Application of Geo-electrical Method in Preliminary Study for Earth Electrode Site Selection

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Abstract. Electrical power transmission is usually done as high voltage transmission for efficiency. For that purpose, effective grounding is necessary especially at the location of the power transmission control center. To obtain a good connection to the ground, very conductive or low resistivity soil should be present up to an appropriate depth at the earth electrode site. In this paper we present the results of the geoelectrical survey performed in a candidate site in the southern part of South Sumatra province, Indonesia. The objective of this preliminary study is to delineate the most appropriate location for the grounding electrodes. Data acquisition for 2D resistivity tomography was done along several lines crossing the survey area. Low resistivity layer of 10 Ohm.m or less up to 50 m depth was found at the north-western sector of the area.

1. Introduction
In a high voltage system for transmission of bulk electrical power over long distances, a proper earth electrode system is required. A significant amount of current is injected into the ground, especially in case of system failure. The electrical conductivity of the host medium for an earth electrode is important for electrode functionality and also for minimizing environmental impact due to the injected current. High resistivity medium around the electrode will create high potentials and strong electric fields leading to an effect on infrastructure. For a proper design, the site selected for the ground electrode should allow current penetration relatively deep into the earth. Therefore, it is important to obtain information about the resistivity structure of the subsurface close to the electrode and also on a regional scale [1,2].

The most common choice for shallow to intermediate depth investigation (50 to 100 m) of the subsurface conductivity structure is the geoelectrical survey. Conventionally, direct current is injected into the ground and its effect, i.e. potential, is measured using a standard electrode configuration. The 2D resistivity tomography consists of systematic measurement with varying the electrode array separation along a traverse to obtain the resistivity variation both laterally and vertically. The latter is obtained from the application of the inversion algorithm where we seek for a plausible resistivity model that fits the observed data [3,4]. In this paper, we focused only on the preliminary study for earth electrode location in a pre-selected area in the southern part of South Sumatra province, Indonesia.

2. Geoelectrical Survey and 2D Modelling
In the geoelectrical imaging technique, a large number of electrodes is placed on the ground along a profile and connected with the multi-core cable to an automatically controlled switching and data acquisition system. Then, each electrode can serve as either current (C1 or C2) or potential (P1 or P2) electrodes in a 4-electrode resistivity measurement array. We used ARES G-5 resistivity-meter from GF-Instruments Inc. powered by a 12 Volt DC car battery. The current source can deliver up to 1000
Volt DC and 5 Ampere of current into the ground [5]. The number of channels or electrodes connected to take-outs of the multi-core cable is 48 with the unit electrode spacing is 12.5 m. Therefore, the measurement at a traverse line corresponds approximately to a 600 m profile.

A combination of Wenner and Schlumberger electrode configurations (Figure 1) was used to optimize both horizontal and vertical resolution that are characteristics of each configuration [4]. The generalized formula for calculating the apparent resistivity ($\rho_a$, in Ohm.m) from measured values of current ($I$, in Ampere) and potential difference ($\Delta V$, in Volt) is expressed by:

$$\rho_a = K \frac{\Delta V}{I} ; \quad K = 2\pi \left( \frac{1}{C_1P_1} - \frac{1}{C_2P_1} - \frac{1}{C_1P_2} + \frac{1}{C_2P_2} \right)^{-1}$$

where $C_1P_1$ denotes the distance (in meter) between current electrode $C_1$ and potential electrode $P_1$ and so on, while $K$ is the geometrical factor of the electrode configuration. With automatic data acquisition system, the measured parameters are directly resistance values or $R = \Delta V/I$, in Ohm. For Wenner electrode configuration, $K = a$, where $a$ is the electrode spacing (Figure 1) which is an integer or $n$ multiple of the unit electrode spacing. For Schlumberger configuration, $K$ is function of $a$ nd $b$ defined in Figure 1. In more general cases of geoelectrical imaging technique, the distance between electrodes is an integer or $n$ multiple of the unit electrode spacing that determines the investigation depth and the position for the data plotting for the construction of pseudosection.

A sequence of all possible measurements in a traverse consisting of 48 electrodes following a configuration of electrodes results in apparent resistivity data that can be plotted as pseudosection. In the latter, the apparent resistivity data are plotted horizontally on the traverse line at mid-points of the current and potential electrode pairs, while their vertical position is a scaled value of the electrode spacing that depends on the configuration used. The colour-contoured values show variations of the measured data with position and with effective investigation depth, rather than with the true depth. It is used for preliminary qualitative interpretation, before more quantitative interpretation using 2D inversion modelling.

The geoelectrical survey was conducted only in the vicinity of the proposed earth electrode site at 6 traverse lines N, W, E, SE, NW and NE, according to their direction or azimuth (Figure 2). We used Earth-Imager 2D resistivity modeling software from Advanced Geo-sciences Inc. (AGI) with apparent resistivity as function of electrode spacing as the input data to obtain 2D resistivity model representing resistivity distribution of the subsurface [6].

**Figure 1.** Wenner electrode configuration with the electrode spacing $a$ (left) and Schlumberger electrode configuration with $a$ and $b$ are half-distances between current electrodes ($C_1$ $C_2$) and between potential electrodes ($P_1$ $P_2$) respectively (right). STA is the measured position.
Figure 2. Outline of the geoelectrical survey profiles at the survey location. The lines are named according their orientation, i.e. N, W, E, SE, NW and NE, with numbers are the electrode number.

3. Results and Discussion
We present only representative results with significant evidence on the existence or non-existence of very conductive layer at the surface up about 50 m depth as required for the in-situ conductive medium for the earth electrodes. The result for line N extending from South to North at the central part of the study area is presented in Figure 3. The figure contains apparent resistivity pseudo-section (data), theoretical response of the inverted model and 2D resistivity section (model) resulting from inversion modelling. The model is limited to a maximum depth of approximately 125 m due to limitation in the unit electrode spacing (12.5 m) and the number of electrodes for each traverse, i.e. 48 electrodes. Note that the vertical axis of the 2D resistivity model is presented as elevation above the mean sea level (MSL). More detailed 2D models for line W, NW and SE are presented in Figure 4 to 6 with vertical exaggeration showing also the topography.

The 2D resistivity model for line N exhibits an almost horizontal and continuous layer with resistivity less than 10 Ohm.m at the extremity of the profile (southernmost and northernmost). The superficial conductive layer has approximately 20 m thick. The central part of the profile is dominated by a heterogeneous zone with more resistive medium up to 100 Ohm.m (see Figure 3, bottom). The subsurface resistivity distribution to the western part of the study area shows more promising conductive zones that extends almost all along the profile W, except at a small part at the eastern end of the profile. The conductive zones are relatively thick with the most homogeneous and horizontal western part is approximately 20-25 m thick (Figure 4). The subsurface resistivity distribution of line NW shows low resistivity layer extending from the center up to south-eastern part of the profile with a limited extent of heterogeneity towards the end of the profile (Figure 5).

As an example of the non-existence of near-surface conductive layer is shown in Figure 6 for 2D model from line SE that extends from North-West to South-East. The superficial layer is dominated by resistive heterogeneity, while more conductive layer is at deeper part of the subsurface. Line E and NE (not shown) exhibit almost similar characteristics of the subsurface. Therefore, the most appropriate area for the earth electrode is to the West and North-West of the central part of the survey area indicated by the position of the bench-mark BM-01 (see Figure 2).
Figure 3. Resistivity section of line N with measured apparent resistivity pseudosection (top), calculated apparent resistivity pseudosection (middle) and 2D resistivity model (bottom).

Figure 4. 2D resistivity model of line W from West to East with vertical exaggeration and topography.

Figure 5. 2D resistivity model of line NW from South-East to North-West with vertical exaggeration and topography.
Figure 6. 2D resistivity model of line SE extending from North-West to South-East with vertical exaggeration and topography. Superficial heterogenities dominated by resistive layer is more pronounced than those from other profiles shown in Figure 3 to Figure 5.

4. Conclusion
We have presented the application of geoelectrical method for earth electrode site selection for high voltage electrical power transmission. The tomography technique was performed both in data acquisition and inversion modelling resulting in 2D resistivity models that fit the observed data. The RMS error of all inversion modelling is in the order of 20% to 30% which is quite high due to relatively high level of noise in the survey area. Heterogeneous superficial layer also contributes to noisy data since the contact resistance of the electrodes was also relatively high (more than 1 kOhm). Nevertheless, our results have been successful in delineating the most promising and appropriate zone for the earth electrode site. The location with dominating low resistivity superficial layer up to 20 to 30 m depth is located to the West and North-West of the central part of the survey area.

References
[1] Thunehed H, Åström U and Westman B 2007 IEEE PES PowerAfrica.
[2] Villas JET and Portela CM 2003 IEEE Transaction on Power Delivery 8(3).
[3] Reynolds JM 2011 An Introduction to Applied and Environmental Geophysics, Wiley.
[4] Loke MH 2012 Tutorial: 2-D and 3-D electrical imaging surveys, www.geoelectrical.com.
[5] GF-Instruments 2010 ARES G-5 resistivity-meter Users’ Manual.
[6] Advanced Geosciences Inc. 2005 EarthImager 2D Instruction Manual Version 1.9.0.