Separation of DC Electrical Method Anomaly By Using Multifractal Modelling

Cao Jing (caojing012@126.com)
Suzhou University

Sun Linhua
Suzhou University

Wu Cancan
Suzhou University

Research Article

Keywords: Direct current method, multifractal C-A, accurate interpretation, experiment

DOI: https://doi.org/10.21203/rs.3.rs-566757/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Separation of DC electrical method Anomaly by Using Multifractal Modelling

cao jing1*, sun linhua1, wu cancan1,2

(1. School of Resources and Civil Engineering, Suzhou University, Suzhou 234000, Anhui, China
2. School of Resources and Geosciences, China University of Mining and Technology, Xuzhou 22116, Jiang Su, China)

Corresponding to: caojing012@126.com

Abstract: A more accurate method of DC processing data to distinguish the anomalous body is important for the prediction and detection of potential risk such as goaf and water inrush. In this paper, we have performed a DC data processing process, which relies on the theory of aggregation-area (C-A). We investigate the apparent resistant log\(\rho_s\) and apparent resistant isograms cumulative area log\(S\) as a function to search the threshold as the boundary value. Comparisons of the conventional data processing method to physical simulation that the C-A identified the higher resistance anomalous body better than the lower resistance because its sensitivity. Scoped the higher resistance area almost identical with the physical model, while the lower approach the nearest boundary. The results are in good agreement with the physical model, validating C-A multifractal theory as an effective way for DC accurate interpretation.

Keywords: Direct current method; multifractal C-A; accurate interpretation; experiment
1 INTRODUCTION

Geophysics is an important tool in geological engineering, especially for solving the issues related to the safety of coal mining, as is can be used for the identification of the anomalies related to the potential threaten (e.g. water and fault). And therefore, a series of geophysical methods/models, including the DC electric method, seismic prospecting, transient electromagnetic method, audiomagnetotellurics method, radio wave tunnels perspective, have been proposed [1-5]. These methods/models have their unique advantages, e.g. DC exploration is very fast and economical, seismic exploration method has a high resolution and transient electromagnetic method is less affected by topographic fluctuation. Their application provides a large number of effective scientific information for identification of the geological anomalies, so as to better guarantee the safety production of coal mines.

Among these methods/models, the Direct Current electric method (DC) is an effective geophysical method to detect the conductivity structure in the shallow part of the earth's surface, and it has long been used for mineral, energy, environment, hydrology and geological structure because of its unique feature of flexible device form [6-8]. However, there are still some problems limited the more extensive and in-depth application of it, especially the raw and qualitative results as it can be provided, rather than quantitative information. For instance, the TEM can provide the information that there is an anomaly in front of the working face, but it is hard to determine how far away and how about the accurate scale of the anomaly. The main reason for this problem is that the geophysical interpretation results based on Kriging interpolation are continuous contour map, and it is hard to determine the mutation value (threshold). If the researcher wants to get the accurate information, more complex calculation or experience must be needed.

The methods long been used in geochemical study might be useful for solving this issue. A series of geochemical studies, for example, the identification of pollution hotspot [10] or, the determination of the metallogenic area [11], have proposed kinds of methods/models, such as the graphical methods (e.g. Quantile or probability plots), the spatial-statistical methods (Moran’s I and spatial cluster analysis) and the multifractal modeling. All of them have a similar feature that their usages are friendly and effective.

In this study, these geochemical methods have been applied tentatively for the explanation of the DC data obtained from an artificial tunnel exploration, and the
results suggested that they can be used for getting the quantitative information about the anomaly.

2 MATERIALS AND METHODS

2.1 Information about the tunnel

The artificial tunnel is located in the southern campus of Suzhou University. A total of 11 survey points and 88 apparent resistivity data points were collected in the study area. The experiment adopts symmetrical quadrupole device and the dot spacing is 2m. The relationship between the line layout and the relative position of the physical simulated object (the simulated tunnel) is shown in Fig. 1. As the relative zero position of survey line, the edge of tunnel is located at the relative position of survey line 3m and 13m respectively. The positions of measurement lines and points in the data collection site are shown in Figure 2.

Figure 1 relative position relationship between surveying line and target.
2.2 DC electric exploration

Electric exploration is a kind of geophysical exploration method that uses the spatial and temporal distribution of electric field or electromagnetic field (natural or artificial) to solve the geological structure or search for useful minerals based on the differences in the electrical properties of various rocks and ores in the earth’s crust.

The apparent resistivity value can be obtained by formula:

$$\rho_s = K \frac{A^U_{MN}}{l}$$  \hspace{1cm} (1)

Where $$K = \frac{2\pi}{AM} \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}$$ is the coefficient of device.

The values of the above parameters can be obtained by instrument measurement. By changing the distance of the supply electrode, the apparent resistivity of the measuring point at different depths can be detected.

2.3 Data analysis

Two kinds of methods have been used in this study: the graphical methods (e.g. electric sounding curve and contour) and the multifractal modeling.

(1) The electric sounding curve (VES)

The electric sounding curve (VES) describes the variation of apparent resistivity with depth at a certain point. In general, the AB/2 relative to depth is taken as the Abscissa,
and the apparent resistivity measured at the point is taken as the ordinate, and the coordinates are Log-log plot\textsuperscript{[18]}.  

(2) The apparent resistivity section chart  

The apparent resistivity section chart reflects the apparent resistivity distribution of the section where the survey line is located. The relative distance of all the survey points is taken as the horizontal coordinate, and the depth of the survey (AB/2) is taken as the vertical coordinate\textsuperscript{[19]}.  

(3) The multifractal modeling  

There are a series of multifractal models have been proposed, e.g. these include the concentration-area (C-A), concentration-distance (C-D) and spectrum-area (S-A) multifractal models [Fractal/multifractal modeling of geochemical data: A review]. In this study, the most popularly used one, the C-A multifractal model has been applied. A detailed information about the model can be found in [Fractal/multifractal modeling of geochemical data: A review]. The process was calculated by the software Geodas (version 10.7).

3 RESULTS AND DISCUSSION  
3.1 Results of traditional analysis  

The apparent resistivity profile is commonly used in electrical data processing, and the shape of the object is deduced by analyzing the equivalent and relative values of the apparent resistivity. Sometimes the position of the anomaly is estimated from the overall variation of the electrical sounding curve from the original data.
The data of 11 measured points are drawn in the coordinate system (fig.2a), the Abscissa is AB/2, the ordinate is apparent resistivity, and the Abscissa and ordinate are double logarithm coordinates. For a clearer analysis of the effect of the target on the detection results, the data are discussed in sections below.

It can be seen from the electrical sounding curve (Fig.2b) that the apparent resistivity of the survey points 1 and 2 changes in accordance with the increase of AB/2, and that the end jump of the survey point 3 begins, it is concluded that the Change Law of Survey Point 4 is related to the existence of underground objects, and survey point 3 is the transitional position with influence.

Figure (Fig.2c) reflects the electrical sounding curve of survey point 4 to 8. The change from survey point 4 to survey point 6 is similar, and the curve of survey point 7 begins to change, which shows that the distribution of underground strata corresponding to this point changes. But it is not easy to distinguish survey point 7 or survey point 8 as the boundary point of stratum change.

Figure (Fig.2d) shows the variation of apparent resistivity with depth at survey point 7 to 11. The subsurface formation information is assumed to be similar.

In the analysis of electric sounding data, it is necessary to combine the data point by point for many times in order to infer the starting and stopping position of abnormal body. If the field work is large and there are more survey points, the work efficiency will be seriously affected. If there are more disturbance factors in the data collection, the variation law of the electric sounding curve will not be easy to be induced and the
interpretation result will be affected.

The apparent resistivity contour map is shown in figure 3.

![Fig.3 apparent resistivity profile](image)

It can be concluded that the shallow layer (about 0-6m) is obviously stratified, and the apparent resistivity is larger than that of the lower layer, especially when there is a high resistivity anomaly (the simulation tunnel) in the middle position (the red area), which location is about 5 meters above the buried depth, within 3-14 meters of the relative coordinates of the survey line, which corresponds roughly to the relative position of the physical simulation tunnel. Since the apparent resistivity contour map is drawn and the apparent resistivity value is the overall reflection of the resistivity value of the surrounding rocks and minerals, therefore, the interpretation of the target body can only qualitatively infer the relatively high and low resistance bodies, while for the boundary of the target body, but they can’t be identified by contour lines.

3.2 Result based on multifractal modeling

Based on the multifractal theory, the isograms of apparent resistivity are drawn with surfer software, and then the different apparent resistivity $\rho_i$ is constructed to
delineate the aggregation-area maps of accumulative area. A scatter plot of apparent resistivity and distribution area (Fig.4) is obtained by least squares fitting.

The slope of the line corresponds to the contour map of the slope area represented by the different data sets. When data points fall on two straight lines, the two groups are interpreted as exception and backgrounds. Through the analysis of fig.4, it can be seen that point A and B is the intersection point of two straight lines (the break point of the area curve), and the break point A and B of the straight line is the boundary value of 23Ω.m and 48Ω.m. The area of the abnormal object delineated by the contour map with 23 and 48 as the threshold is shown in Fig.5. The area C is the higher resistance object, simulated the tunnel, and the area D is the lower resistance, simulated the floor water, which are shown as red, blue, respectively.
3.3 Discussion

The two simulated objects of physical model in Figure 5 show the shape and distribution. The tunnel shows a higher resistance because of air-filled, while the floor water is lower resistance. Comparisons show that the shape of area C the same as the tunnel, the position of the physical model is located between the 3rd and 8th measuring points of the experiment line. The horizontal coordinates of 3 to 13 meters and 7 to 9 meters with respect to the vertical coordinates (the buried depth) of about 2 to 5 and 5 to 7 meters is the higher resistance tunnel, and the lower resistance floor water, respectively. The objects identified by the method of multifractal theory (C-A) is located: at the horizontal coordinates of 3 to 13 meters is regarded as the length of tunnel surface, 5 to 11 meters is the bottom at the depth of 3 meter. The relative height matches the original object, but the burial depth various, shifting up 4 meters. Because of the sensitivity and the influence of the water, it can get the nearest location of the
lower resistance floor water at 6 meters, but can’t correspond to its shape and boundary. The delineation of boundary position plays an important role in the prediction of mine water inrush.

4 Conclusion

By using C-A multifractal method to deal with the study of the separation of abnormal objects from DC electrical data, the following conclusions are obtained:

(1) Using multifractal theory to select the threshold value of object, and then dividing the boundary of Anomaly object, it provides a qualitative explanation for analyzing object anomaly object, and it is also a quantitative exploration.

(2) Constructing multifractal model to extract abnormal information, and reducing the dependence on other information, such as known geological information, drilling verification, etc..

(3) Because there are some errors in the inversion of depth by DC method, the result of lateral detection is more accurate than that of longitudinal detection.

(4) The detection effect of higher resistance is better than the lower, especially the sharp and the boundary.

(5) Although the proposed method is based on the results of the geochemistry, the applicability of the geophysical prospecting method and the accuracy of the interpretation need to be further studied.

Acknowledgement: This work was financially supported by the Natural Science Foundation of Anhui Province (1708085QE125), the Scientific Research Project of Platform, Suzhou University (2017ykf14, 2019ykf01).

References:

[1] YU Youshun, LIU Jintao, WANG Zhu, etl. Application of Direct Current Sounding on detection of collapsing Karst Column in Coal Mine[J]. Resources Environment & Engineering, 2007, 21(6): 736-738.

[2] YIN Guoqiang, ZHAI Peihe, WAN Hao, et. Application of 3D Direct Current Method in Water Prevention and Control in Coal Mine[J]. Coal Technology, 2018, 37(11): 227-229.

[3] LI Bing. Application of DC Law Ahead Detection Technology in Detection of Moisture Fault Structure [J]. Coal Technology, 2015, 34(03): 113-115.

[4] LI Wenxi, ZHAI Peihe, CHEN Jinhao, et. Application of DC Method in Preventing and Controlling Water in Coal Mine[J]. Coal Technology, 2018, 37(7): 211-213.
[5] XU Xingang, YUE Jianhua, WU Jie. The Application of 3D direct current survey to the prospecting of subsurface air-raid shelters [J]. GEOPHYSICAL & GEOCHEMICAL EXPLORATION, 2004, 28(2): 187-188.

[6] JIA Fangyan, ZHANG Fan, ZHENG Guohui, et al. The application of conventional DC electrical method to the evaluation of geological disasters in the Huanghe reservoir Nantun [J]. JILIN GEOLOGY, 2013, 32(4): 106-109.

[7] WANG Yulin. Application of Direct Current sounding on roadbed reconnaissance in the railway bridge junction [J]. China Resources Comprehensive Utilization, 2013, 31(07): 51-53.

[8] LUO Gaoxiong, CHEN Jianguo. The application of direct current electric method in the site selection of cement plants [J]. Chinese journal of engineering geophysics, 2007, 4(4): 391-394.

[9] LIU Xiaofeng. Looking for a direct current prospecting lead-zinc mine effect of empirical research [J]. World nonferrous metals, 2016(15): 192-193.

[10] CHEN Song, LIU Lei, LIU Hui-qing, et al. Application analysis of electrical method in dividing saltwater and freshwater interface in beibu bay [J]. Progress in Geophysics (in Chinese), 2019, 34(4): 1592-1599.

[11] LI Qi-cheng, GUO Lei. Theory and practice on the apparent resistivity method and the apparent ratio parameter method. Progress in Geophysics (in Chinese), 2019, 34(1): 0326-0330.

[12] ZHANG Tianfu, XIE Shuyun, BAO Zhengyu, et al. Fractal and multifractal research on pore system for porous dolomite reservoirs based on high-resolution CT [J]. Geological science and technology information, 2016, 35(06): 55-62.

[13] CHENG Qiuming. Multifractal and geostatistic methods for characterizing local structure and singularity properties of exploration geochemical anomalies [J]. Earth science—journal of china university of geosciences, 2001, 26(2): 161-166.

[14] CHENG Qiuming. Singularity generalized self similarity fractal spectrum (3S) models [J]. Earth science—journal of china university of geosciences, 2006, 31(3): 337-348.

[15] HAN Guohao. Geochemical anomalies identification based on multifractal modeling and mineral prospectivity mapping in Yuhuashan Area of Jiangxi[D]. East china university of technology, 2016.

[16] XIAO Hongyue, LEI Ran, WANG Enying, et al. Extraction of multi-element geochemical synthetic anomalies under multifractal model [J]. Acta mineralogical sinica, 2019, 39(2): 183-191.

[17] TANG Shenghuang. Spatial analysis of Geochemistry anomaly separation [J]. overseas uranium and gold geology, 1998(04): 348-353.

[18] LI Jinming. 2005. Geoelectric field and electrical prospecting [M]. BEI JING: Geology press.

[19] XIAO Hongyue, LEI Ran. 2008. A Course in geoelectricity [M]. BEI JING: Geology press.
Figure 1

Relative position relationship between surveying line and target
Figure 2

distribution of field survey line
Figure 3

Electrical sounding curve of survey point
Figure 4

Apparent resistivity profile
Figure 5

Aggregation area model of Ps
Figure 6

Isograms of apparent resistivity based on fractal inflection points