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Research Paper

Time Domain Electromagnetic Data Modeling based on Zohdy's Technique

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Abstract: The initial model, Jacobian matrix, Frechet derivatives, and digital look-up tables are essential components in most time-domain electromagnetic (TEM) data modeling methods in layered earth. Computations of these components in the modeling process are time-consuming as their determinations need to use iterative operations. Zohdy introduced an alternative method for the rapid inversion of direct current (DC) resistivity data obtained using the Wenner and Schlumberger electrode configurations. The methodology allows for the inclusion of a flexible number of layers, which are chosen in conjunction with the initial model based on the data-derived knowledge, and avoids large and iterative calculations of Jacobian matrix and Frechet derivatives. This paper presents an endeavor to enhance the outcomes of TEM data modeling or inversion utilizing the Zohdy's technique through the elimination of the look-up tables. In this study, various synthetic models of stratified geological formations are examined using the the above-mentioned methodology. The modeling findings demonstrate robustness even when 5% and 10% noise levels are entered into the dataset. Hence, this approach can be considered as a worthy method for TEM data inversion accompanying some levels of noise in the data.

Keywords: Electromagnetic (EM), Time-domain electromagnetic (TEM) modeling, Zohdy's technique.

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INTRODUCTION

Most inversion strategies for layered-earth modeling require a guess for the initial model, Frechet derivatives, Jacobian matrix, and digital look-up tables that cause an increase in the time of calculations and inversion. Zohdy's technique is used for automatic inversion of the Schlumberger sounding curves based on the interpreted depths and resistivities of the layers in which the number of layers in the interpreted model is equal to the measured points on the sounding curve.

Since Zohdy's technique, which can also be used for modeling electromagnetic (EM) data, uses the acquired EM data to determine the initial model, no prior knowledge of the conductivity-depth of the survey area is required. The lookup tables are used to generate the initial model from the acquired data [1], and if these look-up tables are not available, deriving an initial model to start the inversion process based on the Zohdy's technique will be difficult. In this paper, the Zohdy's method, which has been applied only for the modeling of conductivity data, is extended for inversion of time-domain electromagnetic (TEM) data. Using this method, in addition to the elimination of the look-up tables, the accuracy of the results of TEM data modeling for several synthetic models is evaluated.

METHODS

The majority of time-domain electromagnetic (TEM) data modeling techniques in layered earth require the starting model, Jacobian matrix, Frechet derivatives, and digital look-up tables. Because iterative processes are required to determine these components, the modeling method involves time-consuming computations. This method eliminates complex and routine calculations of Jacobian matrix and Frechet derivatives. Zohdy's approach is carried out in two steps: (1) transforming the EM response into an apparent-conductivity-depth curve, and (2) adjusting layer thicknesses and conductivities. Figure 1 shows the inversion of synthetic data modeling using Zohdy's method by eliminating the look-up tables.

Figure (1A): The synthetic model of a layered earth

Figure (1B): TEM response of transient vertical magnetic field (vertical magnetic field or derivate vertical magnetic field) versus time

Figure (1C): Apparent conductivity-time transformation of (1B) derived from Fast Transform Inversion like methods by equations 1-3 [2,3]. (transforming the EM response into an apparent conductivity-time curve whitout any look-up tables)

$$\sigma_i^{app} = \left(\frac{2t_i}{\mu_0}\right)\left(\frac{\delta_i}{F(\frac{\hat{\delta}_i}{R})}\right)^2 \tag{1}$$

or

$$\rho_a^L(\mu_0 \frac{\partial h_Z(t)}{\partial t}) = \frac{u_0}{\pi t}\left[\frac{Z_1(r)\pi I_0}{60t\frac{\partial h_Z(t)}{\partial t}}\right]^{2/3} \tag{2}$$

and

$$h_i = \sqrt{\frac{2t_i}{\mu_0 \sigma_i^{app}}} - \sqrt{\frac{2t_{i-1}}{\mu_0 \sigma_{i-1}^{app}}} \tag{3}$$

Figure (1D): Determination of apparent conductivity-apparent depth profile (Step 1)

Figure (1E): Adjustment of layer thicknesses (At first, layer conductivities held, all thicknesses are decreased simultaneously by a set fraction, e.g., of 5%. The new layer thicknesses are assessed by computing the EM response of the *n*-layered earth model and by calculating the RMS error of the model misfit.

$$RMS = \sqrt{\sum_{i=1}^{n}\left(\frac{Y_i^d - Y_i^c}{2n}\right)^2} \times 100 \tag{4}$$

Where:

Y_i^d and Y_i^c : are the observed and calculated EM responses, respectively,
n: is sampling interval.

The layered-earth responses Y_i^c are computed following the derivations of Ward and Hohmann [4]. This step is repeated until the RMS error reaches a minimum). Figure 2A shows this step.

Figure (1F): The final conductivity-depth profile after adjustment of layer conductivities (The layer thicknesses are held and the conductivities are adjusted. An iterative scheme is used where layer conductivities are adjusted by the ratios of apparent conductivities determined from the observed and calculated EM data [3,5,6]:

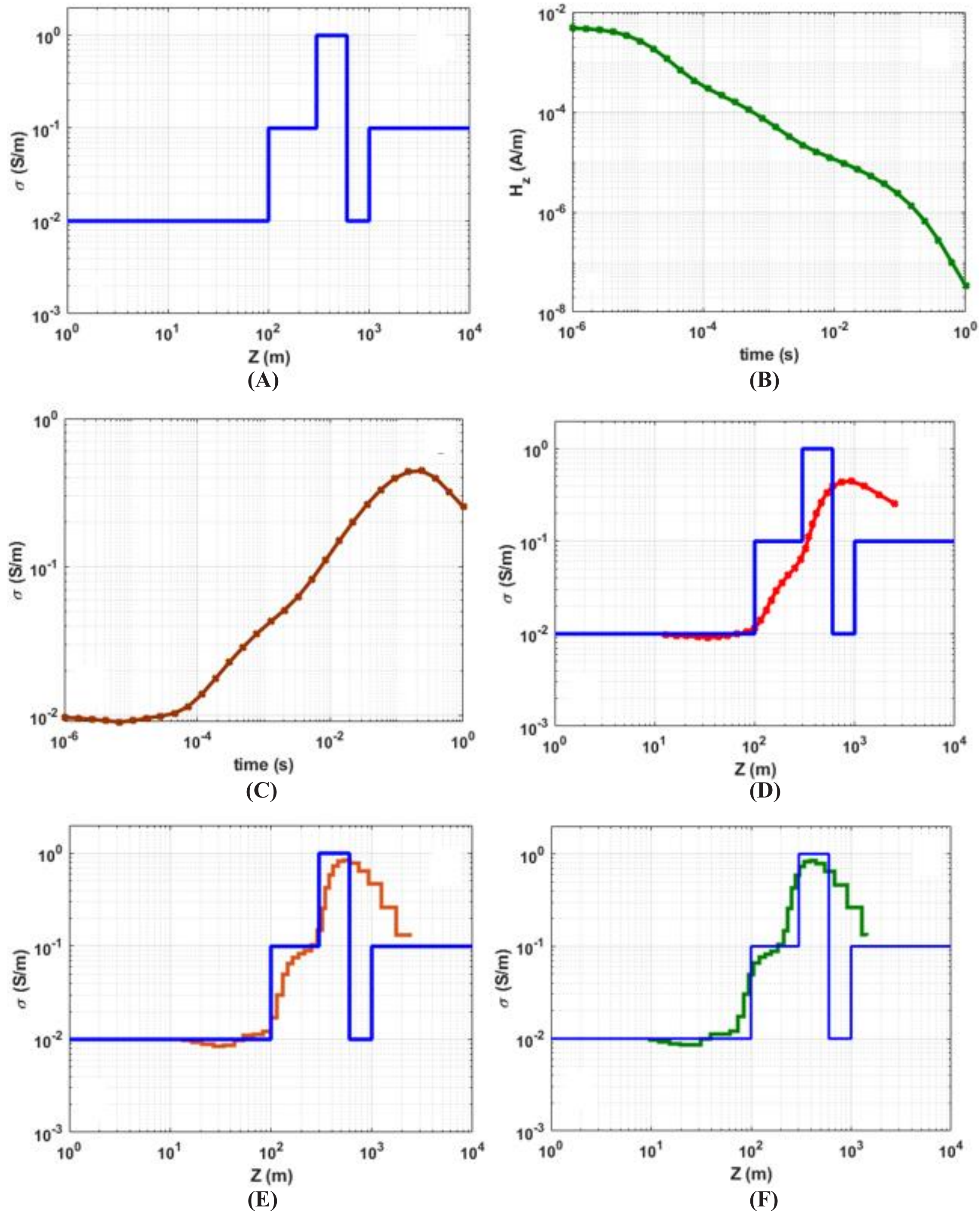
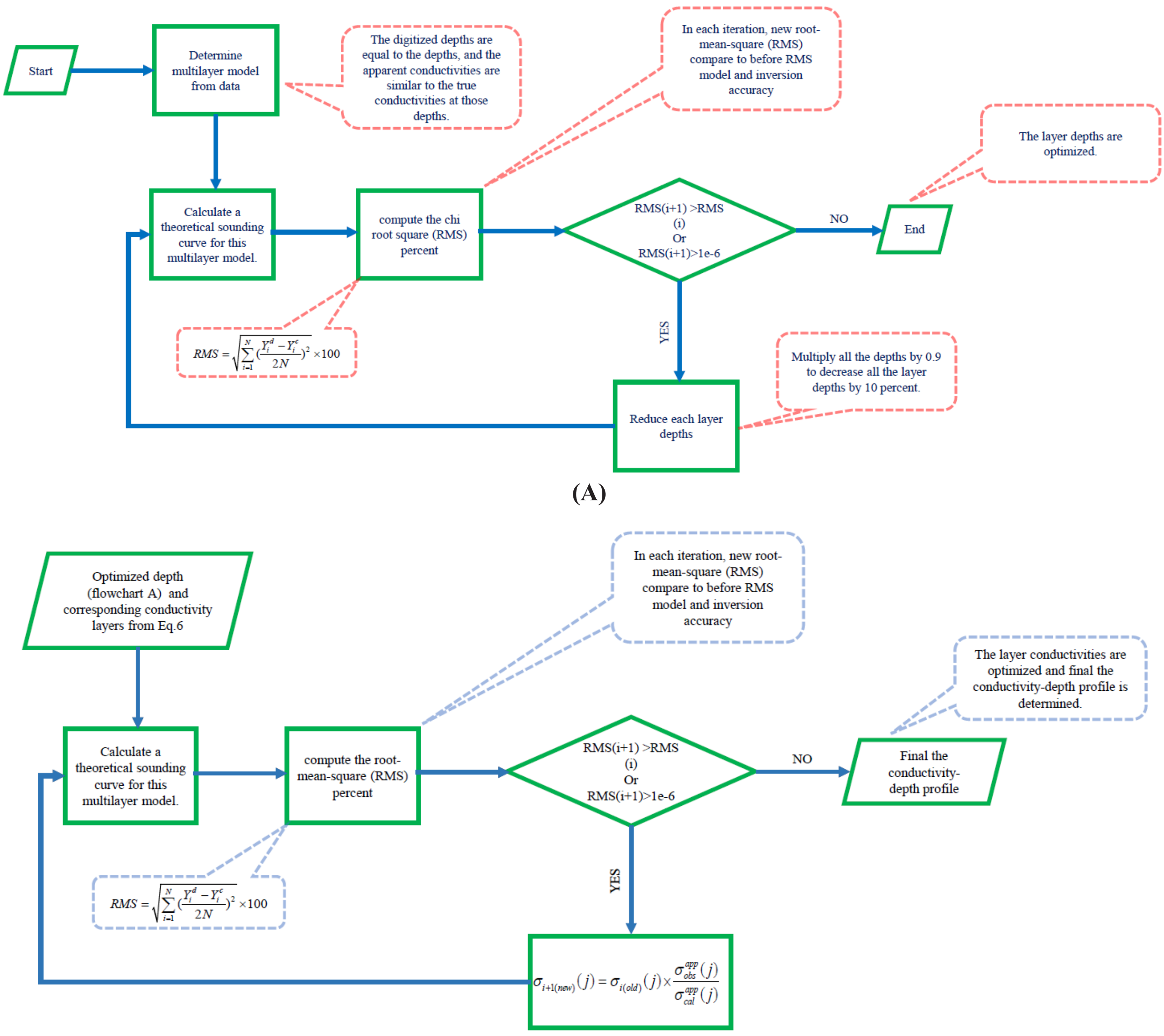


Figure 1. Conductivity-depth models derived by Zohdy's technique

$$\sigma_{i+1(new)}(j) = \sigma_{i(old)}(j) \times \frac{\sigma_{obs}^{app}(j)}{\sigma_{cal}^{app}(j)} \tag{5}$$

All layer conductivities are updated simultaneously, followed by the computation of Y_i^c until the updated RMS error reaches a minimum) [1]. Figure 2B shows this step.



(B)

Figure 2. A: Adjustment of layer thicknesses and **B:** Adjustment of layer conductivities

CONCLUSIONS

In this study, Zohdy's technique is used for the rapid modeling or inversion of TEM data based on an initial model and through the elimination of the look-up tables. The obtained results of modeling for several synthetic models demonstrated that thin layers, especially conductive thin layers, can be detected. Although this technique is based on repition of forward modeling, its results demonstrate robustness, even when the data are likely contaminated by noise. Considering the results obtained from various modeling cases, we can conclude that this technique can be used for modeling noisy TEM data and TEM data from a surveyed area where there is little information about the area.

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