The Utility of a Fully-distributed Direct Current Resistivity and Induced Polarisation System with Common Voltage Referencing

Jonathan Rudd
Dias Geophysical Limited
Cambridge, ON, Canada
jonathan@diasgeo.com

Glenn Chubak
Dias Geophysical Limited
Saskatoon, SK, Canada
glenn@diasgeo.com

SUMMARY

The direct current electrical resistivity and induced polarization (DCIP) method has received another significant upgrade through the introduction of common voltage referencing (CVR) in a fully-distributed array system. An array of single-channel receivers with a CVR wire allows for the extraction of an unprecedented volume of dipole data for the number of receivers deployed. In 3D implementation, this new method reduces noise levels and allows for the derivation of multi-scale and multi-azimuth receiver dipoles.

Operational efficiencies in the CVR method include lower overall wire lengths, less equipment weight and less crew fatigue when compared with conventional and other distributed array methods. Cable-free mesh network capability in each receiver allows for real-time assessment of data quality metrics, safety information, location data, and system health data. These operational efficiencies translate directly to improvements in safety.

With several hundred active receivers, data volume can reach 10s of millions of data records. Careful processing and selection of an optimised data subset with multi-scale and multi-azimuth information will inform highly accurate inversion imaging.

Key words: induced polarisation, resistivity, 3D survey, distributed array, common voltage reference.

INTRODUCTION

The direct current resistivity and induced polarization (DCIP) method received a significant upgrade when distributed array (DA) systems were introduced in the late 1990's. The original DA system, MIMDAS, provided a clear advantage in depth penetration over predecessor technologies, and this advantage in 2D applications remains to this day (Sheard, 2002).

Over the last 10 years, the 3D method has slowly been enhancing value in DCIP surveys by adding directional information to data sets. More recently, full-azimuth surveys are establishing a new standard for 3D surveys as the value of full directionality is being recognized for its importance in delivering unbiased 3D resistivity and IP models in many applications (Eaton, 2010).

By analogy, in the early 1990's, the 3D seismic method was introduced and has now grown to the point where it dominates seismic acquisition. We predict the same growth trajectory for the 3D DCIP method. As the cost of these 3D surveys decreases through natural technology maturation processes, much of the surveying now completed as 2D will move to 3D.

A fully-distributed DCIP system is one in which each of the receivers records a single channel of data. While each receiver only records one channel, a very large number of receivers can be deployed on any given survey. This single-channel architecture provides a long list of advantages. Following are a few of the main benefits:

- Improved survey safety
- Full flexibility in survey design
- Easily record time series data
- More accurate electrode location
- Allows for Common Voltage Referencing

METHOD AND RESULTS

We discuss the fully-distributed DCIP method of surveying with reference to the DIAS32 system as this will allow for the inclusion of a discussion of practical challenges and successes that have been seen to date.

The modernisation of most geophysical systems has involved the replacement of analog components with digital components. This replacement provides two benefits – it reduces size and weight, and it reduces noise. Much energy is spent in moving the digitization function as close to the sensor as possible to minimize noise effects caused by these analog components. In the DCIP method, this involves placing a receiver at every sensor electrode used in the survey area. Therefore, we can expect that a single-channel receiver placed at the electrode sensor would yield the best possible DCIP data.

In traditional DCIP surveying, most surveys are completed by measuring the difference between two adjacent sensors. The potential difference between two electrodes is observed by extending a wire from the receiver to each of the electrodes and measuring the voltage. The wire is sensitive to external noise which is then recorded along with the desired signal.

In the CVR method, this same dipole measurement is made by placing a receiver at each of the two electrode sensors, measuring the voltage between each sensor and the connecting wire, and then subtracting the response from the two receivers. The net effect is similar to that of differential signal cables in professional audio systems as any noise induced in the wire that extends between the two sensors is removed in the subtraction. Figure 1 depicts an example of this noise reduction effect in two nodes in a DIAS32 survey.

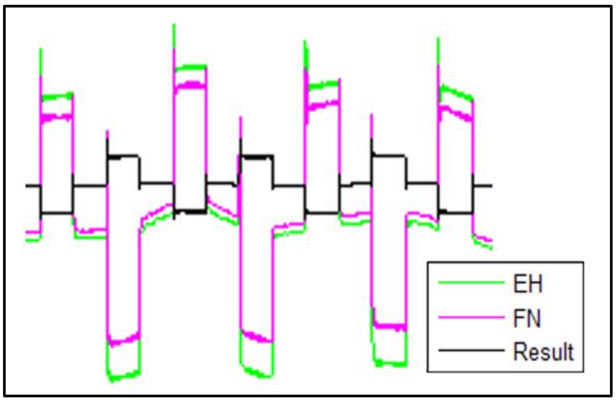

Figure 1: Example of the subtraction of the time series response from two electrode sensors, EH and FN. Sample Rate = 150 sps.

These two receivers measure the earth response relative to a common voltage reference (CVR) wire that extends between the receivers. The acquisition of time-series data is necessary for the effective subtraction of the common mode noise in the CVR wire during the dipole calculation. Stacking or filtering of the individual electrode responses prior to subtraction would alter the character of the noise, and the noise in the CVR wire would not be reduced to the same degree.

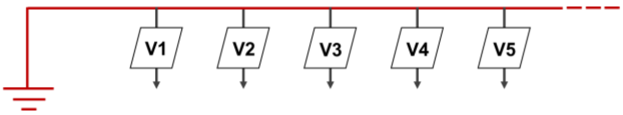

Figure 2: Schematic of a CVR system with five single-channel receivers connected. The CVR wire is grounded in some place close to the survey area.

This CVR concept can be extended to multiple sensors. Rather than measuring dipoles, the DIAS32 system measures each sensor electrode response as poles relative to the CVR wire which extends throughout the survey area, whether it be a few electrodes in a 2D application or hundreds of electrodes in a 3D array. The CVR pole data can then be processed to produce dipoles by simply subtracting the time-series data from any two of the individual pole records.

For a survey in which N sensor electrodes are deployed, the number of different dipoles that can be constructed from the referenced pole data is given as $(N^2-N)/2$. For example, for a small array of 36 sensor electrodes, a total of 630 dipoles can be built for each current injection.

Whereas a conventional acquisition system that measures dipoles records and delivers one dipole for every receiver channel that they deploy, a survey completed using CVR mode effectively measures $(N^2-N)/2$ dipoles for an array in which N receivers are deployed. On a recent DIAS32 survey, approximately 220 receivers were deployed for each current injection, and 1,200 current injections were completed. In this case, up to 24,090 dipoles for each current injection point can be built, so the survey yields a potential total of approximately 29 million dipoles. While each dipole is a unique data point, it is not currently realistic to process and interpret all of these data records. In this case, 1.4 million dipoles were built, and some records were culled to remove the low S/N data.

Several benefits flow naturally from the CVR method. The ability to build dipoles between any two sensor electrodes provides enhanced sensitivity. In the 2D implementation, the S/N of dipoles that are distant from the injection point can have a very low S/N. In this case, the dipole can be removed and replaced with a dipole that spans two or even three electrodes, effectively doubling or tripling the signal, respectively. In the 3D method, some dipoles will have low S/N due to poor coupling with the transmitted current. In this case, the poorly coupled dipole can be removed and replaced with a dipole in the same vicinity that has stronger coupling with the transmitted current (see Figure 3).

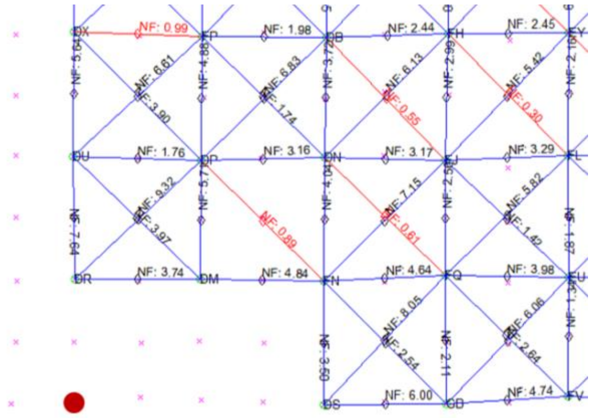

Figure 3: Plan view of part of the dipole building process for a 3D CVR survey. Receivers are located at each of the nodes. Rejected dipoles are red; accepted dipoles are blue, and the current input is the red dot.

A single remote sensor electrode connected to the CVR wire can be established to enable the creation of a pole-pole data set in addition to the pole-dipole data set. This additional data set is derived by subtracting the remote sensor electrode response from each of the electrode responses in the survey area for each current injection event.

Operational Advantages

The single-channel CVR method of DCIP surveying provides several operational advantages. The use of a single CVR wire rather than individual dipole wires effectively minimizes the amount of wire required for any given survey design. We estimate that DA systems with multi-channel receivers require approximately 2-3 times the amount of wire than a CVR survey would require.

In the DIAS32 system, each single-channel receiver is equipped with a GPS receiver that delivers timing control for synchronization of the time series data sets. The GPS also provides an accurate location for each sensor electrode. Where obstacles occur or where access cannot be gained, electrodes can be moved from the planned location and the internal GPS will capture the new location. Where stations are on lakes the GPS will record any movement of the station due to water currents or wind action. An accurate location of each sensor electrode is critical to the successful modelling of 3D survey data, particularly for those dipoles that may be poorly coupled with the primary field.

The DIAS32 system also incorporates a cable-free mesh network node into each receiver. These network nodes can transmit any type of data on demand. Currently, the system harvests real-time data quality metrics, safety information, location data, and system health data. The network facilitates the efficient deployment of the system and real-time verification and control of survey status and data quality. Any operational problems such as a drained battery or an open circuit to the voltage sensor can be identified immediately, located accurately, and remedied promptly.

Safety Aspects

Many of these operational features translate directly into safety enhancements. Lower overall system weight, less wire and greater efficiency in problem solving means that the size of the crew is normally smaller than for a non-CVR system, each crew member has less walking per day, and the load that each crew member carries is lighter. And it follows that fatigue can be managed more effectively.

The DIAS32 system incorporates two new purpose-built safety technologies. The first is a lightning shunt system designed to mitigate the risk of electrocution due to electrical storms. The placement of several lightning shunts through the survey area provides an added measure of protection in the event of an electrical storm. The second technology is a current lock-out system. This system puts lock-out control of the transmitter function into the hands of each crew member that is working near the high voltage current lines. The current lock-out system is integrated with the mesh network system, so does not rely on handheld radios for communication. Both of these safety technologies are designed to be integrated with standard safe operating procedures for electrical surveying. As such, they create an extra layer of protection from these two risks.

Processing and Interpretation

Many of the details of the processing of the data sets that are produced by a CVR survey have already been described. Challenges and opportunities remain. With the extremely high volumes of data that the CVR method yields, there is a challenge in carrying out quality control while significant opportunity lies in the creation of automatic or semi-automatic routines that highlight data that need to be corrected or culled. Several processes can be used to effect quality assessment of these high-volume data sets. Many of the routines and algorithms used in conventional DCIP surveying apply to the processing of 3D CVR data sets, but to be efficient in handling the high data volume, should be automated. Assessment of primary field amplitude and stability, input current waveform quality and stability, and secondary decay quality and stability, can all be automated, and should all be part of the quality control procedure. With full-azimuth 3D surveys, an assessment of the effect of poor coupling between the primary field and each receiver dipole must be completed. The accuracy of the input current, voltage, and most importantly, the positions of all electrodes must be determined in order to properly assess the accuracy of the resultant resistivity and chargeability measurements.

High volumes of inter-related data present an opportunity for the application of machine learning (ML) and artificial intelligence (AI) algorithms.

The high volumes of data generated by 3D CVR surveys are a challenge for available inversion codes. The current practical limit is approximately 1 million data points from 1,000 current injections. An opportunity lies in process of selecting the dipoles to be used in the modelling of the data. This is an optimisation problem which ideally involves both the sensitivity and the resolution of the data set to create a subset that achieves the sensitivity and resolution objectives. Loke (2010), and Kuttai (2016) provide the basis for this approach. In this way, the original high-volume CVR data set becomes a data base from which data subsets are selected for use in the modelling process at various stages in the life of the data set.

Survey Example

A rolling 3D survey was completed in eastern Canada in January, 2019, using the DIAS32 system in CVR mode. The survey area was relatively flat, with frozen lake through the centre of the survey area and forested areas surrounding the lake. The project took approximately 4 weeks to complete from start to finish.

A total of 96 receivers were active for each current injection on a total of 7 lines. Four of the survey lines were occupied by receivers at a 50 m station spacing, and three were occupied at a 100 m spacing. Figure 4 depicts the receiver array for a given line of current injections. Once the line of injections is completed, the line of receivers below the current line is picked up and the array is advanced by one line to establish the same pattern of receivers for the next current injection line. This array is advanced line by line until the entire survey area is covered. A total of approximately 600 current injections were performed. A remote receiver was deployed to acquire pole-pole data in addition to the pole-dipole data.

Figure 4: Rolling 3D survey layout: survey lines are horizontal, red dots are current injection points, green dots are receiver electrodes. The receiver electrode array relative to the current injections is maintained as the current injection progress from line to line to complete the survey

With a total of 26 survey lines, this survey yields just over 2.7 million possible pole-dipole records, and 57,400 pole-pole records. A total of approximately 325,000 data records were extracted, including most of the pole-pole data and a subset of the pole-dipole data set. The final pole-pole data, pole-dipole data and the combined pole-pole and pole-dipole data sets were inverted using the UBC GIF 3D inversion software. Figure 5a shows the chargeability data set in a pseudo-volume format, and Figure 5b shows an image from the pole-dipole inversion model.

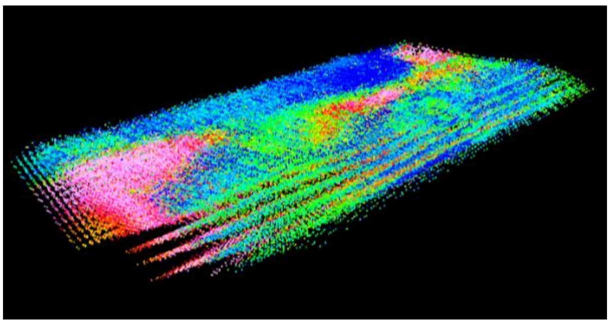

Figure 5a: Pseudo-volume image of the chargeability data set containing approximately 300,000 data points.

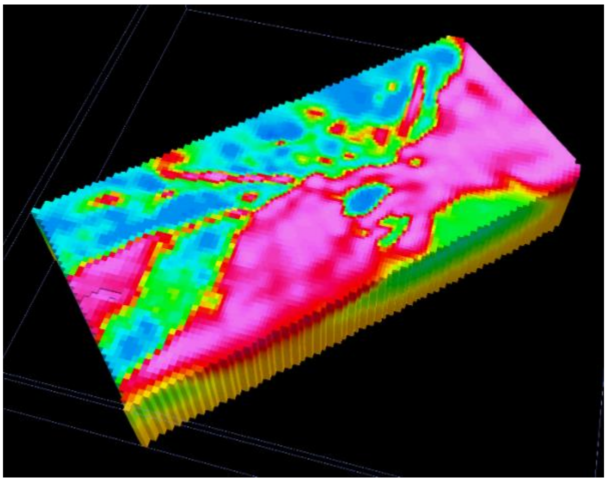

Figure 5b: 3D inversion result based on the pole-dipole data set showing an elevation plan at a depth of approximately 50 m – blue is resistive.

CONCLUSIONS

The fully-distributed DCIP system with CVR comprises a set of single-channel receivers that are deployed through the survey area and connected to a reference wire. This method provides the ability to construct dipoles from all possible pairs of sensor electrodes throughout the survey area.

The benefits of the CVR approach are far-reaching and include data quality, data volume, operational efficiency, and safety. Low noise levels are achieved through the removal of induced noise in the CVR wire and S/N can be effectively managed by the choice of dipole spacing post-survey. In 3D survey mode, the CVR method produces unprecedented data volumes which inform more accurate final interpretations.

The operational advantages of CVR include a lower overall system footprint (less wire and weight), and a cable-free mesh network system that provides time-appropriate information to improve operational visibility and data assurance during acquisition.

This significant enhancement of the DCIP method and the efficiency with which it can be delivered will fuel a move to more full 3D surveys and fully-distributed multi-scale 2D surveys.

ACKNOWLEDGMENTS

Thanks go to Dias Geophysical for allowing the time for the preparation of this paper.

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