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Magnetotelluric Responses at Tiris Geothermal Area Based on One-Dimensional Recursive Forward Modeling Method

Suprianto. A[1,2], Supriyadi[2], Priyantari. N[2], Pujiastutik. R[2]., Suryanto. W[3],. and Wahyudi[3]

[1]*Doctoral Student of Physics Dept, Gadjah Mada University, Indonesia*
[1]*Physics Dept., Faculty of Mathematic and Natural Sciences, Jember University, Indonesia*
[2]*Physics Dept., Faculty of Mathematic and Natural Sciences, Gadjah Mada University, Indonesia*
Corresponding Author: Suprianto. A

Abstract: *The One-Dimensional Magnetotelluric forward modelling response has been carried out at the Tiris Geothermal area to obtain apparent resistivity and impedance phase responses as function of frequency due to the effect of resistivity and different layer depth. The resistivity and layer depth model are obtained from tentative model that result from previous research, using forward modelling with recursive technique. Base on apparent resistivity and impedance phase curve, the value of apparent resistivity varies by frequency and resistivity of each layer. In general, the apparent resistivity value approaches resistivity of the bottom layer determined by skin depth. The impedance phase varies around 45 degrees, affected by the frequency and resistivity of each layer. Finally, the magneto-telluric method can be used for more detailed exploration at Tiris geothermal area..*

Keywords: *1D Magnetotelluric, recursive method, geothermal area, Tiris*

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I. Introduction

The Tiris geothermal area (TGA) is located to the East of Mount Lamongan-East Java, Indonesia, and has hot springs as a manifestation which is located in the Segaran village. This hot spring has a temperature of around 77.6^{0}C [1] and the reservoir temperature of around 280^{0}C [2] Due to the geology of this area is very complex, the control of heat source that exists in this area is still not certain, whether controlled by Mount Lamongan, Mount Argopuro or by maar around manifestation [3][4]. In order to know the geothermal system in this area, several studies using geophysical methods have been done using magnetic and gravity method, but very small in scope [5][6].

Application of magnetotelluric method will obtain the sub-surface information more detailed, but very expensive. In this study, we conduct of magnetotelluric modeling to see frequency response and phase that's correlated with sub-surface layer as a preliminary study. Exploration Geophysics is an activity using Geophysical technology by applying the concepts of geophysics, one of them using the Magnetotelluric method that use electromagnetic waves. Magnetotelluric method is a passive method of utilizing natural resources in the form of electromagnetic waves to know sub-surface structure corresponding to its electrical conductivity [7]. The basic concept of the magnetotelluric is an electric field and a magnetic field perpendicular to each other [8]. The purpose of this research is to know the influence of Earth resistivity and depth with response modeling of one-dimensional (1 D) Magnetotelluric.

The propagation of electromagnetic waves is present on the Earth the conductive medium, where meeting the current ***J*** is no longer equal to zero but proportional to the electric field ***E***, So Maxwell's equations become:

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad (1)$$

$$\nabla \times \vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t} \qquad (2)$$

Where, ***E*** is the electric field (V/m), ***B*** is magnetic field (A/m), ***J*** is current density (Cm^3), and ***D*** is the electric displacement (C/m^2).

In this 1 D modeling, magnetic fields are considered propagate vertically into the Earth and the electric field perpendicular to it, so that each component of horizontal electric and the magnetic field varies to the depth of layers only. The impedance is defined as the comparison between electric field and a magnetic field perpendicular to each other can write as,

$$Z_{yx} = \frac{E_y}{H_x} = \sqrt{i\omega\mu_0\rho} \tag{3}$$

Where, z is the impedance, ω is the angular frequency, μ_0 is the permeability in vacuum, and ρ is the resistivity of the layer.

$$Z_n = Z_{n-1}\frac{Z_{n+1} + Z_n \tanh(ik_n h_n)}{Z_n + Z_{n+1}\tanh(ik_n h_n)} \tag{4}$$

where, z is the impedance, k is the complex wave number and h is the layer thickness.

Based on the above equation, homogeneous Earth impedance is a complex scalar number which is a function of the resistivity of the medium and the frequency of the electromagnetic waves. Resistivity of medium on the 1D model varies to the depth and interpreted as a horizontal layers, each with a homogenous resistivity and certain thickness [9].

According to Grandis [10] solved in the complete calculation of the impedance in the Earth's surface layers has done and produce a recursive equation that can be implemented numerically to 1D Magnetotelluric forward modeling. Pseudo resistivity and phase can be calculated using the following equation,

$$\rho_a = \frac{1}{\omega\mu_0}|Z_1|^2 \; ; \; \phi = \tan^{-1}\left(\frac{\operatorname{Im} Z_1}{\operatorname{Re} Z_1}\right) \tag{5}$$

Where, ρ_a is apparent resistivity of the layers, and ϕ is phase.

II. METHODS

The first step is to make a tentative model of litologi layer at TGA - Probolinggo based on tentative model made by Fernania using magnetic method. A tentative model of sub-surface lithology from magnetic data is shown by Figure 1 below,

The next stage is to determine the point of observation and determine input form the layer thickness and the resistivity values of each layer.

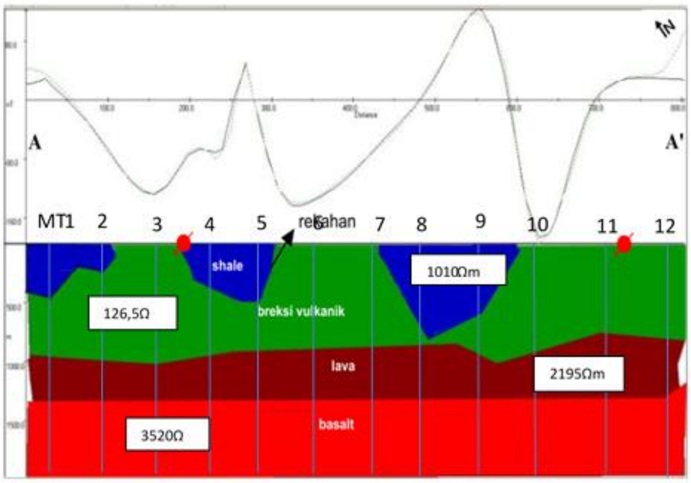

Figure 1. Tentative model of litology at TGA from magnetic data

After this type of rock is known, the value of specified resistivity and thickness used to compute a 1D MT response using frequency range 10-1 Hz to 103 Hz. The Response of 1D MT modeling are two curves, are pseudo-resistivity and phase curves impedance for various frequencies and resistivity of each depth layer using equation (4).

III. RESULT AND DISCUSSION

Pseudo resistivity and phase of the impedance is the output of the 1D MT modeling. The station that is used in this research are 12 point, i.e. MT1 to MT12 stations, with the distance between the MT station is 83 m.

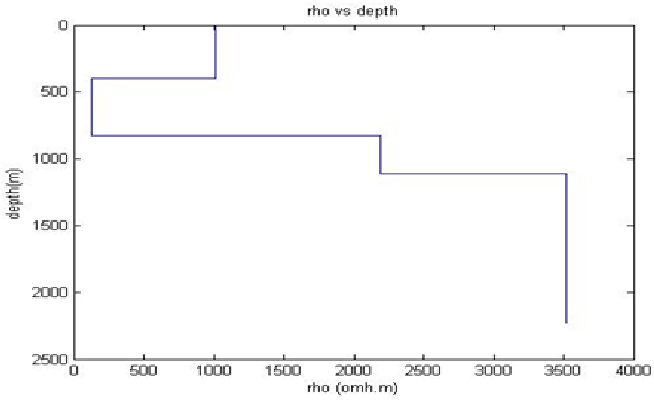

Figure 2. 1 D resistivity model of rocks at MT1 station

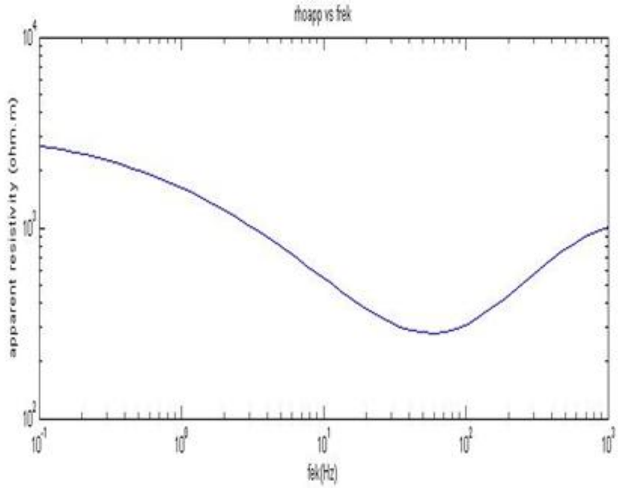

Figure 3. Pseudo resistivity vs frequency curve at MT1 station.

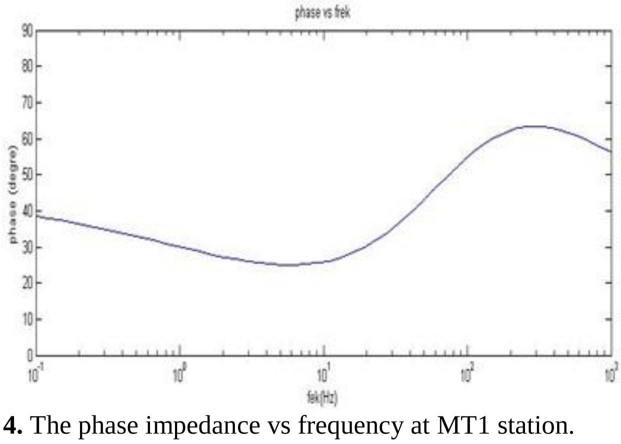

Figure 4. The phase impedance vs frequency at MT1 station.

The waves penetration on the 0.1 Hz frequency indicates the value of 2900 Ωm pseudo-resistivity, which can penetrate all layers with a depth of 1500m. On the frequency of 0, 6Hz up to the 2Hz pseudo-resistivity value decrease from 2000 to 1000 Ωm, so the waves passed through the layer 1, 2 and 3 from 0 – 1100 m depth. 3rd layer resistivity values (Ωm 2195) is the value of the most dominant influence on the value of the pseudo resistivity. At 2-60 Hz frequency, resistivity values of pseudo decrease again until it reaches 290 Ωm. At a frequency of 60 Hz-1000 Hz pseudo-resistivity value increase due to the influence of rock shale formation (1010 Ωm). In this frequency range, the value of apparent-resistivity is 1000 Ωm.

In the curve of Figure 4 impedance phase values can be grouped into 2 parts, namely the value of the impedance phase more than 450 and less than 450. In the frequency range between 0.1 Hz to 50 Hz impedance phase has a value of less than 45°. On the frequency range, the phase value of the impedance decreases, because the value of resistivity on layer 3 of 2195 Ωm-resistivity values smaller than on layer 4 (3520 Ωm), which is assumed to have an effect on the attenuation of electromagnetic waves. At the 50 Hz – 300 Hz frequency range, waves phase rising extremelly from 25° to 63°, it is affected by the change in resistivity of 2195 Ωm at 3rd layer be 126.5 Ωm at 2nd layer. At a frequency of 1000 Hz having a bit of a downturn into 58°, this is a concern because it is affected by the value of resistivity on Shale rocks (1010 Ωm).

On the next simulation, namely at the MT3 station results shown by Figure 5, 6 and 7 below,

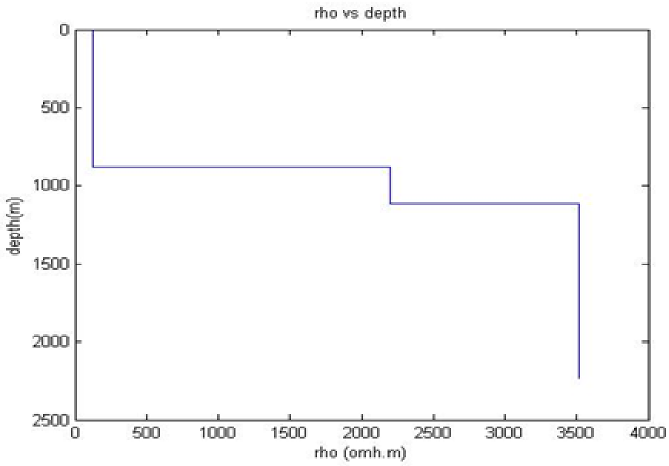

Figure 5. 1 D resistivity model of rocks at MT3 station.

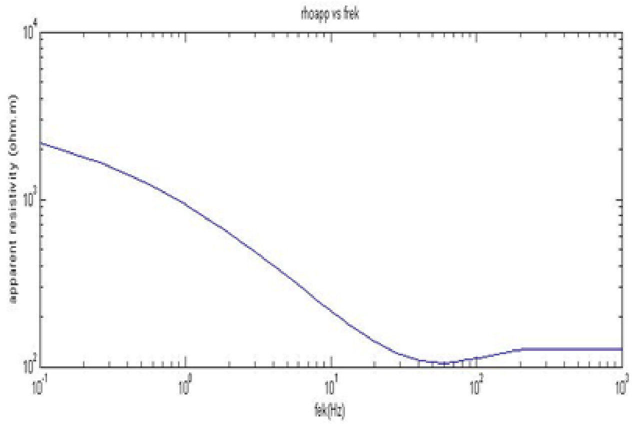

Figure 6. Pseudo resistivity vs frequency curve at MT3 station

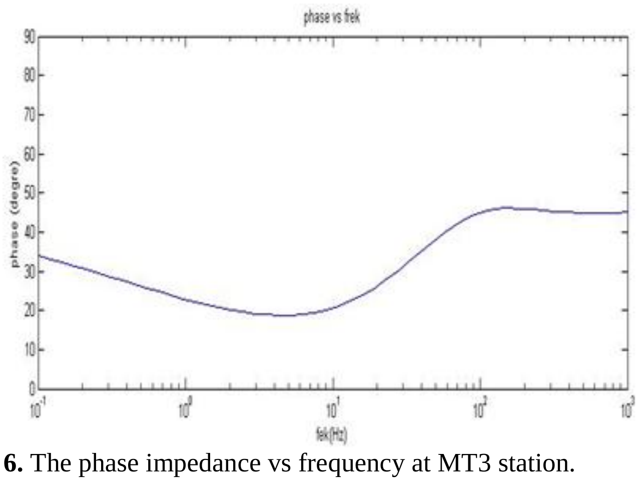

Figure 6. The phase impedance vs frequency at MT3 station.

At 0.1 Hz frequency have a value resistivity of 2100 Ωm. The value of the pseudo resistivity affected layers that have a resistivity value of 126.5- 2195 Ωm, but most predominantly influenced by the layers of lava that has a resistivity of 2195 Ωm with 875 m-1100 m depth. Then occurs at a frequency of 1 Hz to 10 Hz pseudo resistivity value has decreased from 900 to 200 Ωm. On the frequency 10Hz to 1000Hz experienced a slight decrease in the value of the constant challenges tends to resistivity of 120 Ωm. Same as Figure 4, in Figure 7 the value of impedance phase can be divided into 2 parts applies a value less than 45 phase and greater than 45, Impedance phase curve changes influenced by resistivity layers.

The MT responses of the other stations shown in Figs. 7 and Fig. 8. Fig. 7 shows the response of pseudo-resistivity versus frequency and phase impedance at MT2, MT4, MT5 and MT6 stations, while Fig. 8 shows pseudo-resistivity versus frequency and MT phase impedance at MT7, MT8, MT9 and MT11 stations.

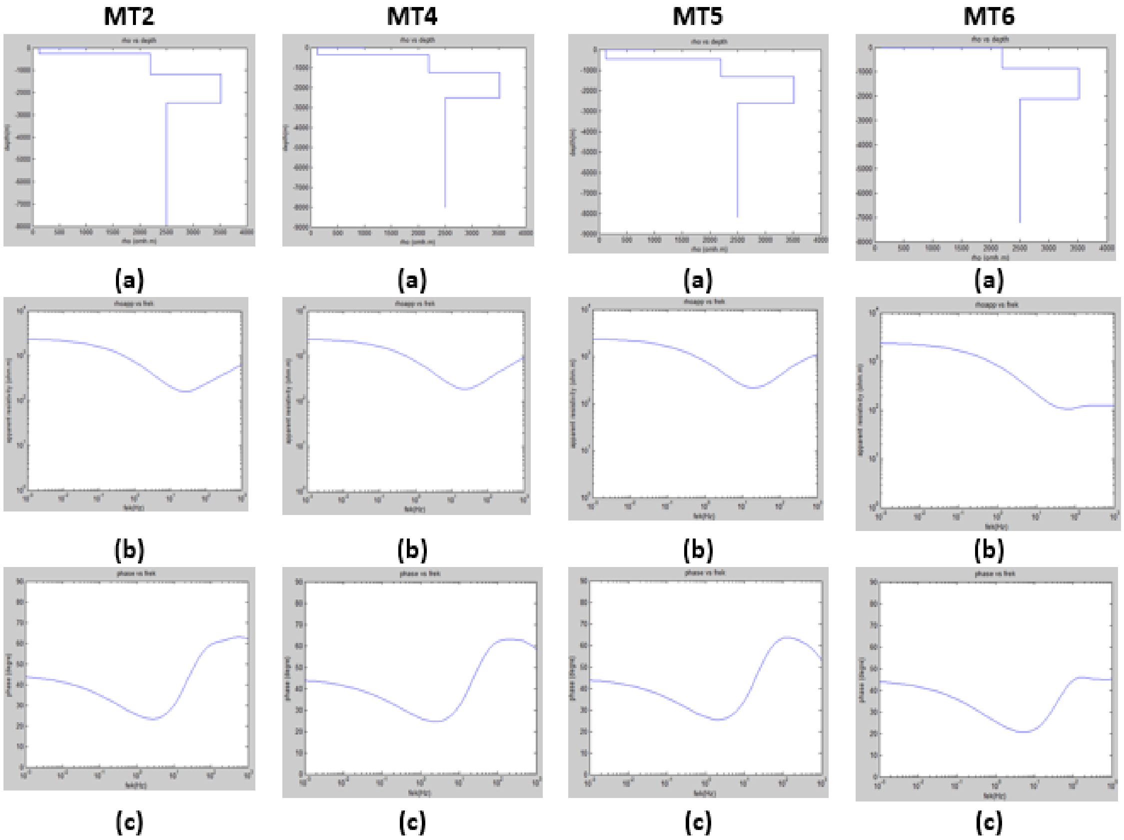

Figure 7. MT responses at MT2, MT4, MT5 and MT6 stations, with: (a) 1 D resistivity model, (b) Pseudo resistivity vs frequency, (c) The phase impedance vs frequency.

The MT1 pseudo-resistivity value is similar to MT2, MT4, MT8 and MT9 where four layers influence the MT response signal, while the MT3 response values are identical to those of MT6, MT7, MT10, MT11 and MT12, where the MT signal caught passed three layers. The phase value generated at that point also depends on the amount of the resistivity layer.

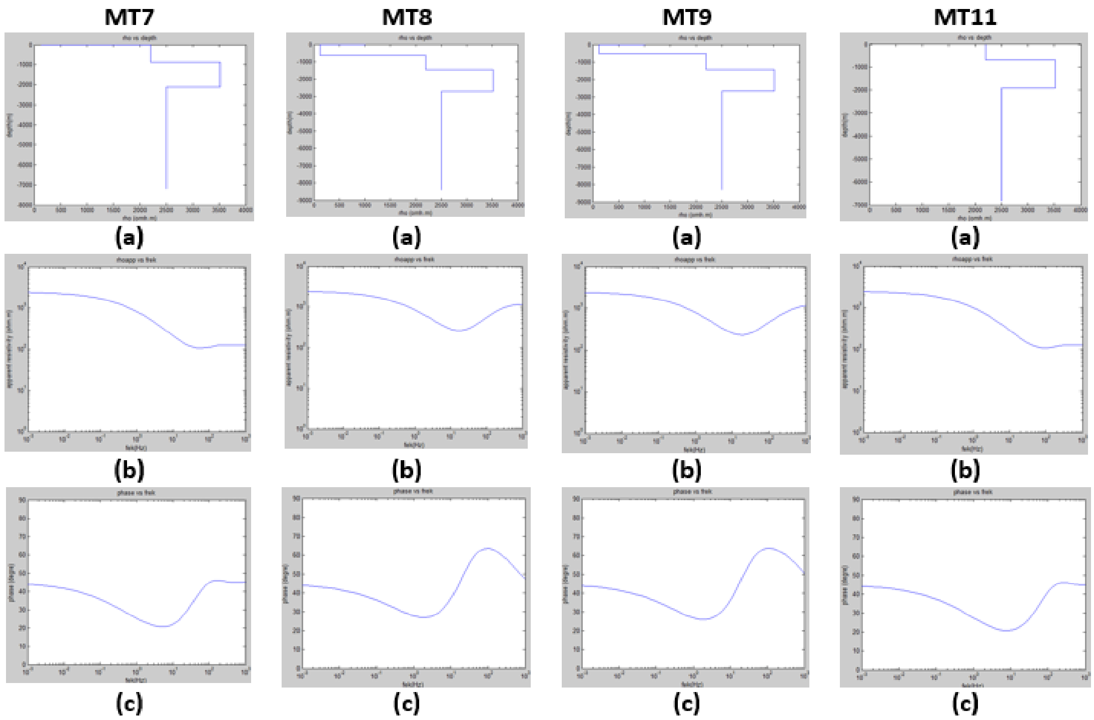

Figure 8. MT responses at MT7, MT8, MT9 and MT11 stations, with: (a) 1 D resistivity model, (b) Pseudo resistivity vs frequency, (c) The phase impedance vs frequency.

IV. CONSLUSION

With 0.1 Hz frequency range 1000 Hz, litologi funds in TGA can be mapped properly. Base on apparent resistivity and impedance phase curve, the value of apparent resistivity varies by frequency and resistivity of each layer. In general, the apparent resistivity value approaches resistivity of the bottom layer determined by skin depth. The impedance phase varies around 45 degrees, affected by the frequency and resistivity of each layer

Acknowledgements

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