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Using Well-Casing Antenna Sources for Electrical Surveys

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SUMMARY

Surface based electrical resistivity and controlled-source EM surveys have always suffered from a lack of sensitivity to deeply buried targets. This characteristic has limited the application of surface electrical techniques to more shallow applications or those involving large subsurface structures. The situation changes when boreholes are available to deploy sensors closer to the targets of interest. In general, however, metallic wells casings are unsuitable for deploying EM sources and sensors, but what if the casing itself could be considered an antenna?

In this paper we describe a workflow for using a casing-deployed low frequency electrical source grounded at the top of a well casing and at depth. We then show a field example where this source is used for imaging.

Keywords: casing antenna, casing current, electrical fields, 3D imaging, carbon sequestration

Introduction:

Surface based electrical resistivity and controlled-source EM surveys have always suffered from a lack of sensitivity to deeply buried targets. Large source-receiver separations are required to detect deep targets and such targets are required to occupy a large volume or have a large resistivity contrast with the background, or both, for detection or imaging. This characteristic has limited the application of surface electrical techniques to more shallow applications or those involving large subsurface structures.

The situation changes when boreholes are available to deploy sensors closer to the targets of interest. In fact crosswell EM and borehole ERT surveys have reported excellent success in imaging a wide variety of deep targets. The issue is that non-metallic well casings or special completions are required to deploy sensors, and typically these are not available, but what about the existing steel-cased wells, could they be used?

This topic is an active research area for a number of workers. Recent analytical solutions have been developed by Cuevas (2013) and numerical solutions by Schenkel and Morrison, 1994, and Heagy et, al., 2015, Weiss et. al., (2015). There are practical applications in well logging (Schenkel and Morrison, (1994), Kaufman, (1990), and some experimental ERT data collected by Daily et al, (2004), and Rucker et. al., (2010), although the latter have used 2D approximations for the source.

In this paper we describe a workflow for using a casing deployed low frequency source grounded at the top of a well casing and deeply within the earth. We then show a field example where this source is used for imaging.

Casing Antenna Workflow

Consider an electrode grounded into an infinitely long vertical steel casing. The DC current from a grounded polar source into the casing will flow up and down the pipe according to the following simple equation (Sckenkel and Morrison, 1994; Kauffman, 1990).

$$I_{cas}(z) = I_0 \exp(-z / L_c)$$

$$L_c = \sqrt{\rho_{formation} S_{case}}$$

Where S_{case} is the conductance (conductivity thickness product) of the steel pipe and rho is the formation resistivity. The casing current is a decaying exponential function controlled by the characteristic length L_c, which describes the length along the casing at which the current has decayed due to leakage in the adjoining formation. For normal (oil field) casing well casing the current decays to 1/e its initial value from 200m to 2km from the grounding point, depending on the background resistivity.

The 'leakage" current flowing from the pipe into the formation provides the distributed source function for electrical surveys that we use for imaging. The variability of this function provides some challenges to its application. For example, for a deeply buried source in a weakly conducting pipe and a conductive background this source is confined to a few hundred meters, whereas for a resistive background and a thick casing, the entire pipe lights up. (Figure 1).

For actual wells, and more involved completions, the current function is more complex and numerical codes are required to calculate the currents. In vertical wells cylindrical solutions are typically used (Heagy et al., 2016). For deviated or horizontal wells 3D codes are required.

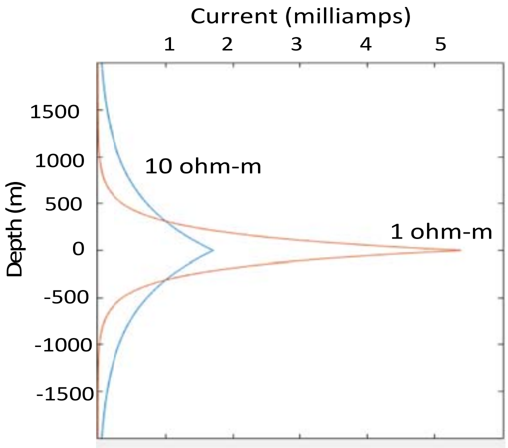

Figure 1. Leakage current from pole source along an infinite steel pipe of conductivity $5.5x10^6$ and thickness 1 cm in a homogeneous medium

The workflow used by GroundMetrics consists deploying current electrodes at the top of casings or downhole, at reservoir depths, in combination with surface based return electrodes for electrical sources. We use a commercial geophysical transmitter driving a 0.1-1 Hz square wave current at 5-10 amps. For each source 40-60 multi-channel receiver stations are deployed on the surface to measure (mainly) electrical fields and fundamental frequency amplitudes are extracted from the receiver time series. The receiver voltage/transmitter current transfer function is then used as a data set for interpretation.

To interpret the data any numerical package must be able to model the casing or alternatively use an expression for the distributed current source. In our case we calculate the leakage current function at DC, from a knowledge of the well completion and background resistivity, and discretize this into a series of current poles. We then calculate the external fields from these sources separately and add them together using superposition. The 3D forward and inverse codes were modified to allow for the multiple sources to be energized simultaneously (Nieuwenhuis et al. 2015).

One advantage to this approach is that it does not entail modeling the casing itself, and thereby allows us to use more grid elements for the formation imaging required. One issue is that assumptions are made on the casing and formation properties, especially in the near surface and this can lead to errors in the current and in the imaging, we discuss this further below. We note that these errors are often evident in the near-well results and can be compensated somewhat by adjusting the pole strengths during inversion.

Field Example Carbon Sequestration test:

Carbon sequestration testing is presently underway at the Kevin Dome in the Williston basin of northern Montana by the Big Sky Carbon Sequestration partnership (Spengler, 2011). The group is planning to extract a million tonnes of CO_2 from the Devonian Duperow formation in Kevin Dome, inject it into the water leg of the same formation and track its movement over the next several years.

The stratigraphy at the site consists of 700m of clastic overburden overlying a multi-layer carbonate basement. Injection is planned into a 30m thick layer at a depth of 1390m. Logs from the injection well indicate a 20ohm-m overburden overlying a highly resistive carbonate basement at 700m to total well depth of 1450m. The injection layer, at the base of the well has a porosity of 10-15% and a resistivity of 10-50 ohm-m, within the highly resistive bedrock.

As part of the monitoring effort GroundMetrics has applied Borehole to Surface resistivity to map the CO_2 distribution; baseline measurements using a top casing source were made in 2014. In Figure 2 we show a single radial electrical field profile from the top casing source extending roughly 1km northwards. As shown we were able to closely fit the data with a 3D model that included structure to more than 1.5 km. This was dramatically improved sensitivity to surface based sources and receivers deployed at the same site. Subsequent modelling has indicated fair to good sensitivity to injected CO_2.

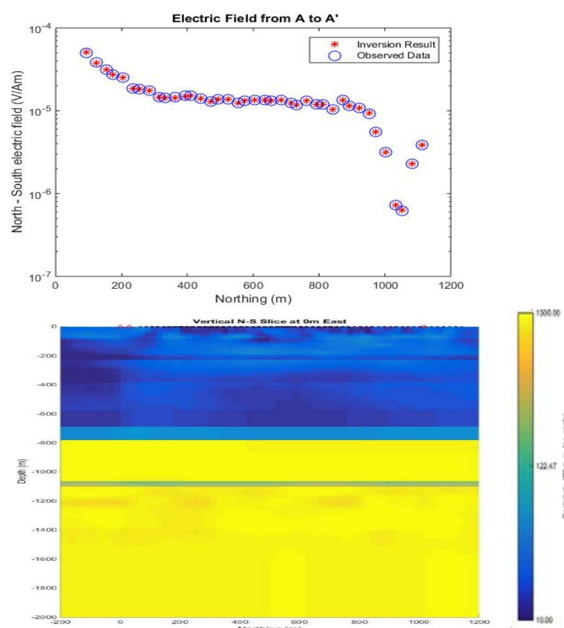

Figure 2. Field and numerical model data 3D model cross-section.

We note that the project at present has been delayed due to insufficient CO_2 production in the initial well. A second well is planned in the near future.

Discussion:
Clearly, the use of a well casing antenna improves the sensitivity to deeper targets, but it also adds complexity of the source term and other issues.

In conductive conditions EM induction must be accounted for: For practical oil field deployments, where source-receiver spacing can scan several km even a low source frequency (0.1-1.0) Hz has significant EM effects. We therefore need to account for both a) induction effects due to the surface transmitter wire and if DC codes are used for inversion, adjust the data for background EM effects.

There is a strong sensitivity to near surface geology: For top casing and even downhole casing sources the electric fields are strongly affected by the near-surface resistivity structure. We typically account for this by using an independent source distribution to build a near surface resistivity model separately.

Well information is often problematic: In older wells completion or logging data may be obsolete or missing, so making a current function can be very problematic.

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