The Facility of a Fully-Distributed DCIP System with CVR

J. Rudd[1], G. Chubak[2]
1. Dias Geophysical, Canada, jonathan@diasgeo.com
2. Dias Geophysical, Canada, glenn@diasgeo.com

BIOGRAPHY

Jonathan Rudd is president of Dias Geophysical. He has wide experience in the application of geophysical methods to mineral exploration. Mr. Rudd was active in the airborne EM industry for much of his career, and in the last 5 years has been focused on the development and application of high data volume electrical methods. Mr. Rudd is a Geological Engineer with a specialty in geophysics (Queen's University, Canada).

Glenn Chubak is VP Technology of Dias Geophysical and has led the development of the DIAS32 DCIP system. Prior to his work at Dias, Mr. Chubak carried out research into geophysical instrumentation and the magnetometric induced polarization and resistivity method. Mr. Chubak completed his master's degree in geophysics at the University of Saskatchewan in Canada.

SUMMARY

The electrical resistivity and induced polarization 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. This new method reduces noise levels through the cancellation of noise in the CVR wire. In 3D surveys, the ability to generate a dipole between any two sensor electrodes allows for the generation of high-volume, full-azimuth data sets that inform more accurate inversion modeling.

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

The current capability of several hundred receivers can yield data sets with 10s of millions of data records. Data volumes such as this are not practical for current inversion routines. Thoughtful processing and culling of the data sets to a manageable data volume is critical to a successful final model. But the high volumes of data and its robust nature support highly accurate final models.

Key words: induced polarization, 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

FULLY-DISTRIBUTED DCIP WITH CVR

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 modernization 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. In a conventional survey, 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.

This same dipole measurement could also be 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.

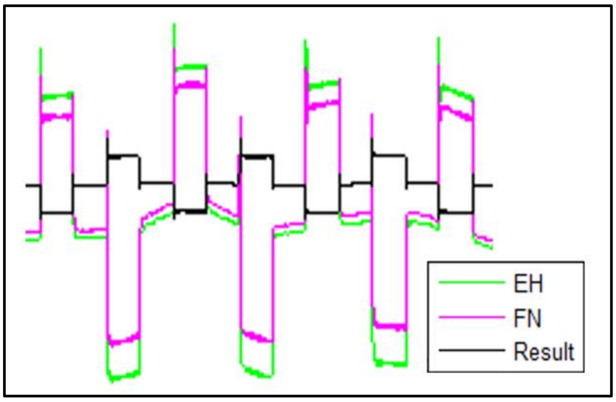

Figure 1: Example of the subtraction of the time series response from two electrode sensors, EH and FN. Sample Rate = 150 sps.

These two receivers measure the earth response relative to a common voltage reference (CVR). This CVR is the 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 of 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.

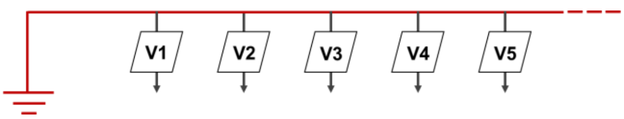

Figure 2: Schematic of a CVR system with five single-channel receivers connected. The CVR wire is grounded in some place close to the survey area.

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 $(N^2\text{-}N)/2$. 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 $(N^2\text{-}N)/2$ 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.

The Benefits of CVR

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 2).

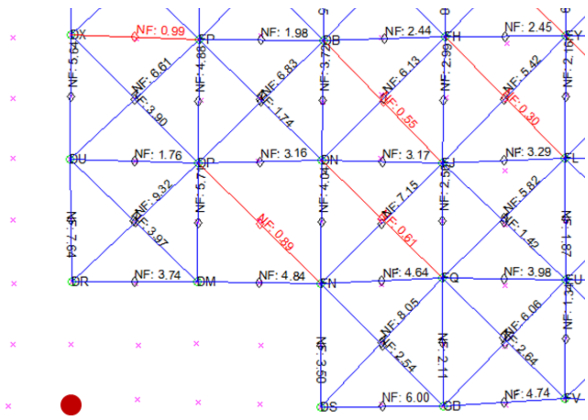

Figure 3: Plan view of the dipole building process for a 3D CVR survey. Receivers are located at each of the nodes. Rejected dipoles are red; accepted dipoles are blue, and the current input is the red dot.

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 dipole data set. This additional data set is derived by adding the remote sensor electrode response to 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 as the DIAS32 CVR system.

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 can be identified immediately, located accurately, and remedied promptly.

Safety Aspects

As we have discussed, the DIAS32 CVR system provides several operational advantages. Many of these 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, 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. We have developed an automated routine that determines which dipoles have too low a S/N based on their coupling with the primary field and the error in the position of the dipole electrodes. This is achieved by converting positional error to resistivity error for the dipole, and then determining if the result achieves the user defined S/N threshold.

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 optimisation process may become an iterative one as the modelling informs the selection of appropriate dipoles to enhance further modelling. In this way, the original CVR data set becomes a data base from which data are selected for inclusion in the modelling process.

SURVEY EXAMPLE

A 3D survey was completed in October, 2015, using the DIAS32 system in CVR mode. A total of 65 receivers were used and approximately 250 current injections were performed. Receivers were deployed in a regular orthogonal grid pattern with a 70 m orthogonal spacing (see Figure 4). A remote receiver was deployed to acquire pole-pole data in addition to the pole-dipole data.

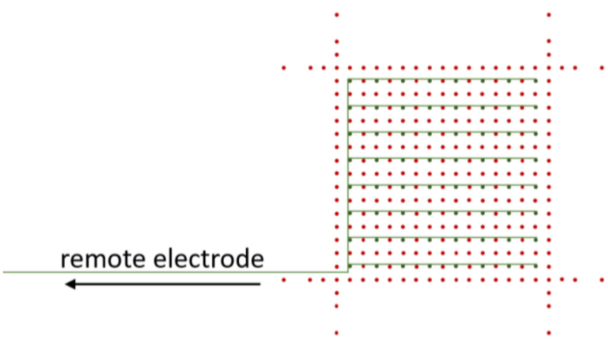

Figure 4: 3D survey layout: red dots are current injection points, green dots are receiver electrodes, green line is the CVR

This survey yields just over 500,000 possible pole-dipole records, and 16,000 pole-pole records. A total of 49,950 data records were extracted, including all of the pole-pole data and a small subset of the pole-dipole data set. These records were reduced to 47,028 records (approximately 6%) through quality control processing. 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 5 shows the result of the pole-dipole inversion modelling.

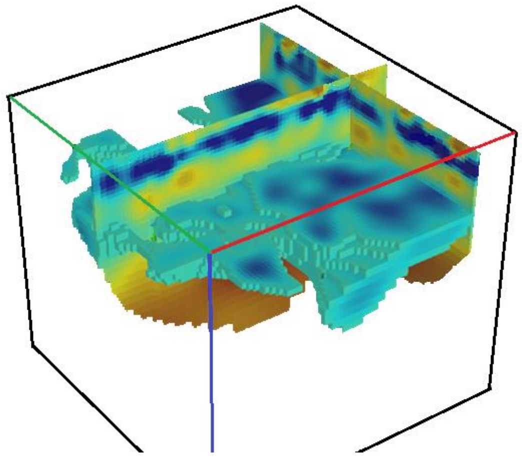

Figure 5: 3D Inversion result based on the pole-dipole data set showing the 20 ohm-m isosurface of the lower resistive layer with two orthogonal cross sections.

CONCLUSIONS

The fully-distributed DCIP system comprises a set of single-channel receivers that are deployed through the survey area. The most efficient deployment of these receivers is through the use of a CVR wire. This method provides the ability to construct dipoles from any two sensor electrodes in 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 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 distributed 2D surveys.

ACKNOWLEDGMENTS

The authors would like to thank Dias Geophysical for supporting the preparation of this paper.

REFERENCES

Eaton, P., Anderson, B., Queen, S., Mackenzie, I., and Wynn, D. (2010) NEWDAS — the Newmont Distributed IP Data Acquisition System. SEG Technical Program Expanded Abstracts 2010: pp. 1768-1772.

Sheard, S.N., Ritchie, T.J., Rowston, P.A., 2002, MIMDAS — A Quantum Change in Surface Electrical Geophysics: 2002 PDAC Conference, Canada