

Magnetotelluric Static Shift Correction Using Time Domain Electromagnetics Case Study: Indonesian Geothermal Rough Fields

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ABSTRACT

Indonesian geothermal prospect areas are generally located in the forest area, hills and mountains which has very rough topographical conditions and also extreme difference elevation levels from the deepest valley to the highest peak. Those conditions cause a static shift effect in magnetotelluric data on apparent resistivity curves. Magnetotelluric (MT) is the best passive geophysical method for geothermal exploration. This method is effective for delineating geothermal reservoirs which are characterized by high resistivity contrast between the reservoir and the cap rock (clay caps) that are located on top of the reservoir zone. Since the magnetotelluric method has a static shift problem in rough topographical areas, it should be corrected using shallow electromagnetic geophysically active methods such as the Time Domain Electromagnetic (TDEM) method. TDEM data is not affected by the natural electrical topography effect since the method injects a big artificial electric current (8-20 Ampere) to the earth. TDEM data has high resolution for shallow resistivity structures (effective for 50m to 500m below the surface) where MT can not see the shallow zone in as much detail as TDEM. Then, for all Indonesian Geothermal MT surveys, we always conduct a TDEM survey as a standard procedure for correcting MT static shift effect at all MT sites. This paper will explain the MT static shift correction method using TDEM data.

1. INTRODUCTION

Tectonically, the Indonesian region is located along a subduction zone of the three large tectonic plates. The output of plate subductions cause the appearance of volcanic series such as Sumatera island, Java island, Flores island, Sulawesi island up to Maluku island as part of "Volcanic Ring of Fire" belt surrounding the Pacific Ocean. These conditions give Indonesia a large geothermal potential, or about 27 GW or equivalent to about 40% of total world geothermal potential. There are about 252 geothermal locations that have been identified. They are distributed along a belt extending from Sumatera island to Maluku island. The areas are mainly volcanos, mountains or forests. Geothermal prospect areas generally also cover the areas which have rough topography. Some of the developed Indonesian geothermal areas are Kamojang, Sibayak, Salak Mount, Wayang Windu, Ulubelu, Dieng, Patuha, Drajat, Sungai Penuh, Hululais, Lumut Balai, etc.

Having total potential of 27 GWe, puts Indonesia as the largest geothermal potential country in the world. To encourage investments in geothermal energy, it is important to provide detailed information about geothermal working areas and reserves values that can be developed. Since only 31% of 252 geothermal locations that have detailed data, we need detailed research to investigate all prospect areas. One of the effective geophysical method to investigate geothermal prospects is known as the magnetotelluric method.

2. MAGNETOTELLURICS: BRIEF THEORY

Magnetotelluric (MT) signals are natural electromagnetic waves induced by magnetosphere or ionosphere currents. The signals are used to image the resistivity structure of the earth (Vozoff, 1991; Jiracek et al. 1995). Since the source is far away from the earth's surface, MT waves can be treated as planar (Zhdanov and Keller, 1998). The MT wave is comprised of electric and magnetic fields. The fields are recorded orthogonally, using two electric channels and three magnetic channels as shown in Figure 1.

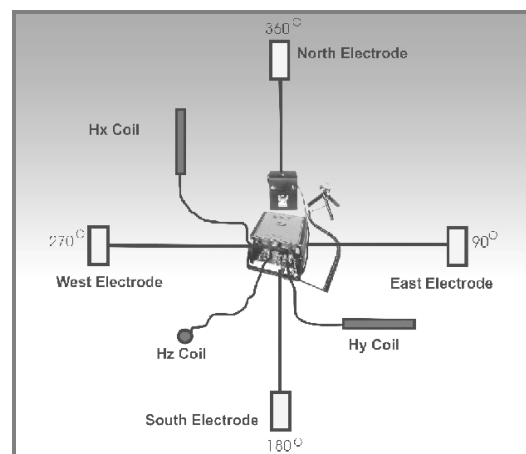


Figure 1: MT field configuration layout.

The electric channels are often aligned north-south, and west-east, so-called E_x and E_y respectively. The magnetic channels are aligned north-south, west east, and down, i.e. H_x , H_y , and H_z respectively. Maxwell's equations are the basis of MT. From a practical point of view, the apparent resistivity (ρ_{xy} and ρ_{yx}) of the earth as a function of frequency can be found from the relationship:

$$\rho_{xy} = 0.2 \text{ T } |E_x/H_y|^2 \quad (1)$$

$$\rho_{yx} = 0.2 \text{ T } |E_y/H_x|^2 \quad (2)$$

where T is the Period of the wave, E_x and E_y are electric fields in mV/km, while H_x and H_y are magnetic fields in nanoTesla.

3. MAGNETOTELLURIC STATIC SHIFT EFFECT

Magnetotelluric (MT) static shift effect is a galvanic distortion effect that locally shifts apparent resistivity sounding curves by a scaling factor s that is independent of the frequency, keeping the phases unchanged. Electrical charges accumulate at the boundary of the conductive medium, resulting in a secondary electric field independent of frequency (deGroot-Hedlin, 1991). Charge accumulates at the boundaries of shallow conductive heterogeneities, which disturb the regional electric field locally, isolated horizontal resistivity gradients near the surface and rough topography factor can cause this effect on MT data curves. A schematic of topography conditions causing MT shift effect is shown in Figure 2.

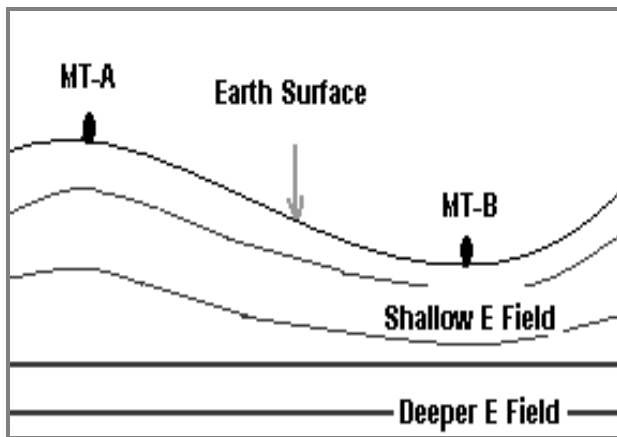


Figure 2: Scheme of topografi condition of MT site cause lateral discontinuity of Electric field.

The vertical shift of the apparent resistivity curves can lead to errors in the inverted model because the resistivity's and depths of the final model will be scaled by s and $(s)^{1/2}$, respectively, for a 1D layered model. Correction for this effect is then of first importance before any interpretation of MT data.

The magnetotelluric data were collected using Phoenix 24 bit instrument of PT ELNUSA which consist of : MTU-5 box recording units, MTC-50 magnetic sensor coils, magnetic cable, electric cable and $PbCl_2$ porouspot electrodes. The data quality was good but some of the MT curves which was collected in rough topography fields had the static shift problem. Shifts of MT curve soundings are based on MT site locations relative to the heterogenities of local surface anomalies. The tranverse electric (TE) curves and tranverse magnetic (TM) curves were split at high frequency, then more data is needed to make a static shift correction. A type of geophysical data that is effective to solve this topography effect on MT is Time Domain Electromagnetic method.

4. TIME DOMAIN ELECTROMAGNETIC DATA

Time Domain Electromagnetic (TDEM) is an active geophysical method using electromagnetic (EM) induction to determine the resistivity structure of the shallow sub-surface. In this study, the TDEM data were collected using a set of Phoenix V8 Multifunction system instruments of PT ELNUSA in an *in-loop* mode. A receiver coil (Goenix MTEM AL, diameter 1m) is placed in the center of the transmission loop cable (100x100 m of AWG-12 cable) to measure the secondary magnetic field. The transmission cable loop is connected to a Phoenix T-4 transmitter box, which is connected to a Phoenix BP72 battery (power source). An RXU-TMR current control device is connected to the transmitter box, controlling the timing for current transmission and recording the transmitted current. Current strength injected is usually about 8-10 Amperes. The field TDEM instruments configuration is shown in Figure 3.

When a steady current in a square cable loop is terminated a time varying magnetic field is generated (Figure 4). The decaying secondary EM signal induced by these eddy currents is measured over a series of time windows immediately after the transmitted signal is shut-off using a receiver coil. Then the apparent resistivity curves can be deduced from these data, which is the curve that serves as a leveling reference for the MT soundings.

Since TDEM is measuring a secondary magnetic field, it relatively unaffected by local surface anomalies and also not

affected by topographical conditions on the surface. TDEM data has high resolution for shallow resistivity structures (effective for 50m to 500m below the surface) where MT data can not see the shallow zone as detailed as TDEM. Then TDEM is very effective for correcting static shift problems in the Magnetotelluric method.

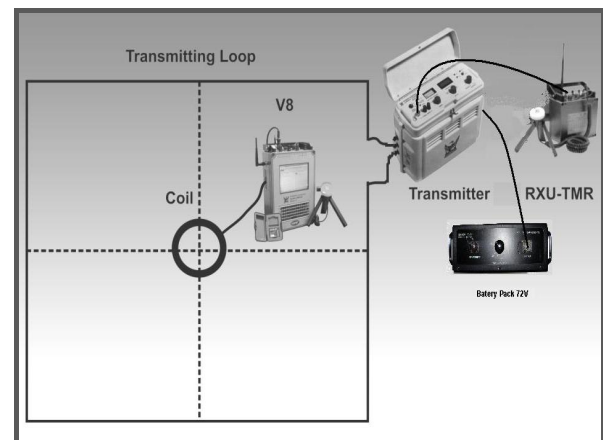


Figure 3: TDEM instruments configuration.

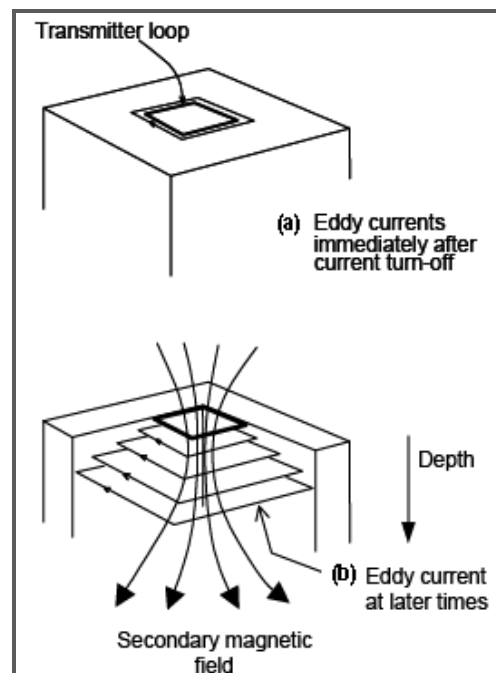


Figure 4: Scheme of TDEM Eddy current flow.

5. THE STATIC SHIFT CORRECTION

Magnetotelluric (MT) method is a powerful geophysical method to investigate resistivity in the subsurface. Since almost all Indonesian Geothermal areas have rough topographical conditions, the MT curves have a shift effect in the high frequencies part. In this research, we use Time Domain Electromagnetic (TDEM) method to solve the MT static shift problem which is TDEM soundings conducted at the same location as the MT site (Pellerin, 1990).

TDEM soundings were conducted after MT data recording. TDEM Cable loop (100x100m square) was laid down to cover the MT site. The artificial current (8-12 Ampere) is injected from the T-4 Current transmitter to the ground trough a cable loop for about 4-10 minutes to get the secondary field which is recorded by the V8 receiver.

During the current injection, the V8 receiver recorded the decay curves and automatically converted the data to apparent resistivity curves. The V8 system also has a monitor display for monitoring apparent resistivity curves so we could control the quality of the data directly.

Time Domain Electromagnetic data that passed field quality control check was processed and modeled to generate a 1D inversion model. This data was converted to MT apparent resistivity curves. TDEM resistivity curve will be present at the high frequency part of the MT curve. It will be used to correct the MT static effect. In this study we use a static-stripping method to correct MT curves that vertically match with the TDEM apparent resistivity curves. Distortion tensor stripping of topographic distortions is possible since the terrain is deterministic. Static stripping is an analytic technique for eliminating the frequency independent offset of one apparent resistivity curve from the other (Geosystem, 2008).

Practically, the static-stripping method is to select a point at the high-frequency end of the MT apparent resistivity curve that matches with the TDEM curve at same frequency. When the original MT apparent resistivity curve is dragged to its new position, a scalar multiplier of the e-field value is

derived. This is applied to a recalculation of all the impedances of that MT sounding. The curves are then redrawn. Only the apparent resistivity curves are affected by this procedure. If the data show a very large static shift at high frequencies, the results can sometimes be unstable. Then we need to repeat the operation several times to get the best result. Examples of MT static shift correction using WinGLink static stripping are shown in Figure 5 and Figure 6.

Another way to do the MT static shift correction is by converting TDEM data to an apparent resistivity curve then compare it with MT curve that shifted. The next step is to shift the TE curve and TM curve to match the TDEM curve. This method is based on the relationship between TDEM diffusion depth and MT skin depth as shown below:

$$\text{TDEM diffusion} : \partial = 36 (\rho t)^{1/2} \quad (3)$$

$$\text{MT skin depth} : \partial' = 603 (\rho T)^{1/2} \quad (4)$$

Here T is the period (second) of MT and t is delay time of TDEM (millisecond). At the same depth of penetration we assume that TDEM delay time (t) will be equivalent with MT period (T). Then from the above equation we get the conversion factor: $k = (t/T) = 195$.

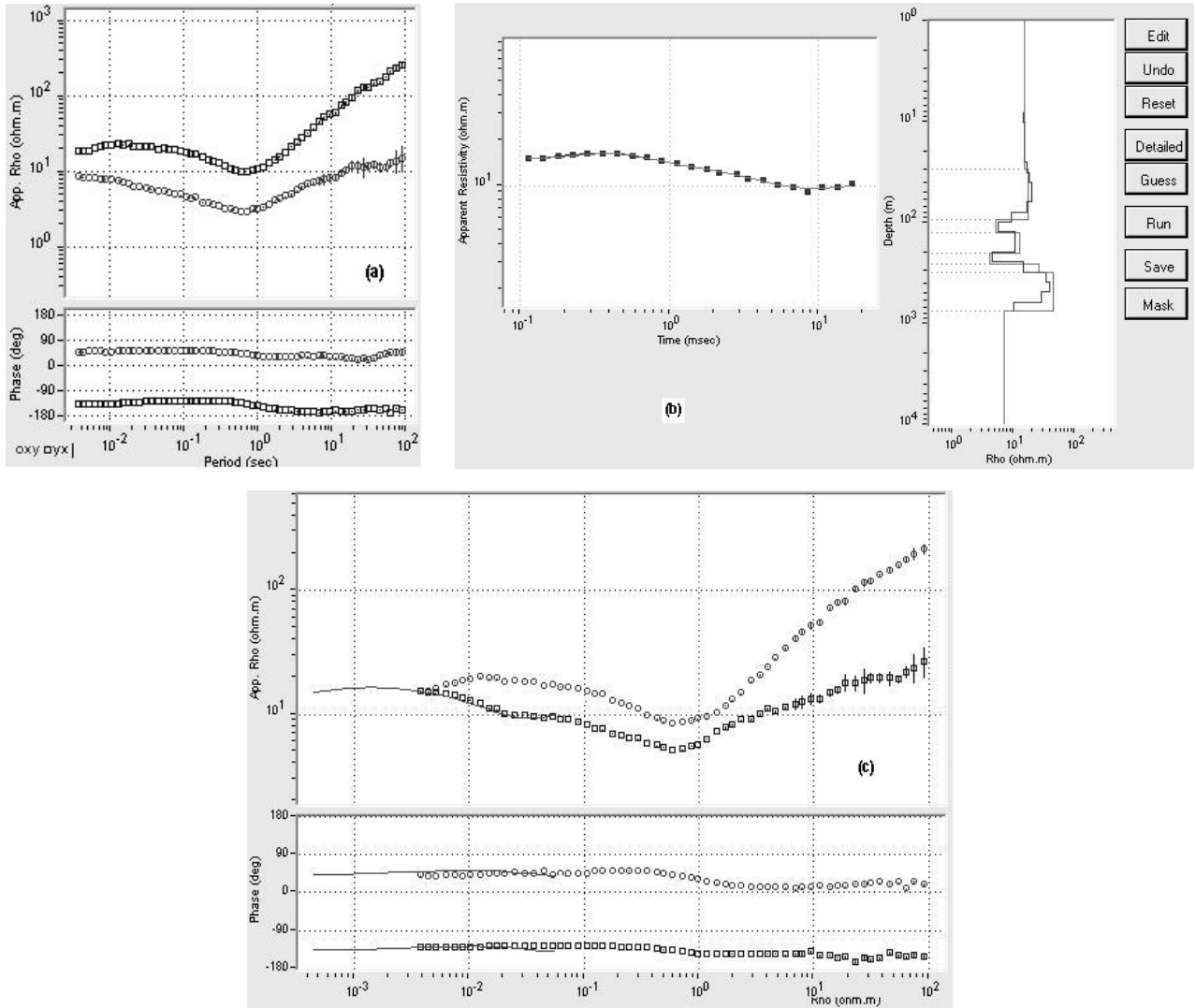


Figure 5: MT static shift correction using TDEM data : (a) MT-X apparent distortion curve; (b) TDEM site-X curve and 1D model; (c) MT-X apparent resistivity corrected curve using static-stripping technique.

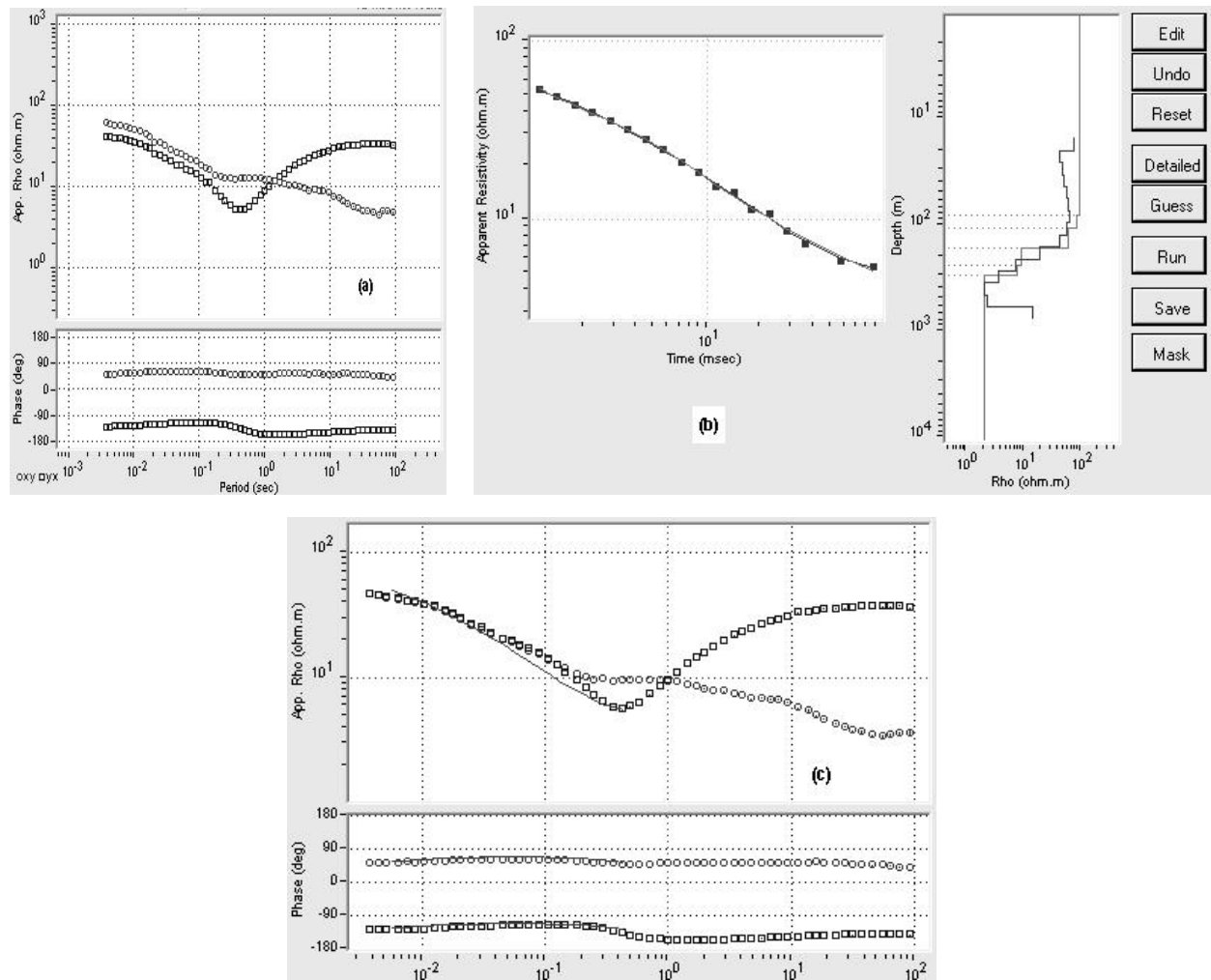


Figure 6: MT static shift correction using TDEM data : (a) MT-Y apparent distortion curve; (b) TDEM site-Y curve and 1D model; (c) MT-Y apparent resistivity corrected curve using static-stripping technique.

6. CONCLUSIONS

Almost all of Indonesian geothermal prospect areas are in rough topographical terrain. These conditions cause static shift effects in MT apparent resistivity curves where TE curves and TM curves are split at high frequency. To solve this problem, we use TDEM data for static shift correction since TDEM is relatively not affected by topography. One way to correct MT distortion curves is using a static-stripping technique to move the MT curve to match the TDEM curve at the highest frequency. Then for all Indonesian rough geothermal fields, we suggest conducting TDEM surveys as a standard data for solving MT static shift problems in every Magnetotelluric survey.

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