Analysis for Geoelectric Strike Direction of Magnetotelluric Data from a Geothermal Area

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Abstract. Magnetotelluric (MT) method plays an important role in geothermal exploration. For MT data interpretation, 2D modelling is still performed in a routine basis since 3D MT modelling is computationally intensive and needs significant computational resources. In 2D modelling, information on geoelectric strike direction is a requirement. In this study, analysis of geoelectric strike was performed on MT data from a geothermal prospect using phase tensor and tipper strike. The results from phase tensor analysis and verified by tipper strike show that the geoelectric strike of the study area is about N300E that agrees well with the regional structure of the study area. The MT tensor data were rotated to the dominant geoelectric strike and 2D inversion modelling was performed. The subsurface resistivity model reveals the geothermal system of the study area.

1. Introduction
The magnetotelluric (MT) method is a geophysical method that uses natural electromagnetic fields to determine variation of subsurface resistivity. The MT method is effective and useful in geothermal resources exploration due to its ability to image Earth’s subsurface resistivity related to temperature [1,2]. In subsurface resistivity modelling from MT data, 2D modelling is still preferred although 3D modelling has been widely used. This is because 2D modelling is computationally faster and “cheaper” than 3D modelling [3].

In 2D MT modelling, information on the geoelectric strike of the study area is needed. The MT impedance tensor data have to be rotated to its geoelectric strike. There are several approaches to obtain information about the direction of geoelectric strike from MT data. Analysis of phase tensor is one of methods that can be used to obtain the geoelectric strike [4,5]. Since there is ±90° ambiguity that remains in the phase tensor analysis, the ambiguity can be resolved using the tipper strike [6]. In this study, analysis of geoelectric strike using phase tensor and tipper strike was performed on MT data from a geothermal prospect in Sumatra, Indonesia. The 2D modelling inversion using WinGLink software was also done to obtain information on the geothermal system of the study area.

2. Method
The horizontal magnetic (H) and electric (E) field vectors are related to the MT complex transfer function, i.e. tensor impedance (Z) by [6],

\[ E = Z H \]  \hspace{1cm} (1)
The MT phase tensor ($\Phi$) is defined as the ratio between the imaginary part ($\mathbf{Y}$) and the real part ($\mathbf{X}$) of the impedance tensor ($\mathbf{Z}$). Then, the phase tensor can be expressed as [4],

$$\Phi = \mathbf{X}^{-1} \mathbf{Y}$$

Parameterizations similar to the Singular Value Decomposition (SVD) of a square matrix result in the phase tensor decomposed as,

$$\Phi = \mathbf{R}^T (\alpha - \beta) \begin{bmatrix} \Phi_{\text{max}} & 0 \\ 0 & \Phi_{\text{min}} \end{bmatrix} \mathbf{R} (\alpha + \beta)$$

where $\mathbf{R}$ is the coordinate system rotation matrix (clock wise), $\Phi_{\text{min}}$ and $\Phi_{\text{maj}}$ are principal or singular values of $\Phi$, while $\beta$ is the skew angle. When the medium is 1D or 2D, $\beta = 0$ such that $\alpha$ is the orientation of the major axis of the phase ellipse [4]. Both $\beta$ and $\alpha$ are defined by,

$$\alpha = \frac{1}{2} \tan^{-1} \left( \frac{\Phi_{12} + \Phi_{21}}{\Phi_{11} - \Phi_{22}} \right) \quad \beta = \frac{1}{2} \tan^{-1} \left( \frac{\Phi_{12} - \Phi_{21}}{\Phi_{11} + \Phi_{22}} \right)$$

The vertical component of the magnetic field $H_z$ can be expressed by a linear combination of the horizontal components, i.e. $H_x$ and $H_y$ of the magnetic field such that [6],

$$H_z = \begin{bmatrix} T_x & T_y \end{bmatrix} \begin{bmatrix} H_x \\ H_y \end{bmatrix}$$

where $\mathbf{T} = (T_x, T_y)$ is known as the tipper. For a 2D earth, $H_z$ is only related to the E-polarisation. Thus, the orientation that minimize the magnitude of $T$ will align the $x$-axis with the tipper strike direction. Unlike the approach based on analysis of the impedance tensor, the tipper does not suffer from $\pm 90^\circ$ ambiguity. Therefore, tipper strike can discriminate between the principal axis or direction from its right angle complement.

3. Application

The data used in this study are from 180 MT observation points (Figure 1) located on a geothermal prospect in Sumatra, Indonesia. The regional structure of the area is expected to be aligned with that of the Great Sumatra Fault Zone, i.e. NW-SE. The MT stations are more or less regularly distributed on a grid with the distance between stations that varies between 500-2000 m. All MT data were used in the analysis of geoelectric strike such that it is expected to provide accurate information.

Figure 2 shows the rose diagram depicting the results from the phase tensor and tipper strike analysis. Phase tensor analysis for all period range of the MT data ($10^{-6} - 10^{10}$ sec.) indicates a dominant strike around N30°E. Tipper strike analysis shows a direction in different quadrant, i.e. around N330°E with less net orientation than the phase tensor results. Separation into short ($10^{-6} - 10^{2}$ sec.) and long ($10^{12} - 10^{10}$ sec.) period range lead to a better trend delineation, especially at the long period range, for both phase tensor and tipper strike. The geoelectric strike at shorter periods exhibit no distinct direction which is associated with domination of 1D environment at shallow depths. The latter is confirmed by superposed (identical) or parallel (in case of static shift effect) of TE-mode and TM-mode sounding curves at short periods.

We used the tipper strike to correct $\pm 90^\circ$ ambiguity of the phase tensor analysis result. Therefore, the geoelectrical strike is estimated at N300°E or N-60°E which is in a good agreement with the NW-SE regional structure of the area. After MT impedance tensor rotation to the geoelectric strike, 2D inversion was performed along a profile chosen perpendicular to that strike (line 1, see Figure 1). We used the well-known WinGLink software for 2D MT inversion. The modelling result presented in Figure 3 shows...
low resistivity layer at the central part of the profile that can be interpreted as the conductive clay-cap of the geothermal field.

**Figure 1.** The map of study area with grey shaded topography and distribution of 180 MT stations used in the geoelectric strike analysis with the profile for 2D modelling (see text for details).
4. Conclusion
Phase tensor and tipper strike analysis have been performed to obtain the dominant geoelectric strike from MT data of a geothermal prospect area. The results show that the geoelectric strike is around N300°E or N-60°E and confirm the regional structure of the area. The geoelectrical strike was then used to determine the profile orientation and to rotate the MT impedance tensor data for 2D MT modelling. Based on the resistivity model, the conductive zone (<10 Ohm.m) from surface up to around 1000-1500 m depth can be interpreted as clay cap zones, while the moderately resistive zone (10-100 Ohm.m) and resistive zone (>500 Ohm.m) are interpreted as transition zone and reservoir respectively. Further study is still underway to emphasize the necessity of geoelectric strike analysis and the use of correct TE- and TM-mode MT data for 2D MT modelling appropriately.

References
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