Magnetotelluric Data Analysis Using Phase Tensor and Tipper Strike to Determine Geoelectrical Strike in “DKH” Geothermal Field

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Abstract. The magnetotelluric (MT) method is passive geophysical method that measures natural electromagnetic field to estimate the subsurface resistivity structure. Before conducting 2D MT data inversion, data analysis, dimensionality, including determining the direction of the geoelectrical strike must be performed. It is needed to fulfill the assumption of 2D MT modeling. 2D modeling of magnetotelluric data is an important part because the results can determine the quality of the subsurface interpretation. Therefore, this paper describes the determination of the dimensionality and geoelectrical strike using the phase tensor and tipper strike parameters. The invariant parameters of phase tensor including skew angle (β) and ellipticity are used to get the information about the dimensionality and geoelectrical strike. The results from the phase tensor are plotted in a rose diagram to determine the main direction of the geoelectrical strike. The phase tensor analysis contains ambiguity 90°, therefore tipper strike used to validate the analysis. From the analysis, the result shows the 1D or 2D structures of the MT data in high frequency, meanwhile the lower frequency, the majority of the data show 3D structures. The dominant geoelectrical strike is around N15°E and it is confirmed with the regional structure of the area. Determination of dimensionality and geoelectrical strike are applied to MT data from the geothermal field.

1. Introduction
The Magnetotellurics method is applied to investigate the geoelectrical structure information in the geothermal field. This method measures natural electromagnetic to provide an image of subsurface resistivity structure. The relationship between the temperature effect to rock formation and mineralization with the conductivity or resistivity [1] makes this method is powerful in geothermal exploration. To increase understanding of the subsurface condition, before conducting 2D MT data inversion, data analysis, including determining the direction of the geoelectrical strike, must be carried out. It’s valuable to rotate MT database on the geoelectrical strike direction. The geoelectrical strike is
the direction representing the electric current flow in the subsurface [2]. Phase tensor is one of the methods that can be used to determine the geoelectrical strike direction. However, this approach implies the 90° ambiguity in the strike angle. Tipper strike and geological information is used to help resolve the ambiguity in the impedance rotation angle. The geoelectrical analysis in MT data is needed due to limited geological information in the subsurface. The continuation of geological structure into the subsurface can be identified using magnetotellurics data analysis. The geoelectrical strike may be related to the geological strike direction, particularly when there is an elongated conductor [2]. The results of the geoelectrical strike analysis from the MT data followed by the same geological strike direction can be a reference in rotating the MT data (impedance). MT modeling after rotation result a better resolution of the geometry subsurface.

2. Geological Setting
The research area is located in a volcanic environment with regional tectonic results large fault in northeast-southwest direction. This type of fault is a left-lateral strike-slip fault [3]. Besides the reginal geology, there are local structures developed in the research area. The local geological structure map of the “DKH” geothermal field shows the complex structure in the surface. The geological structures developed in the area are dominated by north-south, northwest-southeast, and northeast-southwest trends as shown in (Figure 1).

![Figure 1. Geological structure map of the geothermal field.](image-url)
3. Method

The magnetotelluric method is a geophysical method that measures natural electromagnetic to provide an image of subsurface resistivity structure. In 2D earth structure, resistivity changes in-depth and in one horizontal direction (x or y) (Figure 2). Therefore, the electromagnetic field can be decoupled into two independent modes. Transfer electric (TE), which means Ex parallel to the strike (vertical contact) and transfer magnetic (TM), which means Ey is perpendicular to the strike. To increase understanding of the subsurface condition, before conducting 2D MT data inversion, determining the direction of the geoelectrical strike is needed. Phase tensor and tipper strike from MT data analysis can be used to determine the geoelectrical strike from the field.

![Figure 2. Simple 2-D model with vertical contact [4].](image)

Electric fields (E) and magnetic fields (H) obtained from MT measurements are used together to calculate impedance (Z). As a tensor, Z contain information about dimensionality and geoelectrical strike direction from MT data. The impedance tensor (Z) given by:

\[
E = Z \cdot H
\]  
(1)

The magnetotelluric phase tensor is the ratio of real (X) and imaginary (Y) part of the complex impedance tensor (Z). The phase tensor can be expressed as [5]:

\[
\Phi = X^{-1}Y = \begin{pmatrix}
\Phi_{xx} & \Phi_{xy} \\
\Phi_{yx} & \Phi_{yy}
\end{pmatrix}
\]  
(2)

The invariant parameters of the phase tensor are ellipticity (\( \Phi_{\text{max}} \) dan \( \Phi_{\text{min}} \)) and skew angle (\( \beta \)). Both ellipticity and beta can determine the dimensionality of the regional impedance tensor [5]. In case of 2D structure, \( \Phi_{\text{max}} \) dan \( \Phi_{\text{min}} \) have different value and \( \beta \) become zero, thus \( \alpha \) is the orientation of the major axis of the phase ellips. The direction of the geoelectrical strike can be determined from angle value \( \alpha - \beta \). Both \( \alpha \) and \( \beta \) are defined respectively by:

\[
\alpha = \frac{1}{2} \arctan \frac{\Phi_{xy} + \Phi_{yx}}{\Phi_{xx} - \Phi_{yy}}
\]  
(3)

\[
\beta = \frac{1}{2} \arctan \frac{\Phi_{xy} - \Phi_{yx}}{\Phi_{xx} + \Phi_{yy}}
\]  
(4)

Strike direction from phase tensor contains 90° ambiguity. This ambiguity is resolved by tipper strike analysis and regional geology information of the area. The tipper can be calculated from the vertical magnetic field component (Hz), generated by a linear combination of the horizontal magnetic field (Hx and Hy). It is given by [6]:

\[
H_z = T_x H_x + T_y H_y
\]  
(5)
where $T$ is Tipper. For 2D structure (x-axis in the strike direction), $H_x$ can be minimized given the condition X-axis in the strike direction. It is called the tipper strike. Unlike the phase tensor, this approach does not imply 90° ambiguity.

4. Application
Phase tensor and tipper strike analysis of all 26 sites are used to investigate the geoelectrical strike of the area (Figure 3). The distance between the stations varies between 500 – 1000 m. Figure 3 shows the map of MT sites location. The geological structure of the area is dominated by N-S, NE-SW, and NW-SE trends. We analyze the dimensionality and geoelectrical strike from phase tensor and tipper strike following the formula from [5] and [7] and calculated in Python 2.7.16. Dimensionality data is estimated from the phase tensor given threshold criteria on the skew angle ($\beta$) based on [5]. The result from phase tensor for all periods (Figure 4) shows the complexity of subsurface structure. The phase tensor and tipper strike show the consistency of geoelectrical strike direction. Therefore, the dominant geoelectrical strike is estimated at N15°E. The result shows a good correspond with the NE-SW trend geological structure of the area.

![Figure 3. Location of MT sites, dashed line shows the line used in the phase tensor section analysis.](image-url)
To determine the MT data's dimensionality, we use the skew angle parameter from 26 MT stations divided into two lines (L1 and L2, see Figure 3). Small skew angle value shows that the resistivity structure is 1D or 2D. Meanwhile, the large skew angle value shows the 3D structure (generally, $\beta > 3^\circ$ and $\beta < -3^\circ$). The analysis from L1 (MT027 – MT038) shows that most MT data in high frequency (low period) suggests evident 1D or 2D structure; meanwhile, the low frequency shows the 3D structure (Figure 5). This evidence similar to phase tensor analysis. The circle shape of phase tensor in high frequency (short period) data shows 1D and 2D structures, meanwhile the ellips shape with large skew angle value in low frequency shows the 3D structures.

![Figure 4. The rose diagram from phase tensor and tipper strike analysis for all period data.](image1)

![Figure 5. Dimensionality analysis resulted by phase tensor and skew angle parameter from line 1 (L1).](image2)
Phase tensor analysis from L2 (MT070 – MT083) shows that most MT data in high frequency (low period) suggest evident 1D or 2D structure, except MT070 which shows 3D structure at all frequencies (due to poor data quality), meanwhile the low frequency shows the 3D structure (Figure 6). This evidence similar to phase tensor analysis. The circle shape of phase tensor in high frequency (short period) data shows 1D and 2D structures, meanwhile the ellips shape with large skew angle value in low frequency shows the 3D structures. This 3D structure indicates the complex of the geological structure in greater depths.

Figure 6. Dimensionality analysis resulted by phase tensor and skew angle parameter from line 2 (L2).

5. Conclusion
The phase tensor and tipper strike analysis have been conducted to obtain the dimensionality and geoelectrical strike direction of the area. The result shows the 1D or 2D structures of the MT data in high frequency. Meanwhile, the lower frequency, the majority of the data show 3D structures. The dominant geoelectrical strike is around N15°E and it is confirmed with the geological structure of the area.

Acknowledgments
The research project was supported by PT. Geodipa Energi (Persero). The authors benefit fruitful discussion with Elfitra Desifatma, Anggie Susilawati, and Pesta Sigalingging from Earth Physics Department, ITB. The authors would also like gratitude to geothermal laboratory and modelling and inversion laboratory.
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