fig. 6). Using this property, we can "turn" Γ to the required side. The coincidence of the receiver line center with the point on the curve Γ allows us to obtain a needed signal behavior. This, in turn, provides recovery of parameters of conducting (without IP) section. Thus, we have obtained one more way for searching optimum galvanic system of measurements that gives feasibility for decreasing the number of sought parameters of a section.

When a real measuring system is used, the system sizes affect the values of angles φ and ψ , but availability of such systems is of fundamental importance.

EFFECT OF ERRORS WHEN CONSTRUCTING THE MEASURING SYSTEM

Having proved that there exists such a position of sounding system elements that provides essential reduction of the IP effect, we turn immediately to investigation of effect of errors in constructing sounding systems on a measured signal.

The modeling has shown that in sounding polarizable media, nonobservance of parallelism of lines can lead to significant errors (Fig. 7). In this case, at the same deviations of one or another angle (ψ, φ) from optimum values, the signal changes in different ways: minor change of the azimuth angle φ more strongly affects late times as compared with deviation of the angle between lines ψ . Thus it can be inferred that when constructing the galvanic sounding system, it is essential that the given angles would be set correctly. In spite of such systems are extremely sensitive to the geometry, existence of points with the weakened IP effect is of fundamental importance for us.

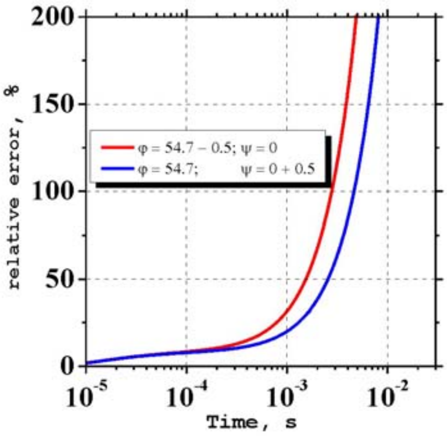

Fig. 7 Change of signal when receiver line is deviated from optimum position by 0.5°

CONCLUSION AND DISCUSSION

Although the position of boundary with the weakened IP effect differs for different models, but existence of points in a space independent on polarization is of fundamental importance.

There exist combinations of angles φ and ψ, which allow the galvanic measuring system to be constructed with a weakened IP effect.

The interpretation quality of data acquired by sounding with the galvanic system can be improved by introduction the correction for angles ψ and φ.

ACKNOWLEDGEMENTS

The programs **FwPr_LL** , **Unv_QQ** and **Inv_QQ** , and **Inv_LL** (by Antonov E.Yu.) for calculation of transient fields in line-line systems and in constructing isolines have been used.

The authors would like to express their gratitude to employee of Scientific-Industrial Enterprise of Geophysiacl Equipmet “Looch” A.E. Plotnikov for the help in performance of the experimental part of this work.

REFERENCE

Pelton W.H., Ward S.H., Hallof P.G., Still W.R., Nelson P.H. Mineral discrimination and removal inductive coupling with multifrequency IP. Geophysics, vol. 43,No3 (April, 1978).

Veshev A.V.Electrical dc and alternating profiling [in Russian]. // Leningrad: Nedra, 1980. – 391p.

Kormiltsev V.V. Transient processes in induced polarization: Theory and application in geophysics [in Russian]. // Moscow: Nauka, 1980.- 112 p.

Svetov B.S., Ageev V.V., and Lebedeva N.A.. Polarizability of rocks and phenomenon of high-resolution electrical survey [in Russian]. Geofizika, 1996, No 4, pp. 42-52.

Tabarovsky L.A. Application of the method of integral equations in problems of geoelectrics [in Russian]. Novosibirsk: Nauka: 1975.- 142 p.

Tabarovsky L.A. Electromagnetic fields of transversely electrical and transversely magnetic types in multi-layer media [in Russian]. // Electromagnetic method of investigations in boreholes. – Novosibirsk: Nauka, 1979, pp. 225-233.