A Matlab program to invert 1D Spectral Induced Polarization data for Cole-Cole model including electromagnetic effects

A. GHORBANI*, C. CAMERLYNCK*, N. FLORSCH
* UMR 7619 Sisyphe, Université Pierre et Marie Curie-Paris6, Paris, France
ghorbani@ccr.jussieu.fr

Introduction
At low frequencies, electromagnetic (EM) coupling between the transmitter, the receiver and the ground and normal polarization effects of the subsurface material have similar functional behaviour with respect to the conductivity of the earth and their combined effects are recorded in an Spectral Induced Polarization (SIP) survey. EM coupling is a major impediment in the interpretation of induced polarization (IP) data. A forward modeling code which calculates the mutual impedance in different frequencies of 1D ground layers for Cole-Cole model and different grounded electrode arrays is developed by Ingeman-Nielsen and Baumgartner (2006). We developed an 1D inversion of IP and EM coupling integral according to forward modeling code. A homotopy method is applied to overcome the local convergence of Gauss-Newton and Quasi Newton methods.

Mutual impedance
According to Sunde (1968), the EM coupling, \( Z \), between two grounded wires in an arbitrary configuration on the surface of the earth can be calculated as an integration of mutual impedances of virtual dipoles along the paths of the wires:

\[
Z(\omega) = \int \int P(r) \cos \theta \frac{\partial^2 Q(r)}{\partial \lambda^2} \, dS \, \, dS
\]

and \( P \) and \( Q \) are often referred to as the grounding function and coupling function, respectively. These are dependent on the generalization reflection coefficients and the electromagnetic properties of each subsurface layer.

Removal of EM coupling
- Measuring SIP data at frequencies low enough that any EM coupling is either negligible or predictable. However, elimination of high frequency IP spectrum, eliminates the important information.
- Fitting a linear or quadratic equation to the measurements at two or three low frequencies. However, IP phase is not always constant, nor linear, and can vary depending on various factors such as earth layer texture.
- Fit the phase spectrum with a multiplication or addition of two Cole-Cole dispersions. However, two figures show that for larger N-spacings, the applicability of the method is reduced accordingly.
- Panin and Ostenberg (2001) suggested the observed response could be approximately described by the infinite frequency-conductivity \((\infty)\)-based EM-coupling multiplied by a complex and frequency-dependent function describing the complex resistivity dispersion (hence the multiplicative approach).

Inversion procedure
A homotopy method is designed to overcome the local convergence of iterative methods.

Homotopy theory
Example 1: Dipole-Dipole: AB=MN=50m, N=1
Freq. range: \([0.183 - 12000]\) Hz

Result of synthetic data
17 frequencies in the \([0.183 - 12000]\) Hz range with a logarithmic step of SIP FUCHS-II equipment (Radic Research).

Example 2:
- dipole-dipole array, AB=MN=50m and \( n=1 \) to 5.
- Transmitter and receiver cables are in same line.

The number of parts in \( x \)-direction is 10.

Different trajectories in the space of \((a, m)\) are converged into simple response.

Inversion program facilities

Data entering
Prior parameters entering

Real values
-8.0 0.3 0.3 0.3 0.3

Standard deviation of parameters
-8.0 0.3 0.3 0.3 0.3

Relative error (%)
-8.0 0.3 0.3 0.3 0.3

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- Dipole-Dipole array, AB=MN=50 m and \( n=1 \) to 5.
- Transmitter and receiver cables are in same line.
- The number of parts in \( x \)-direction is 10.
- Different trajectories in the space of \((a, m)\) are converged into simple response.

Example 2:
- Schlumberger array, the transmitter lines AB change from 0.6 to 60 m.
- Transmitter and receiver cables are in same line.
- The homotopy inversion consist 5 steps.
- The Quasi Newton is considered for misfit minimization.