3-D Magnetotelluric (MT) Modelling Using Transient Electromagnetic (TEM) Data as Constraints for Imaging the Geothermal Reservoir in Saudi Arabia

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Abstract

There is a strong emphasis in Saudi Arabia's vision 2030 on developing renewable energy sources, including geothermal resources, to diversify the energy mix. Al-Lith area in western Saudi Arabia has geothermal surface manifestations such as hot springs, and its geothermal reserve is considered the most prominent site of Saudi Arabia's geothermal resources. This study aims to investigate and explore more comprehensively the prospect of geothermal resources in the Al-Lith area by using active and passive Electromagnetic (EM) methods, specifically Magnetotellurics (MT) and Transient Electromagnetic (TEM) techniques. Due to its ability to probe deep into the subsurface, image electrical properties (fluids, hot source, fracture zones, etc.), cover large areas, and provide cost-effective insights, MT has emerged as a valuable and widely used technique in geothermal exploration.

To achieve this goal, we acquired broadband MT data in the period range 0.001–512 seconds at 50 locations to obtain a three-dimensional electrical resistivity model that can be used for imaging the geothermal system. A robust processing scheme is applied to the MT time series to estimate the MT transfer functions (impedance and tipper). In addition, several TEM soundings were collected using a central-loop configuration with a 40m x 40m transmitter loop to correct for possible static shift effects in MT data.

The MT phase tensor dimensionality analyses and its skew calculations reveal a complex subsurface conductivity structure, characterized by 1D/2D geoelectric structures for short periods (< 2 seconds), and a 3D behavior for longer periods. Thereby, we carry out a number of extensive 3D MT inversion tests by changing the type of data to be inverted, the smoothing factors, the inclusion of static-shift corrections, the implementation of topography, as well as variation of the initial resistivity model in order to systematically assess the robustness of the results. The resistivity model derived from TEM shallow data was also incorporated into the starting model to optimize the 3D MT inversion. Thus, unconstrained and constrained inverse models are achieved and appraised.

The final 3D resistivity model images the geothermal system's heat source, convection pattern and groundwater system with an error-weighted RMS of 2.06 after 121 iterations. The heat source is represented by deep elongated conductive bodies (<10 Ωm) ranging from depths of 3 to 10 km. The individual protrusions indicate the pathways of geothermal fluids forming the convection cell from the heat source to the surface or near the surface that would lead to an active geothermal surface manifestation (hot spring). A detected near-surface localized low-resistivity (~ 50 Ωm) zone with an average thickness of less than 200 m, can be interpreted as sediments fully saturated with freshwater. In addition, the high

resistive zones (>200 Ωm) are associated with hard-rock geological formations. The outcome of this study serves as the key input to understand the characterization and complexity of the geothermal system of Al-Lith region.