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Dimensionality and Geoelectrical Strike of Magnetotelluric Data Using Tensor Impedance in "X-Area" East Nusa Tenggara, Indonesia

Haidar Ismail [1)], Y Yatini[1*)] and Asep Sugianto[2)]

[1]*Geophysics Engineering, Universitas Pembangunan Nasional Veteran Yogyakarta, SWK (104) North Ring Road Street Condong Catur 55283, Yogyakarta.*
[2] *Geological Agency of Ministry Natural Resources, Soekarno Hatta Street No.444, Pasirluyu, Regol, Bandung, West Java*
Email: jeng_tini@upnyk.ac.id*

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ABSTRACT

Geothermal exploration was conducted using the magnetotelluric method in "X-area" East Nusa Tenggara, Indonesia, to obtain the potential area and subsurface structure information. Dimensionality analysis and rotation by tensor impedance were conducted to determine the data character and regional geoelectrical strike direction of the 9-point measurement. Skew and polar diagrams were produced to estimate dimensionality inversion and azimuth rotating MT data as geoelectrical strike research areas. The result shows that the domination of skews greater than 0.3 indicates 1-D and 2-D data character. The data was validated by polar diagram analysis at 10^{-2} Hz to 10^{3} Hz frequency to find 2-D characters and 2D modeling. The geoelectrical strike analysis obtained MT data rotation shows the research area with regional strike N 107° E as an azimuth for rotating nine sites' MT data. The result of modeling by data analysis shows no ambiguity model, lowest RMS grade, and matches with the geological condition of the research area.

Introduction

A geophysical exploration survey could use the Magnetotelluric (MT) method to determine the geothermal potential. MT surveys, in general, are divided into five: acquisition, processing, analyzing, modeling, and interpretation. Data analysis in magnetotelluric is frequently being forgotten, which causes the data produced model ambiguity, and the result contains

ambiguity [1,2]. MT Data dimensionality analysis is a kind of analysis for determining the characteristics of data 1D, 2D, and 3D, which is purposed to fulfill the medium assumption on MT [1]. MT data rotation changes the coordinate system axis at the measuring phase, which is unidirectional, with the strike becoming unidirectional or plumb toward geological strike [3, 4, 5, 6]. MT rotation data is based on the dominant direction, shown by the polar diagram from Z_{xy} impedance, so the electric field and magnetic field could be polarized flush with the strike direction [7]. MT data analysis and rotation minimize model ambiguity caused by wrong data characterization and better interpretation [1, 2].

The research applied MT data analysis by conducting dimensionality analysis and MT data rotation with tensor impedance from MT. Dimensionality analysis with skew parameter and polar diagram as an indicator of data dimensionality [7]. Data rotation analysis finds geoelectrical strike angle as rotation input to produce a model with minimum ambiguity and fulfilling medium assumption on MT method [1, 2].

The research aims to produce MT Model with the best interpretation based on geological and RMS error results from several rotation modes. Dimensional analysis was carried out to determine the character of the MT data in the research area, namely I-D, 2-D, or 3-D. The rotation of the impedance tensor is done before performing the data inversion. Plotting the polar diagram on the structure map resulted in a different geoelectrical strike at all MT data points. This research is an interpreted MT section with the best modes of rotation MT data.

Geological Research Area

Koesoemadinata et al. 1997 mentioned that the "X-area" geological history started in the mid-Miocene. The stratigraphy of the research area consists of rock formation Tertiary up to Quarter epoch started from early Miocene to Holocene which could differ to sedimentary rock, surface sediment, volcano product rock, and breakthrough rock. The tectonic position of this area is included as the back-arc basin.

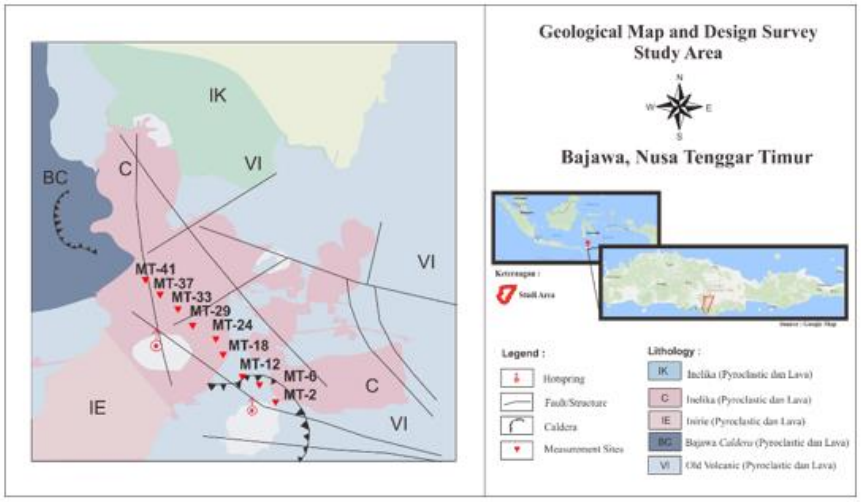

Figure 1. Geological Map and MT Measurement Sites.

The research was located at the "X-area" East Nusa Tenggara, Indonesia. The geological structure pattern of the research areas, in general, is directed to the northwest – the southeast. However, the other strike was directed towards the north – south reflecting the intrusion or

magma chamber as dyke beneath the "X-area" geothermal system [8]. The geological map of the study is shown in **figure 1** with lithology, manifestation, and structure information.

Methods

Theoretical background

The plot of grades on the x' axis changed from 0 to 189, resulting in points descript the closest curves and the polar impedance diagram. For example, diagram $|Z_{xy}|$ is the grade result on equation (2). This research applied data analysis using skew parameter impedance to determine data dimensionality. Skew is one of the dimensionality parameter analyses with simple calculation from impedance tensor, the ratio between on-diagonal components and off-diagonal components.

$$Skew = \left|\frac{Z_{xx}+Z_{yy}}{Z_{xy}-Z_{yx}}\right| \quad (1)$$

The skew grade could determine dimensionality, which states that if the skew grade > 0.3, it couldn't match with 1D and 2D interpretation [9]. Dimensionality analysis could be validated with polar diagram analysis because it has no limitation structure and frequency [2].

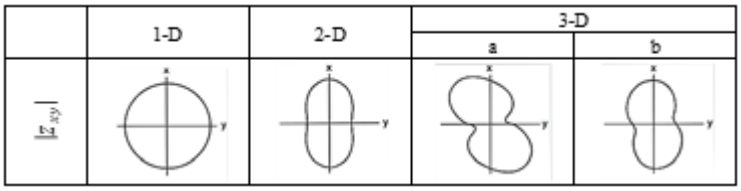

Figure 2. Polar diagram classification from Z_{xy} impedance tensor as MT characterization data indicator.

Figure 2 describes the relationship between the form of diagram polar with the character of MT data. The polar diagram is calculated by the impedance tensor component, which is plotted in the polar coordinate (equation 2).

$$\left|Z_{xy}(\alpha)\right| = |Z_1 + Z_3 \cos 2\alpha - Z_4 \sin 2\alpha| \quad (2)$$

The coordinate axis on MT measuring field is not always accurate with strike direction, which is generally not determined where the direction of the strike is. Rotation is a process of numerically axis change as if the measuring is done using flush or plume with strike coordinates [3]. Mathematically the angle acquired by an impedance that rotated by $\vec{Z}'_{(\omega)}$ [7].

$$\vec{Z}'_{(\omega)} = R_{(\alpha)} Z_{(\omega)} R^T{}_{(\omega)} \quad (3)$$

R is the rotation matrix, and Z is the impedance matrix from impedance tensor data. Information related to data dimensionality and strike direction must be analyzed because it affects models and inversion [1].

Acquisition and Processing Data

MTU-5A did data gathering from Phoenix Geophysics Ltd as the main unit in 2017. Track direction oriented to North West-South East with interval 1 km where the 3 points taken on the "X-area" and 6 points located at another "X-area", East Nusa Tenggara. The whole measuring points also sliced through Wololobo volcano, which got two hot springs manifestation. The track got the purpose of mapping the underground condition, which is the main target. The geological map and MT point distributions are shown in **figure 1.**

The result of the acquisition is raw data consisting of 5 component, which is the electric field and magnetic field. MT data processing started with a Fourier transformation to change time scale into frequency. Next, robust reprocessing was conducted with the rho variance weighting parameter to banish the outlier of MT. Then it continued with the cross power editing process, so MT data got a better resistivity pattern.

MT data analysis in this research was divided into 2 phases: dimensionality and rotation analysis. First, perform a dimensionality analysis based on the classification of Berdichevsky and Dmitriev 2008. Next, use the skew parameter for the polar impedance diagram. Softwares conducted this analysis like Microsoft Excel and MATLAB for calculating and computation. Plot into a roset diagram to see the dominant direction of geoelectrical strike research areas.

Result and Analysis

Dimensionality Data Analysis

The dimensionality analysis was conducted by two parameters, which are skew and polar diagrams. Based on equation (1), the skew was calculated simply by the impedance tensor component. The skew was [3] with range classification based on practitioner agreement if range <0.3 is 1D and 2D and range 0.3> is 3D. **Figure 3** shows the result of the skew calculation.

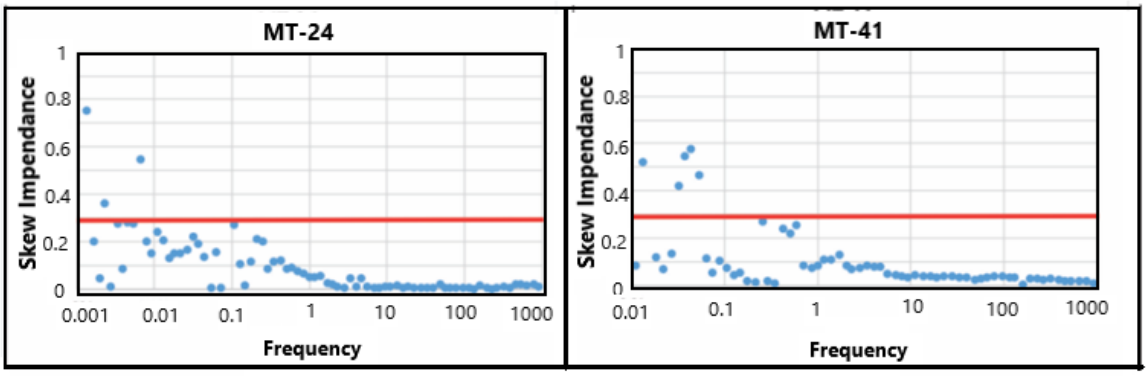

Figure 3. Skew impedance diagram values on MT-24 and MT-41 sites with 0.3 cutoff value as MT data classification.

All point shows the skew range <0.3, which dominates on moderate frequency to low frequency. On high frequency, the skew grades got >0.3 because one shallow medium got a 3D trait, and on low frequency, the skew grades got a 1D or 2D trait. Therefore, skew grades got a 1D or 2D trait. Therefore, skew analysis on MT data research produced two data characterizations, between 1D and 2D data, so validation was conducted by conducting additional analysis using the impedance polar diagram parameter.

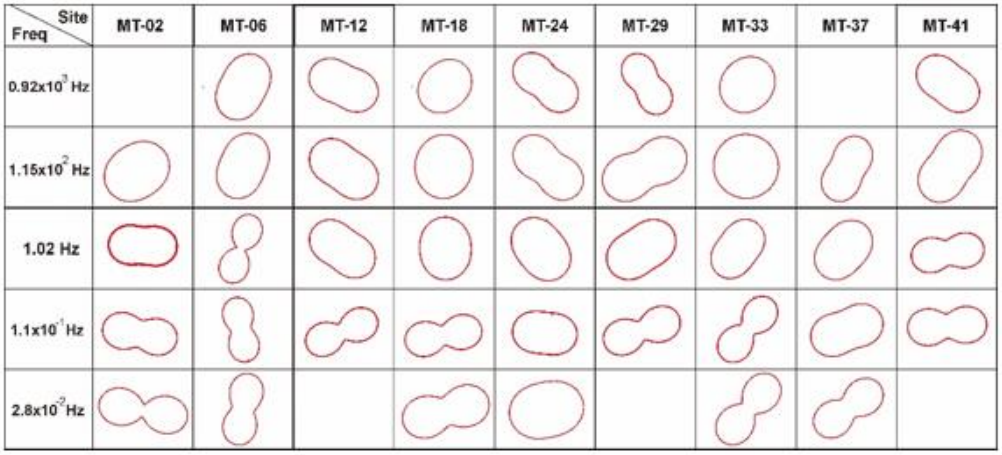

Figure 4. Polar diagram of impedance tensor on all MT sites from 10^3 to 10^{-2} Hz. Data characterization based on the form of a polar diagram with the perfect circle is 1-D data, oval is 2-D data, and *peanuts-like* is 3-D data. In this study, the MT data sets have 2-D characters.

The polar diagram was analyzed by dividing it into some frequencies 10^3 up to 10^{-2} to every point. The result of the polar diagram was dominated by a 2D character polar diagram shaped with oval geometry compared to a 1D character or 3D shown in **figure 4**. The polar diagram on low frequency almost got the pattern of 3D data, which proves the deeper MT penetration, so the geological condition of research areas become more complex than others.

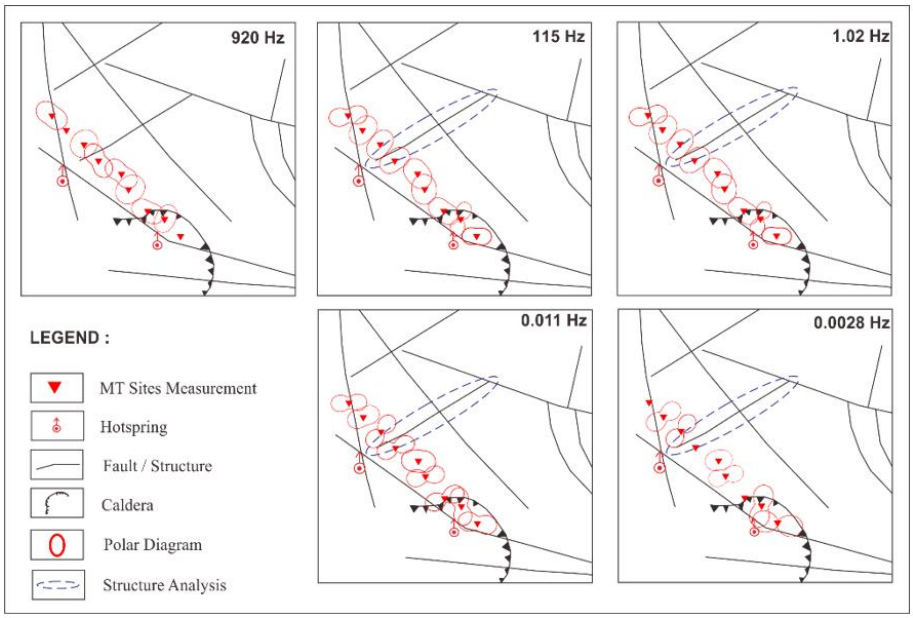

Figure 5. Plotting polar diagram on structure geology map on the surface. In addition to analyzing the polar diagram phenomenon that shows an anomaly in lower frequencies. Delineated lines are the unsuitable responses with a polar diagram.

Figure 5 shows the response of the polar diagram got a pattern toward the geological structure. Impedance polar diagram shows fracture structure if the shapes of polar diagram

perpendicular toward each other. The polar diagram on frequency 320 Hz – 0.0028 Hz shows an unsuitability response with structural geology on the surface, different compared to the 920 Hz polar diagram with perpendicular response

Rotation of Impedance Tensor Analysis

Rotation analysis was conducted to find the geoelectrical strike using the impedance tensor parameter. According to Muraoka et al. 2005, a regional fracture in the direction of NNW-SSE is based on the geology of research areas. The result of MT strike analysis shows that strike direction varies start from 11° up to 121°. MT strike obtained by impedance tensor calculation represents structural condition by regional or local, but application by impedance tensor more represents regional strike [7].

The geoelectrical strike angle from the calculation is put into a roset diagram to examine the dominant direction to every point. The geoelectrical strike result is put into a roset diagram that shows one dominant way on one track. **Figure 6** shows ambiguity and suitability with structure geology pattern and the surrounding [8].

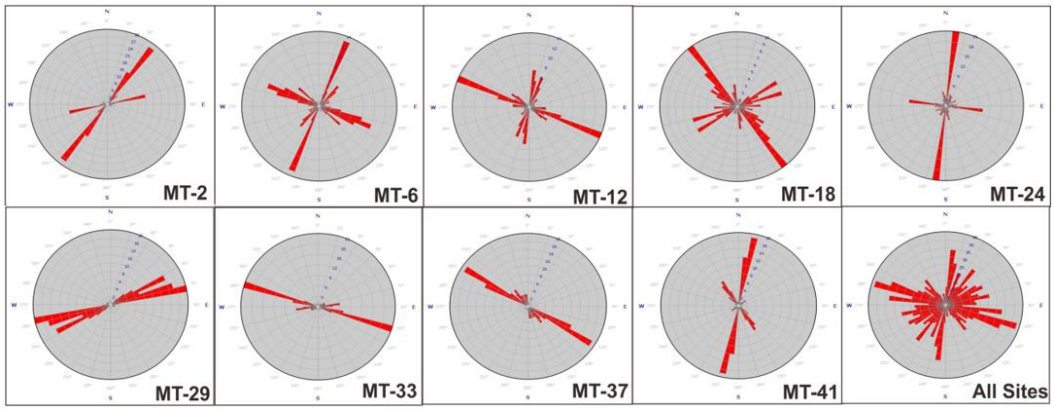

Figure 6. Rosette diagram from *geoelectrical strike* produces a variety of strike azimuth from N11°E to N121°E and one dominant azimuth N107°E relatively Northwest-Southeast (NNW-SSE).

The 2D modeling is done to prove the rotation result based on the different modes. The result of all the 2D inversion models produces different RMS errors. For example, the 2D model section without rotation analysis has a 3.431 % of RMS error. In contrast, the result of the section with rotation analysis has differed from the rotation for every MT point, and it has one dominant strike direction. The result for the rotated one in every point and dominant strike direction is 2.793% and 2.328%, respectively. The result of 2D inversion modeling for one strike rotation mode can be seen in figure 7.

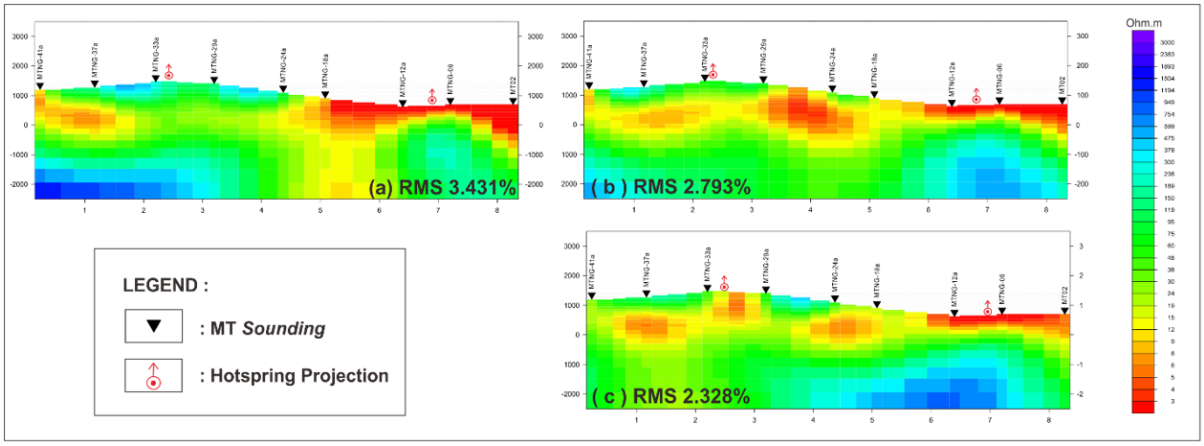

Figure 7. Result of 3 rotating modes (a) default or not rotate modes, (b) rotating every single site mode, and (c) one dominant strike rotating mode.

Based on 2D modeling analysis, the best rotation model refers to the lowest RMS error grade and is suitable for the geological model. Figure 8 is the best 2-D inversion model compared to the complete modeling result. One with RMS error values of 2.328% shows a contrast result that more matches the geological condition.

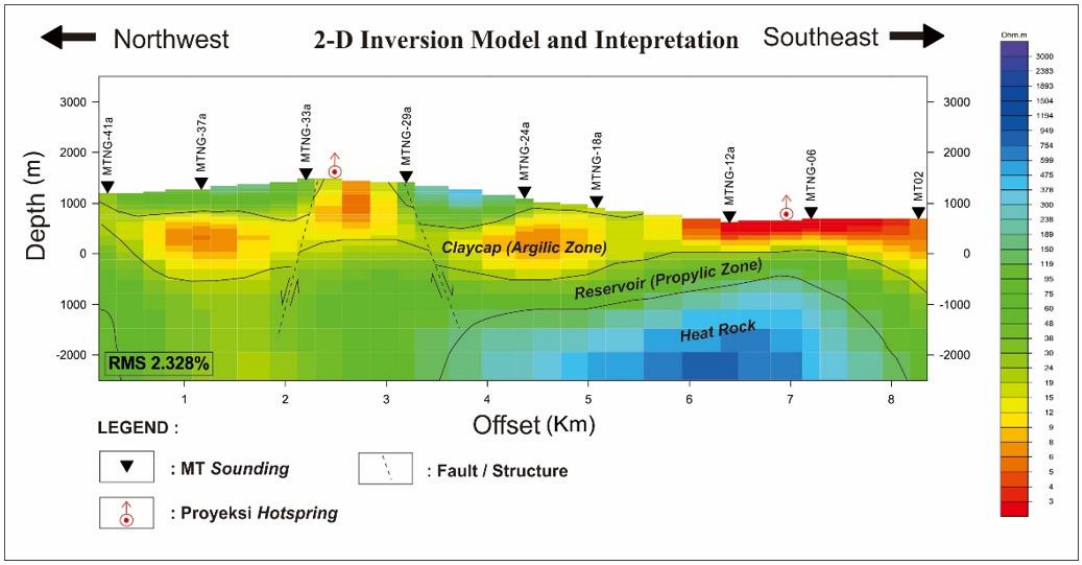

Figure 8. 2-D Inversion Model of One Dominant Rotating Strike Modes.

Based on the analysis of the technique, model ambiguity could be resolved by rotating the MT data by one dominant strike mode. Furthermore, the 2D inversion result proves that the model produced through analyzing process could give information about dimensionality and rotation direction of research areas.

The interpretation result of the 2D section has identified the existence of geothermal systems like heat rock, reservoir, clay cap, structure (dis/recharge area), and hot fluids. Structure delineation and system component of geothermal based on resistivity contrast and literature study [10]. Low resistivity <15 ohms.m is the clay cap identified as the old volcanic sedimentary rock that angelically alternated. Moderate resistivity ranges 15-150 ohm.m is the reservoir identified as carbonate sandstone that prophylactically alternated. High resistivity >150 ohm is a heat source identified as a crystalline rock. A geoelectrical strike used as rotation input before conducting inversion modeling could fulfill the assumption of the medium on MT data by detouring the coordinate along the structure direction to show a better result.

Conclusions

Dimensionality analysis using the skew parameter produces a dominant MT dataset value <0.3, which indicates the character of 1-D or 2-D MT data. Polar diagram analysis shows that the data have an overall form of oval shapes, which validates the MT dataset with a 2-D character. The geoelectrical analysis concludes that the one dominant rotating modes with N107°E matches with geological background NNE-SSW. Therefore, the dominant rotating modes are the best MT modeling and fulfilling the 2-D MT assumption, resulting in 2.328% *RMS error* and unambiguity interpretation.

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