Theses of the PhD Dissertation

METHOD DEVELOPEMENT IN THE SERIES EXPANSION-BASED INVERSION SUBJECT WITH LOCALLY 1D FORWARD MODELING

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2015.

I. RESEARCH BACKGROUND AND AIMS OF THE STUDY

In the last two decades the development of the measuring and computing techniques brought significant changes in the geoelectric measurement practice. In several cases the traditional measuring systems have been replaced with the computer-controlled multielectrode method which has great practical advantage over the Vertical Electric Sounding, speed. The investigation of geological structures can be solved with only one setting with this equipment. Parallel with the measuring system development, the software of the data processing and interpretation has been appeared (for example Loke & Barker, 1996). Because of the development of the computers increasingly demanding modeling and inversion method improvements have been made.

In case of the inversion techniques the time of calculation is influenced by the applied method in the forward modeling process. In case of the 2D model the 2D forward modelling and inversion technique would be the ideal method but this solution takes long calculation time that is disadvantageous in the engineering practice. The researchers look for quicker possibilities. Frequently applied technique is the simplification of the forward modeling, for example applying 1D direct problem in the approximate inversion on 2D model. As an upgrade the „Stich together" technique appeared which uses in the new point the previously calculated parameters from the previous model as a start model so it joins the interpretation of the 1D model.

Christiansen & Auken (2004) used lateral force conditionals to connect the 1D model. In 1996, M. Dobróka in his academic doctoral dissertation used local 1D forward modeling and introduced the series expansion-based inversion to determine the parameters of the model. The main idea of series expansion-based inversion is to describe thickness and physical parameters of the layers along the profile with proper functions expanded into series.

In 1997, Gyulai and Ormos gave the thickness and resistivity functions of the 2D model with Fourier-series and power function applied in the discretization. This method applies locally 1D forward modeling on the VES measurement points to estimate the model parameters (thickness, resistivity) of the 2D geological structure.

Kis (1998) in her PhD dissertation dealt with further development of 1.5D inversion to investigate laterally inhomogeneous structures in strikes directions. In her examination she applied Chebyshev polynomials for the discretization and used 1D forward modeling with such modelparameters which have been defined with the integral-mean of the thickness function.

Turai and Dobróka (2001, 2002) worked out a series expansion-based method for solving TAU-transformation of the induced polarization (GP) data measured in the time domain. In 2013, Dobróka et al. used series expansion inversion procedure for the processing of magnetotelluric data.

The interval inversion method for the interpretation of well-logging data was developed (Dobróka 1995, Szabó 2004) on similar principles.

Based on these backgrounds, my research aims to increase the accuracy and stability of the series expansion-based geoelectric inversion procedures with 1D forward modeling in case of 2D structure with lateral changes, as well as helps the data processing of the multielectrode systems (including dip-direction).

II. PERFORMED INVESTIGATION

In dip-direction setting, the synthetic data for the numerical examinations have been calculated with the enhanced FD program of Spitzer (1995) by Gyulai. I used symmetrical and asymmetrical models to test the developed methods in which the resistivity values were considered and dealt with the definition of the thickness functions laterally homogeneous.

To solve the direct problem under the 1.5D approach the estimated model thickness data have been calculated at the reference point and with these values I determined the apparent resistivity of the homogeneous (1D) model with horizontally stratified layers in various distances of the setting.

In the 1.5D inversion process, I examined the applicability of a new orthogonal and orthonormal basis function involving the inversion in order to increase the accuracy and stability of the parameter estimates in addition to discretization with Fourier series and power functions which were used in previous researches.

The results of Legendre- and Chebyshev-polynomials were compared to the results of the discretization with the Fourier series and the power function in order to trigger the power function from the base functions and provide a more stable result.

I improved the Generalized Series Expansion method (Kis 1998) in dip-direction setting in order to make the technique feasible in multielectrode measurements. The method uses the integral mean of the thickness function below the measurement lines instead of the local thickness values.

I derived on the basis of the law of error propagation the covariance and correlation matrices in case of the Integral Mean method. Furthermore I investigated the integration interval in case of the layer borders in different depths. I introduced the Fourier-series and Legendre-polynomials as basis functions in the inversion process besides the Chebyshev polynomials.

The results of the Integral Mean method was compared with the results of the 1.5D inversion technique.

The Integral Mean method takes into account the lateral sensitivity of geoelectric measurements, which provides a more accurate approximations than 1.5D method. It seemed to be reasonable that the lateral sensitivity of the geoelectric measurement in the integral mean calculation decreases when we are moving away from the center.

Török and Kis (2001) carried out initial investigations in strike-direction, but the detailed analysis of the problem had not been achieved.

I carried out my research on data that were measured in dip-direction and I worked out the Weighted Integral Mean method and determined the covariance and correlation matrices. During the development Fourier series and Legendre- and Chebyshev polynomials were used as discretization method.

The applicability of the Weighted Integral Mean and the Integral Mean methods was investigated on 2D structure and I compared the methodes based on there accuracy.

I proved the practical applicability of the Weighted Integral Mean method on field example, comparing the result to ones obtained by the 2D analytical method (Gyulai 2004).

NEW SCIENTIFIC RESULTS

Thesis 1.

As the modification of the 1.5D inversion method I proposed the replacement of the power function with Legendre- and Chebyshev-polynomials.

On data systems of symmetrical and asymmetrical models I pointed out that the application of the orthogonal or the orthogonal weight function polynomials in the discretization is equivalent to using the initial discretization based on Fourier-series in the 1.5D inversion method. My results showed that in the discretization of the Legendre- and Chebyshev polynomials in the 1.5D inversion can be efficiently used in case of the data measured in dip-direction.

Thesis 2.

As the further development of the Generalized Series Expansion inversion method was proposed the series expansion-based inversion with implementation of the discretization with Fourier series and Legendre polynomials. On Symmetrical and asymmetrical models, on a profile calculated with FD procedure in dip-direction array I pointed out that the Integral Mean method gives in a small compass better solution than 1.5D inversion method. During the investigation of the integration interval I established that the required integration interval is different in the different depths of layer boundaries. The optimum values of the integration intervals were determined. The discretization with Fourier series, Legendre- and Chebyshev polynomials implemented in my numerical investigations showed that the three orthogonal function systems provide very close results to each other.

Thesis 3.

As the development of the Weighted Integral Mean method the exp (- (x / D) $^{2)}$ function was introduced as a weightfunction and for the discretization of the laterally variable thickness functions, Fourier-series, Legendre- and-Chebyshev polynomials were used. During my numerical investigations the optimal parameter of the weightfunction was established in case of the layer boundaries at different depths. Using synthetic data system calculated on the symmetrical and asymmetrical models with FD method the optimum value of the parameter D was calculated in different layer boundaries.

I demonstrated that the Weighted Integral Mean method results better parameter estimation than the 1.5D inversion and the Integral Mean inversion methods in case of the measured profiles in the dip-direction, in each cases of the Fourier-series, the Legendre- or Chebyshev polynomials discretization.

Thesis 4.

The qualification of the inversion results was determined based on the law of error propagation. From the local 1D forward modeling the covariance matrix of thicknesses has been given and the correlation matrix and the variances derived from it.

A.) In case of the Integral Mean method

$$\left\{\underline{\underline{COV(\hat{h}(x))}}\right\}_{i,j} = \sum_{n=1}^{Q_i} \sum_{m=1}^{Q_j} \frac{1}{2\Delta} \int_{x_j-\Delta}^{x_j+\Delta} \Phi_n(x')dx' \left\{\underline{\underline{COV(\vec{B})}}\right\}_{l,h} \frac{1}{2\Delta} \int_{x_j-\Delta}^{x_j+\Delta} \Phi_n(x')dx'$$

B.) In case of the Weighted Integral Mean method

$$\left\{\underline{\underline{COV(\hat{h}(x))}}\right\}_{i,j} = \sum_{n=1}^{Q_i} \sum_{m=1}^{Q_j} \frac{1}{\int_{-\Delta}^{+\Delta} W(u)du} \int_{x_j-\Delta}^{x_j+\Delta} \Phi_n(x')dx' \left\{\underline{\underline{COV(\vec{B})}}\right\}_{l,h} \frac{1}{\int_{-\Delta}^{+\Delta} W(u)du} \int_{x_j-\Delta}^{x_j+\Delta} \Phi_n(x')dx'$$

Thesis 5.

The newly developed Weighted Integral Mean method was applied in field example. The result of this inversion was compared with the results of the analytical 2D simultaneous inversion. The comparison shows that the result of the new method is in good agreement with the result of the inversion that is based on a 2D forward modeling so the new method is suitable for the interpretation of the field measurements.

UTILIZATION OPPORTUNITIES OF THE RESULTS

In the geoelectric practice, in the processing of data collected by the use of multielectrode measurement systems it is an important factor to reduce the computation time. This effort makes it acceptable for the application of various simplifications and approximate solutions. The applied methods in this study carried out simplification in the forward modeling process with locally 1D direct problem solving. My investigations have shown that the application of the Integral Mean or the Weight Integral Mean methods reduced the time of calculation (compared to 2D methods) with acceptable accuracy. Thus, the developed methods in this dissertation can play an important role in the processing of the field data.

Another application opportunity can be seen in the method development of the inversion. The main direction of development of the inversion is the inversion on 2D / 3D structures. The discussed locally 1D forward modeling and the methods of series expansion discretization provide sophisticated start model for the so-called combined 2D / 3D inversion techniques which give acceptable results via less iteration (with less computing time).

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