Determining the best 2D model based on tensor impedance rotation on magnetotelluric data

Dimas B Maulana¹, G M Lucki Junursyah², Eleonora Agustine¹ and Asep Harja¹,*

¹Geophysics Departement, Padjadjaran University, Jl. Raya Bandung-Sumedang Km 21, Jatinangor, Sumedang 45363, Indonesia
²Pusat Survei Geologi (PSG), Ministry of Energy and Mineral Resources, Jl. Diponegoro No.57, Bandung, Jawa Barat 40115, Indonesia
asep.harja@geophys.unpad.ac.id

Abstract. Magnetoteluric data can be formed in 2D model, however the data that was used to produce the best 2D model should contain less noise. Field data contains a lot of noise due to the source is derived from the natural activities, like solar wind and lighting activity. One of the noise reduction methods used is time series analysis. The reduction can increase data coherence attain 94.36% from the lowest field data before it is reduced, 40.15%. Time series analysis data was used to describe 2D direction model of the subsurface structure appropriately. However, in the measurements between the magnetic field and the electric field in a perpendicular field are not necessarily had the same direction as the structure beneath the earth's surface, so rotation was needed in order to equate both. There are two types of rotation, strike angle rotation and fix angle rotation. Structural direction in 2D MT modelling can be predicted using invariant impedance by comparing data after strike angle rotation, fix angle rotation and before rotation over overlay model. The strike angle rotation model is the best of the three comparative results by showing the distribution of 67.31% resistivity in the range 1 Ωm – 364 Ωm.

1. Introduction
2D Magnetoteluric (MT) data can be modeled using several methods one of them by using invariant impedance. The direction of strike below subsurface can be predicted using invariant impedance rotation by counting the noise in the data and the fact that the resistivity structure on earth does not really fit the simple 1D, 2D or 3D model [1,2].

\[
\theta_0 = \frac{1}{4} \arctan\left( \frac{(Z_{xx}-Z_{yy})(Z_{xy}+Z_{yx}) + (Z_{xx}-Z_{yy})^* (Z_{xy}+Z_{yx})^*}{|Z_{xx}-Z_{yy}|^2 - |Z_{xy}-Z_{yx}|^2} \right)
\]

(1)

formula an equation for calculating invariant values based on the principle of determinant as follows [4]:

\[
Z_{inv} = \sqrt{(Z_{xx} Z_{yy} - Z_{xy} Z_{yx})^2}
\]

(2)

* To whom any correspondence should be addressed.
the invariant magnitudes as a result of the main component (anti-diagonal) tensor impedance [5]:

\[ Z_{\text{inv}} = \frac{1}{2} (Z_{xy} - Z_{yx}) \]  

in the 2D model the tensor impedance earth must be diagonal when x 'and y' are parallel or perpendicular to the strike [6].

Invariant quantities can be used as an alternative to determine the strike's direction roughly if the medium is not too distant from the 1D condition [7]. The two most commonly used invariant impedances are determinants and averages [4]. The invariant impedance tensor rotation can be used to obtain information about the geometry of basic geological structures because the inversion results from impedance tensor rotation are independent of the direction induction field [8,9].

2. Geology of Research Region

The Tomori region is part of the tectonic East Arm of Sulawesi which can be divided into the northern part of Sulawesi (Banggai-Sula) and the southern part (Kendari, Muna, and Buton). The Tomori Basin region belongs to the Luwuk - Banggai basin (tectonic northern part of East Sulawesi) formed by the horizontal faulting of the Sorong (transverse) fault system that decomposes into the South and North Sula fault, then forms a fault of Batui.

Stratigraphically (figure 1), the sequence of rock from old to young in the Tomori Basin is divided into three dominant geological flats on Mendala of East Sulawesi and Mendala Banggai-Sula covered by the Molasa Sulawesi Group. The entire rock is covered by surface sediments of Lake Sludge (Ql) composed of clay, silt, sand and gravel, and Alluvium (QaI) composed of mud, clay, silt, sand, gravel and crust, in the form of river deposits, swamps, and beaches [10].

Figure 1. The LINE-01 path of the study area is correlated with the modification of the regional geological map [11].
3. Research Method

The Magnetotelluric (MT) data used in this research is 1 measurement path in Tomori Basin and its surroundings, with LINE-01 path of 12 measurement point (figure 1). The field data used for 2D modelling is field data of noise reduction time series analysis.

The research flow is generally divided into two stages, namely rotational modelling and distribution analysis of variation of resistivity in each model to overlay.

This study used two types of rotation, namely the rotation of the strike angle and rotation fix angle. The principle of strike angle rotation refers to the mathematical equation (1), while the fixed angle rotation is motivated by the presence of subsurface structural phenomena that are incompatible with the isotropic homogeneous earth assumption.

The quantitative analysis uses the broad ratio of the resistivity distribution between the inversion model before rotation and after rotation which represents the best resistivity distribution area because its extent is in every cross section of inversion.

From the overlay result has taken an area of dispersion of variation of resistivity value residing in all three such as distribution of variation of resistivity value which ranged between 189 Ωm to 364 Ωm (Figure 2d). For the determination of other areas adjust to the color change as the resistivity value changes. Furthermore, all the areas in the three models are combined and a new model will be produced as a model approach to determine the quality of the data.

![Figure 2](image-url)

**Figure 2.** The 2D inversion model (a) Field data of XPR results (b) Strike angle rotation (c) Fixed angle rotation (d) Overlay results in the range 189 Ωm - 364 Ωm.
Figure 3. The cross-sectional model of a 2D type resistance in the LINE-03 to 30 iteration paths with a trajectory length of ± 26,000 m, the distance interval between tracks ranging from ± 500 m to ± 2000 m. Data modelling without rotation with RMS error 4.3% (a), Field data error 4.9% (b), Strike Angle Rotation RMS error 4.1%. (c) Fix Angle Rotation RMS error 4.7%.
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4. Result and Discussion

The 2D cross-section contains information of resistivity change to depth for all measurement points. The spread of resistivity values in this trajectory varies from 1 Ωm to 5000 Ωm. The 2D model inversion of field data without rotation (Figure 3a) shows the highest resistivity distribution reaches 700 Ωm between the TR-03 and TR-32 measurements at a depth of 500 m - 5000 m, on a strike angle rotation (Figure 3b) reaches 189 Ωm - 700 Ωm between TR-35 and TR-40 measuring points at depths of 6000 m - 10000 m, and fixed angle rotation (Figure 3c) reaches 189 Ωm - 5000 Ωm between TR-25 to TR-04 at varying depths ie on surface to 2500 m and 6000 m - 10000 m. While in the most conductive layer on the 2D model without rotation reaching 1 Ωm - 7 Ωm is between TR-32 and TR-04 at 4000 m - 6500 m depth, in the strike angle rotation model 1 Ωm - 7 Ωm is between points TR-16 to TR-40 at a depth of 0 m - 7000 m just above the resistive layer, and a fixed angle rotation model of 1 Ωm - 7 Ωm is between the TR-35 and TR-40 points from the surface up to 4500 m. There is a clear distinction between the two inversion 2D models, so it will affect both the scale range and the extent of the resistivity distribution in each model.

After performing a comparison of each of the resistivity values of the 2D inversion results (field data, strike angle rotation, fix angle rotation) the best resistivity distribution is obtained by looking overlay model (Figure 4a) where the high resistivity value at 6000 m - 10000 m depth point TR-06 - TR-40. Whereas low resistivity is shown on TR-32 - TR-40 at a depth of 500 m - 10000 m just above high resistivity over resistivity of 1 Ωm - 7 Ωm. However, in TR-25-TR-26 there is also a sufficiently conductive layer below 0 m - 2000 m surface with a very low resistivity value there is a possibility that it is influenced by human activity at that point which causes a decrease in resistivity value.
Quantitative calculations on the three models show that the layers in the variation of resistivity values ranging from 1 Ωm to 700 Ωm best results indicate the strike angle rotation type with the highest data quality of 67.31% (Figure 4b). However, the results shown in the linear regression curve approach (Figure 4c). The data quality of the fix angle model to the overlay model shows the best model with the determination value (R2) 0.972 whereas in the strike angle model the determination value is (R2) 0.8543. This may be due to the influence of the overlay model which has a tendency towards the deterministic fix angle model, thus indicating that on the LINE-01 path the best model is the fix angle model.

5. Conclusion
The rotation of the strike angle is determined by minimizing the diagonal elements of the tensor impedance by having the ambiguity of 900. The strike angle rotates align the TE (Transverse Electric) mode with the strike direction and the TM (Transverse Magnetic) mode perpendicularly. The value of the resistivity distribution in the rotation of the strike angle and the rotation of the fixed angle is similar to the inversion model in the data before the rotation and the predicted rock type are unchanged, but the area of the resistivity distribution is changed. Based on the 2D model analysis the overall inversion has a tendency toward 2D model of strike angle rotation and has the smallest RMS error of 4.1, so it can be predicted that strike angle rotation type is the best model.

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