Comparison of the Static Shift Corrections Applied to MT Data in Geothermal Area Using Geostatistics and TDEM Methods

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ABSTRACT
Magnetotelluric (MT) is a powerful method for exploring geothermal resources globally. The main objective of the application of MT technology is to delineate zones with high temperature and high permeability. MT technology can be utilized for outlining the low resistivity cap rock, reservoir geometry, indication of fluid flow pattern, resistive basement or plutonic body. However, since geothermal systems are mostly located in complex volcanic settings with high terrain and deep-concealed reservoir, application of MT technology should be done properly to obtain the best results. In such conditions, static shift often influences the MT data. If the static shift is not corrected from the MT data, it would influence to the interpretation of the MT data. Furthermore, delineating well targeting derived from the uncorrected MT data would be unsuccessful. Accordingly, static shift effects must be corrected from the MT data. This paper presents the static shift corrections conducted by using TDEM and geostatistical methods over the MT data in a geothermal area. The results from both methods are then compared to get common understanding about the methodology for the static shift corrections. In addition, the static shift corrected MT data is then inverted using 3D inversion modelling approach for testing and comparing the MT data corrected by geostatistic and TDEM data. It can be concluded that the geostatistic method for static shift correction is comparable with that using TDEM data. This result could be used for reducing geothermal exploration drilling risks.

1. INTRODUCTION
Indonesia has huge geothermal potential resources of about 29,000 MWe (Darma & Wirakusumah, 2015). However, the geothermal potential faces big challenge in geothermal exploration. The challenge occurs from the complex geological problem, data acquisition, processing, modeling and the interpretation. One of the most effective and proven method for geothermal exploration is Magnetotelluric (MT). MT is a geophysical method that measure natural electromagnetic field so that the subsurface resistivity distribution can be calculated and modelled. The objective of the MT method is to delineate geothermal prospect zone characterized by high temperature and high permeability. MT technology can be used to delineate reservoir geometry, cap rock, basement layer or plutonic body. The application of MT technology in geothermal exploration should be done properly due to complex geological condition in volcanic environment as well as rugged topography. Strong topographic effect and near-surface inhomogeneity will influence to the MT data, namely static shift, should be removed or reduced. Otherwise, it can influence the processing result and modelling of MT data, which finally influence the interpretation result and drilling recommendation.

Study of static shift correction of MT data have been carried out by Sulistyo (2011) by using forward modelling of synthetic and real data, regardless of TDEM or geostatistic usage. In addition, study of static shift using 3-D forward modelling has been done by Liati et al. (2015).

This paper describes the application of static shift correction using TDEM and geostatistical methods to the real field of geothermal area and confirmation of the results with the subsurface data from well. This study is expected to be a reference for the application of the static shift correction in other areas.
2. METHOD REVIEW

MT data measured during data acquisition frequently suffered static problems, where the resistivity curve in frequency domain is shifted independent of frequency. This static problem can be caused by galvanic potential triggered by near surface inhomogeneity, vertical contact and surface topography (Daud, 2016; Jiracek, 1990). These factors are typically found in mountainous areas where geothermal prospects are usually associated with.

The static shift problem is usually overcome by using Time Domain Electromagnetic (TDEM) data and geostatistical method (Sulistyo, 2011). TDEM data is used for static shift correction since TDEM data measurement is not influenced by galvanic potential. The MT resistivity curve is then shifted to the TDEM curve or to the averaged resistivity defined by geostatistical method in a resistivity – frequency graph.

To compare the effectiveness of the TDEM and geostatistical methods in the application of static shift corrections, the results are then compared by using resistivity – frequency curve as well as using 3D inversion of MT data with the input data using static shift corrected MT data as well as using uncorrected MT data. Furthermore, to validate the accuracy of the static shift correction methods, the results are then compared with well data (Figure 1).

To study the applicability of the static shift methods to a real data, MT/TDEM data as well as drilling data from a geothermal area is selected for the case study since the first deep slim-hole drilling was successful as recommended by 3-D MT inversion (Daud et al., 2017).

Among the existing MT data collected in the geothermal area, only six data significantly influenced by static shift problems. Static shift correction used in this study are TDEM and geostatistic averaging methods as described in the following paragraphs.

2.1 TDEM Method for Static Shift Correction

By using TDEM data for correcting the static problem, almost all the TDEM data shows the resistivity in the range of 25 – 35 ohm-m (Figure 2). Furthermore, the MT data is then corrected by shifting the MT resistivity curve to the TDEM curve so that both curves are fit. This method is then applied to all the MT data.
2.2 Geostatistic Averaging Method for Static Shift Correction

Beside TDEM method, Static Shifted MT data can be corrected using Geostatistic Averaging method. Principally, Averaging method is done by using undisturbed MT data as references for calculating the average resistivity statistically in the high frequency range (associated with shallow depth). In addition, the average resistivity value resulted from this method is approximately 30 ohm-m. Furthermore, every shifted MT data should be moved back by stripping TE and TM curves to the calculated average resistivity. The corrected MT data using the Averaging Method will influence the curves that look similar on each station because of the statistical averaging process.

2.3 Comparison between Static Shifted MT Data Corrected by TDEM and Geostatistic Averaging

MT data corrected from Static Shift by using both methods are then compared for further analysis. The results (corrected MT data) show similarity as shown in Figure 2. The Averaging Method is, therefore, interchangeable with the TDEM Method.

2.4 3D Inversion of MT Data

MT data after static shift correction is then become input data for 3-D inversion. Result of the 3-D inversion is then visualized as a cross-section of resistivity distribution. The cross-section line is selected crossing the position of well. Figure 3 shows 3-D inversion results with different data input; (a) MT data without static shift correction; (b) MT data with static shift correction using TDEM method; (c) MT data with static shift correction using Geostatistic Averaging method. From the Figure 3, it can be observed that the resistivity distributions for (a) without static correction looks different with those of (b) and (c) with static corrections. The 3-D inversion of MT data without static correction shows shallower and thinner low resistivity zone, so that the BOC (Base of Conductor) which is associated with top of reservoir, is found at shallow depth compared to the drilling data. Meanwhile, the distribution of resistivity of section (b) is similar with that of section (c). Furthermore, BOC lines in both sections are in good agreement with the drilling data. In addition, another significant difference is also observed in the deepest part. Three-dimensional inversion result without static shift correction (a) show a deep resistive body clearly which is not imaged in both static-shift corrected model (b) and (c). Moreover, the pattern of conductive layer, such as thickening and thinning patterns are also different between uncorrected (a) and corrected model (b) and (c). As seen in detail, the conductive body beneath MT-52 looks thinning in uncorrected model (a), while in corrected models (b) and (c), it looks thickened. The similar phenomena is also discovered beneath MT-16. Since there is a possible correlation between resistivity and temperature (Ussher et al., 2000), the pattern of conductive layer would provide an indication of the hotter and the cooler part. This indication is very crucial, because it would guide to the misinterpretation as well as wrong location of drilling target recommendation.

3. DISCUSSIONS

Well data is a good tool for verifying the MT data in terms of low resistivity distribution, base of conductor (BOC) and reservoir zone. For the 3-D inversion of MT data without static shift correction, the result shows in-agreement with the drilling data. The low resistivity clay cap is thinner and, therefore, the BOC is shallower. In addition, the resistivity distribution of inferred reservoir zone is more resistive and shifted to the left of the section. Apparently, the 3-D inversion result with static shift correction using TDEM data as input data (Figure 3 (b)) shows in good agreement with the drilling data. The thickness of low resistivity data, BOC line, and reservoir zone is in good agreement with zone of clay layer, TOR (Top of Reservoir), and high temperature and high permeability up-flow zone, respectively. The same condition (good agreement) between 3-D inversion of MT data and drilling data can be noticed in the Figure 3 (c), where the static-shift influencing MT data has been corrected by using Geostatistic Averaging. It can be concluded...
that static shift problem should be overcome from MT data before inputting to the 3-D inversion software. Furthermore, misleading in 3-D inversion would lead in misleading in interpretation and consequently, misleading in drilling recommendation (Daud, 2016).

Figure 3: Comparison of 3-D inversion results with different data input: (a) MT data without static shift correction; (b) MT data with static shift correction using TDEM method; (c) MT data with static shift correction using Geostatistic Averaging method
4. CONCLUSION

Geothermal systems in Indonesia are commonly situated in complex volcanic settings with high topography and deep-concealed reservoir. Accordingly, applying exploration technology in such conditions should be carried out carefully and properly in order to get the best results. Special attention should be directed to the topographic effects and subsurface inhomogeneities in applying geophysical technology (especially MT) to avoid misleading in interpreting the subsurface information and well recommendation. In such conditions, static shift often influences the MT data. This paper has been discussing about static shift corrections by using TDEM and Geostatistic Averaging methods over the MT data from a geothermal area. The results from both methods are then compared in term of resistivity vs frequency curves. It can be concluded that the static shift corrected curves from both methods have good agreement. In addition, the static shift corrected MT data is then inverted using 3D inversion modelling approach for testing and comparing the MT data corrected by Geostatistic and TDEM data. The results show that the 3-D inversion applying both methods produces similar resistivity distributions in terms of low resistivity distribution, base of conductor (BOC) and reservoir zone. It means that Geostatistic Averaging method can be effectively used for correcting the static shifted MT data if the TDEM data is unavailable. This result could be further used for reducing geothermal exploration drilling risks.

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REFERENCES


