Capacitive Electric Field Sensors for Long-Term Reservoir Monitoring

Andrew D. Hibbs, Todor Petrov, Joseph Pendleton, Steven Milberger, Tavis Hall, and Joseph Chambers, GroundMetrics Inc., San Diego CA

Measurement of the in-ground electric (E)-field provides superior sensitivity to variations in formation resistivity than does a measurement of the magnetic field at the same location. However, acquiring E-field data has historically meant using galvanic electrodes which rely on electrochemical coupling to their local environment. It is unfeasible to deploy such electrodes for long-term monitoring owing to their inherent continual electrochemical degradation, and the effects of changing near-surface groundwater content and temperature which act to produce measurement artifact. In addition, by their very nature, galvanic electrodes require continual ionic exchange with the local ground material. This means that the ground must be relatively moist, or water and/or specialty mud must be added to the ground where the sensors are emplaced. In many instances, such as desert or Arctic environments, the ground is too dry or the conditions too harsh for galvanic E-field sensors to be used.

In 2011, GroundMetrics introduced a new type of E-field sensor that employs chemically inert electrodes that couple capacitively to potentials in the Earth. This coupling is a purely electromagnetic phenomenon, which, to first order, has no temperature, ionic concentration or corrosion effects, providing unprecedented measurement fidelity. The sensor contacts the ground via a passivated surface. The protected, nonreacting nature of this contact can potentially provide an operational lifetime of tens of years, even when exposed to extreme environmental conditions.

The inherent capability of the sensors to operate without ionic coupling has been recently demonstrated in deep sand conditions at the Imperial Sand Dunes National Recreation Area (the “American Sahara”) in Southern California. The capacitive E-field sensors were simply placed on the surface of the sand, as shown in Figure 1.

Figure 1. Capacitive Electric Field Sensors (shown inside circles) Deployed on Deep Sand to Demonstrate the Capability to Operate without Ionic Exchange with the Ground

Two independent E-field measurements were made along parallel axes 3 m apart with their individual ground potential sensors separated by 100 m. A frequency domain cancellation algorithm was used to cancel the component of environmental noise that was coherent between the two sensors. The resulting spectra shown in Figure 2 represent the E-field signal that could be acquired in a 1-second duration measurement with a signal-to-noise ratio of one.

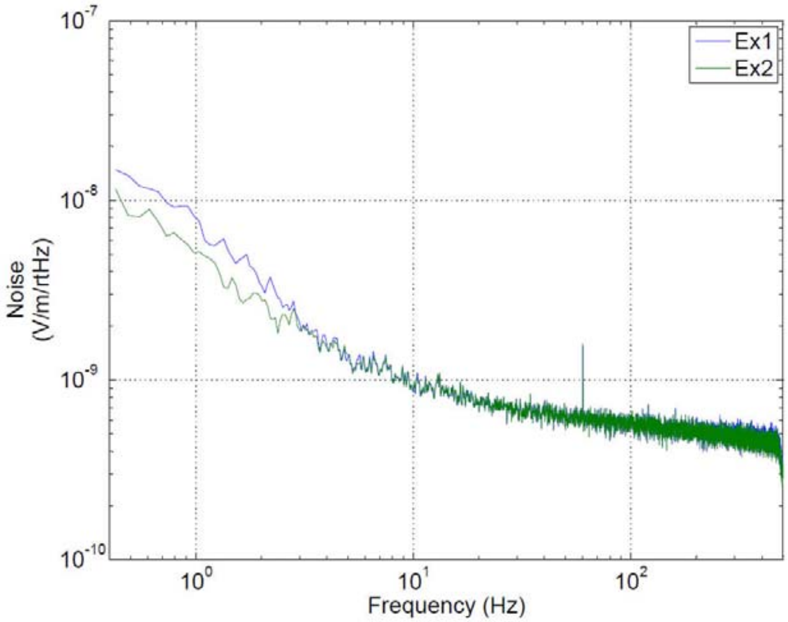

Figure 2. Electric Field Spectra Collected from Sensors 100 m apart after Cancellation of Background Environmental Electromagnetic Noise. Data Collected on top of Sand at the Dunes National Recreation Area (see Figure 1). The Minimum Detectable E-field at 10 Hz is 1 nV/mHz$^{0.5}$

Despite being collected under desert conditions with surface sensors, the data in Figure 2 are comparable to the best reported data for buried, galvanic electrodes under ideal conditions. With their chemically inert coupling, it is realistic to expect capacitive E-field sensors could be permanently installed, making accurate measurements year-round. Alternatively the capability for simple deployment on the ground surface may be leveraged to enable fast, affordable time-lapse surveys in cases where the operator can accept less accuracy and prefers no permanent infrastructure. Both methods open the door to economical long-term electromagnetic surveillance of reservoirs in all regions of the world. A joint industry project to monitor fluid movement through time-lapse resistivity images on 2-3 oil fields is currently being planned with a diverse group of service providers and producers.