Intelligent signal and noise separation (SNR) technology for near-surface 3D distributed spectral induced polarization exploration

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Now, spectral induced polarization (SIP) exploration has developed rapidly, based on a 3D distributed instrument system such as Newmont distributed data acquisition system (NEWDAS) [Eaton et al., 2010], Quantec's 3D system [Gharibi et al., 2012], IRIS instrument [Fichtner et al., 2010] and Spread Spectrum IP system [Xi et al., 2013, 2014]. 3D distributed SIP is effective to characterize the complex resistivity structure of the shallow crust. However, observing the SIP response at low frequency band (10^{-3}~10^{-1} Hz) is challenging and difficult in field surveys, because electromagnetic (EM) interferences caused by natural and artificial sources are strong at these frequencies. A complete intelligent signal and noise separation (SNR) technology, including correlation analysis, empirical mode decomposition, robust statistics, and relative phase calculation, was proposed to process the full waveform IP data. Through the analysis and testing, we found that the method can effectively suppress electromagnetic interference in the IP data, especially when the current electrode space is large, and the frequency is low. The method was applied to the practical data collected from a mining area in southern China. The data quality was considerably improved by the proposed method.

Almost all the original full-waveform IP data are threatened by electromagnetic interference caused by artificial and natural sources. Electromagnetic interference mainly includes: low frequency trend item interference caused by telluric current, discontinuous interference by machinery and equipment in mines, outliers caused by spike interference, and electromagnetic coupling interference caused by electromagnetic induction between the power supply line and the earth. To ensure the data quality, we propose a complete anti-interference data processing method including four branches: correlation analysis is used to evaluate and extract high quality data segments; empirical mode decomposition (EMD) is used to separate the low frequency trend item interference and the time domain IP signal; robust statistics are used for multiperiod time series stacking; A relative phase spectrum was calculated to reduce the electromagnetic coupling interference.

(1) In SIP survey, the IP signal was observed for a long time, discontinuous noise may appear at an unknown moment. We found that the correlation between potential difference and transmitting current signals for each period can be used to assess data quality. When the potential signal is seriously disturbed by EM noise, the correlation coefficient is very low, and vice versa. By testing and seting a certain threshold to remove the data segment of low correlation coefficient from the original data series, the calculated complex resistivity is more accurate than before.

(2) In IP survey, the original long-time multi-period original IP signal is superimposed on the low frequency trend item drift, which can seriously distort the calculated complex resistivity. EMD is used to remove it from the original time series. We first identify several maximum and minimum values of different periods, then the upper and lower envelopes of the raw data were obtained by interpolating between the extreme values of all periods. Finally, the trend item drift can be obtained by averaging all envelope lines. After removing trend drift from the raw IP time series, a pure IP signal can also be obtained.

(3) After removing the contaminated data segment and detrending, the pure multi-period IP time series should be stacked to suppress random noise. When the noise is hypothetically of Gauss distribution, a mean stack is appropriate. However, this assumption is usually not satisfied, and there are outliers caused by sferics impulse interference in the original data. Very few outliers can bring great deviations to the

mean estimate, so we use a Robust M estimate to stack the original data. The outlier is suppressed by reducing the weight automatically in stacking.

(4) After stacking, a complex resistivity spectrum can be calculated using potential difference data and current data. EM coupling is a theoretically inherent interference in complex resistivity spectrum, which is caused by EM induction of the earth. An IP survey is a geometric sounding method and the EM induction response is not the useful signal. Removing EM coupling from a complex resistivity spectrum at high frequency is complicated, whereas it is simple at low frequency. The complex resistivity phase spectrum caused by IP effect changes little with frequency, however, phases caused by EM induction change a lot with frequency. The change is approximately linear at 10^{-3}~10^{-1} Hz, so the EM interference can be removed by calculating a relative phase spectrum to replace the conventional phase spectrum, which is a linear correction method. Figure 1 shows the anti-interference data processing flow of one survey point.

Based on the anti-interference processing algorithm, an automatic processing software for the large-scale full-waveform IP data was developed. This algorithm does not require too much manual settings and can automatically identify and remove burst interference, trend term drift, outlier interference and electromagnetic coupling interference. This method is applied to full waveform IP data collected from a mining area in southern China using a spread spectrum IP instrument system. Sample frequency is 64 Hz, period is 256 s. Complex resistivity at 0.0039 Hz, 0.0078 Hz, 0.0156 Hz, 0.0313 Hz, 0.625 Hz can be calculated after signal processing of the time domain IP series. In this survey area, about two hundred survey lines with 100 survey points per line were arranged using scanning and sounding arrangements separately. Survey line distance was 40 m and survey point distance was 20 m. A high-quality 3D complex resistivity spectrum data set was finally obtained after anti-interference data processing. The electrical conductivity and induced polarization structure of the region are revealed.

Acknowledgments

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There is no Fig. 1