

THE DEVELOPMENT OF MAGNETOTELLURIC (MT) DATA PROCESSING SOFTWARE USING CALCULATION OF THE CALIBRATION PROCESS

Ratna Dewi^{1,3)}, Dzil Mulki Heditama^{1,2)}, Andy Rusbianto³⁾, Yunus Daud^{2,3)}

¹⁾ PT NewQuest Geotechnology, Pesona Khayangan Estate, Depok

²⁾ Master Program in Geothermal Exploration, University of Indonesia

³⁾ Geothermal Laboratory, Department of Physics, University of Indonesia
e-mail: ratna.de1807@yahoo.com

ABSTRACT

Development of Magnetotelluric (MT) technology is absolutely needed in case of saving the 'million dollar decision' in geothermal exploration. But, in Indonesia, where the biggest geothermal potency laid, the exploration technology used is from overseas. Therefore, the authors make an effort to develop the MT data processing from the time series data to frequency domain data in form of apparent resistivity and phase using MATLAB. The calculation of calibration factor is added as the consequence of the converting process of electromagnetic wave signal to integer in the recording process. Using this software, the time series data processing is done from the Fast Fourier Transform (FFT), calibration, estimation of impedance using robust technique. The frequency domain data is the produced in form of apparent resistivity and phase. The result of this data processing is then compared to the result of data processing using the commercial software, SSMT2000. Then, the 2-dimension inversion is also done to compare the subsurface image of both result of data processing. The apparent resistivity and phase from the software developed is comparable to those produced from the SSMT2000. In addition, the inversion result of the developed software is better in representing the subsurface resistivity.

Keyword : magnetotelluric, calibration, time series, impedance, apparent resistivity, phase

INTRODUCTION

Coincide with the increasing of energy demand due to the increasing of the population, the new primary energy source is needed. Geothermal is the best

solution for this energy demand in Indonesia, where the biggest potency of geothermal lies. Unfortunately, the technology used in the exploration are mostly made by overseas. This condition comes to our concern to develop the technology for exploration. The technology developed is the MT data processing software to process the time series data into frequency domain data in form of apparent resistivity and phase.

This software has been made previously by Heditama (2011) and has been modified by adding the calculation of remote reference by Rusbianto (2011). The recent development is focusing in improving the software by adding calibration calculation.

BASIC THEORY

In MT survey, calibration recording must be done before the acquisition. In the calibration process, the response of the instrument and components is measured using a known input signal. The signal includes components at odd harmonics, starting with a different fundamental for each frequency band the instrument can acquire. The calibration become the important process because the calibration data can shows us whether the instruments is working well or not. In addition, calibration process can also help us to examine the filter setting used, whether it is the right setting or not.

The calculation of calibration process consists of four steps (Simpsons and Bahr, 2005), they are:

1. **Frequency-independent calibration of the sensors**

The frequency-independent calibration of the sensors is also called sensitivity. For the magnetic sensors, the unit of the sensitivity (S_B) is V/T or usually mV/nT. For the electric sensors, the unit of the sensitivity (S_E) is mV/(mV/m) or m. It is calculated from dimensionless amplification factor A and the distance between the electrodes, d.

$$S_E = A \times d \quad (1)$$

2. Frequency-dependent calibration of the sensors

Some sensors, such as the induction coil, have the frequency-dependent sensitivity. This sensitivity is described by dimensionless complex factor $w_m = w(f_m)$, where f_m is the m^{th} frequency in the output of the Fourier Transform.

3. Calibration of the A/D converter

The Analog to Digital converter also give a calibration factor as the consequences of converting process. This calibration is called *least count* and calculated based on the resolution of the A/D converter. For example, for the modern MT systems that used 24-bit A/D converter and can take any voltage in the -5V, +5V range has the l.c. $10V/2^{24}=0.6 \mu\text{V/bit}$.

4. Application the calibration coefficient to the output of the transformation.

From the explanation above, the first and third calibration can be applied at any stage, but the second one can only be applied following the Fourier tranform step. The calculation of those calibration can be formulated as:

$$\tilde{X}_m \rightarrow lc \times w(f_m)^{-1} \times S_B^{-1} \times \tilde{X}_m \quad (2)$$

$$\tilde{N}_m \rightarrow lc \times w(f_m)^{-1} \times S_E^{-1} \times \tilde{N}_m \quad (3)$$

SOFTWARE DEVELOPMENT

The development of this software is applied by modifying the software developed by Heditama (2011). The modification is applied by adding the calculation of the calibration process.

This calculation is made based on the calibration setting of the equipment used. Here, the equipment has two types of calibration output file. One is sensor calibration and one of the main unit calibration. Both of those calibration are complex number in form of the value and radian.

All of calibrations (frequency-dependent, frequency-independent, and least count) are calculated based on the equation (2) and (3) after the fourier transformation step.

DATA PROCESSING

The data processing using this software developed is began with the Fast Fourier Transform (FFT) process to convert the time series data into frequency domain data. Here, the FFT process is followed by linear trend removal and hanning window process to optimalized the FFT process. The input data is in form of magnitude of Ex, Ey, Hx, Hy, and Hz vs time, and the output data is in form of Ex, Ey, Hx, Hy, and Hz vs frequency.

After the process of Fourier transform, the frequency domain data is calibrated, so that we get the calibrated value of each element. Then the calibrated value of Ex, Ey, Hx, Hy, and Hz is calculated to get the impedance value and further to get the apparent resistivity and phase using these following equation:

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \begin{pmatrix} H_x \\ H_y \end{pmatrix} \quad (4)$$

$$\rho_{xy} = \frac{1}{\omega\mu} |z_{xy}|^2 \quad (5)$$

$$\rho_{yx} = \frac{1}{\omega\mu} |z_{yx}|^2 \quad (6)$$

$$\phi_{xy} = \tan^{-1} \left(\frac{\text{Im}\{Z_{xy}\}}{\text{Re}\{Z_{xy}\}} \right) \quad (7)$$

$$\phi_{yx} = \tan^{-1} \left(\frac{\text{Im}\{Z_{yx}\}}{\text{Re}\{Z_{yx}\}} \right) \quad (8)$$

The next step is to calculate the robust estimation of the value for each frequency. This step is used for the noise reduction, so we can get the noise-free data set of apparent resistivity vs frequency and phase vs frequency. The frequency domain data resulted is then compared with the frequency domain data produced by SSMT2000.

The inversion using MT2DInv-X software (developed by Geothermal Laboratory of the University of Indonesia) is then carried out to compare the subsurface image of each processing result.

RESULTS AND DISCUSSIONS

1. Processing Result

The data processing is done to seven stations on a line. The result of the processing is presented in an apparent resistivity vs frequency and phase vs frequency curve. The curves of the processing using

the software developed are compared with the curves of the processing using SSMT2000.

Figure 1 shows us the curves of apparent resistivity vs frequency and phase vs frequency for the MT001 station. The red curve is the TE mode apparent resistivity and phase for uncalibrated processing using the software developed. The blue one is for TM mode for uncalibrated processing using the software developed. The pink one is for TE mode for processing using the SSMT2000. The blue one is for TM mode for processing using the SSMT2000.

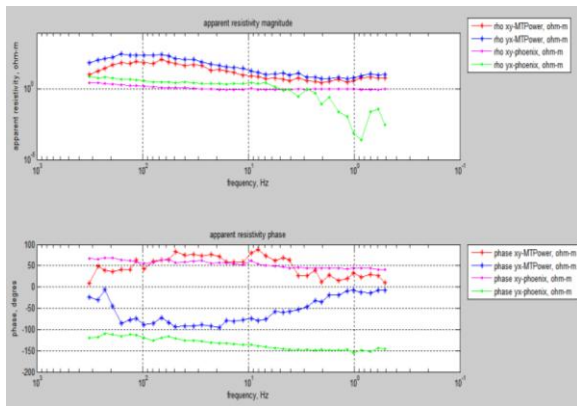


Figure 1: The apparent resistivity and phase vs frequency curves of uncalibrated processing using software developed and processing using SSMT2000 for station MT001

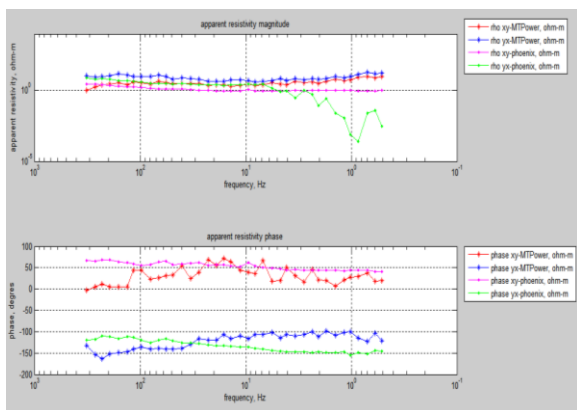


Figure 2: The apparent resistivity and phase vs frequency curves of calibrated processing using software developed and processing using SSMT2000 for station MT001

From figure 1, we can see that the uncalibrated apparent resistivity curves, both TE and TM, are bending up on the high frequency and then going down on low frequency. And for the phase curves of TE mode, we can see the tend-to-straight line, but the

TM curves still bending down for the high frequency and then going up on the low frequency.

From Figure 2, we can see that the calibrated apparent resistivity curves, both TE and TM, have the straight trend and tend to up on the low frequency. The value of apparent resistivity of both TE and TM mode are significantly decrease down to two decades for the high frequency. And for the phase curves, we can see the tend-to-straight line for the both TE and TM modes.

If we compare the calibrated processing curves and the processing using SSMT2000, we can see that the TE mode apparent resistivity is tend to be similar, but the TM curves is different on the low frequency. On the low frequency, the value of TM mode of processing using SSMT2000 is very low, which is 0.0001 ohm-m. For the phase curves, the curves of the calibrated processing using the software still rough, but the trendline can be seen.

Overall, the comparison of apparent resistivity and phase vs frequency of the other six MT stations are similar with the comparison of station MT001.

2. Inversion Result Using MT2DInv-X

The inversion is done using the MT2DInv-X, the software developed also by Geothermal Laboratory of The University of Indonesia.

The result of the inversion of the processing data using SSMT2000 can be seen on Figure 3. The high resistivity is colored by blue and the low one is red. We can see from that figure that there is the conductive layer near the surface until 1000 meters depth. But, the near surface between MT004 and MT005 has the high resistivity. The high resistivity is also laid on the right side of the line above the conductive layer, started from the 1000 meters depth.

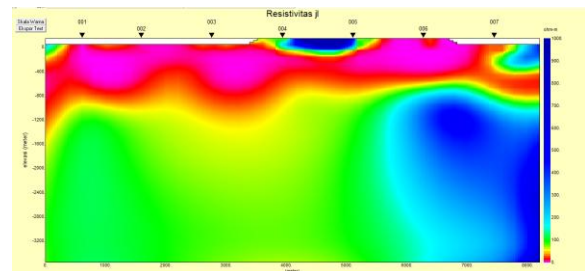


Figure 3: Inversion result of the processing data using SSMT2000.

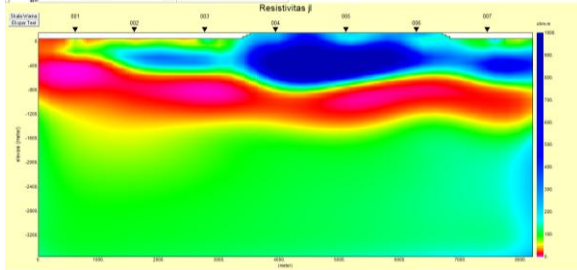


Figure 4: Inversion result of the uncalibrated processing data using the software developed.

Figure 4 shows us the inversion result of the uncalibrated processing data using the software developed. From this figure we can see that there is the resistive layer on the near surface until the 400 meters depth. Under the resistive layer, the conductive layer is laid until 1500 m depth, and on the right edge of the line there is the slight-resistive layer under the conductive layer.

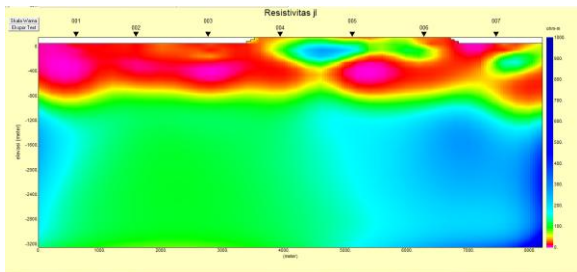


Figure 5: Inversion result of the calibrated processing data using the software developed.

Figure 5 shows us the inversion result of the calibrated processing data using the software developed. From this figure, we can see that there is conductive layer near the surface until the 800 meters depth and between the station MT004 and MT005 there is a slight-resistive layer. On the right side of the line, there is also high resistivity layer under the conductive layer.

CONCLUSION

Overall, we can see that for the apparent resistivity and phase curves of the calibrated processing data using the software developed is comparable to the SSMT2000 curves. Although the phase is rougher, the apparent resistivity shows us the better quality (smoother and straighter) curves compared to the SSMT2000 curve.

If we compare the inversion result, the inversion result of the calibrated processing data is similar to the inversion result of the processing data using SSMT2000. Both of the inversion result shows the

conductive layer near the surface with high resistive layer between the station MT004 and MT005 and high resistive layer is laid under the conductive layer on the right side of the line.

REFERENCES

- Heditama, Dzil M.. 2011. Pemrosesan Data *Time Series* pada Metode Magnetotellurik (MT) menjadi Data Resistivitas Semu dan Fase Menggunakan MATLAB. Geothermal Laboratory. Universitas Indonesia.
- Rusbianto, Andy. 2011. Reduksi *Noise* Pada Pemrosesan Data Magnetotellurik (MT) Dengan Menggunakan *Remote Reference*. Skripsi. Geothermal Laboratory. Universitas Indonesia.
- Simpson, F., dan Bahr, K.. 2005. *Practical Manetotellurics*. Cambridge University Press.