Application of EH4 Electromagnetic Imaging System in Goaf detection

Jiangtao Xu¹, Zhenwei Yang²,* and Yaohui Zhang¹

¹ Henan College of Industry Information Technology, Henan Jiaozuo, China
² Henan Polytechnic University School of Resource, Henan Jiaozuo, China

*Corresponding author e-mail: yzw@hpu.edu.cn

Abstract. During the site selection process of a proposed wind farm, it was found that there was a coal field nearby and there might be a goaf. In order to avoid the goaf of coal mine and eliminate the hidden safety risks brought by the goaf to the construction, geological exploration was needed. After comprehensive consideration, the author chooses EH4 electromagnetic system to probe the research area. Through the practice of wind farm site selection project, it is proved that the detection results are accurate and the method is reliable, which provides reliable reference and effective Suggestions for the later construction of fan station.

1. Introduction
The proposed construction project of a wind farm is located in a low mountain area, and there are normally producing coal fields within 5 kilometers nearby. The construction of fan station requires that potential hazardous geological bodies such as goaf should be avoided as far as possible within a certain range underground. Considering the characteristics of goaf, such as strong concealed property, poor spatial distribution regularity, and difficulty in predicting roof caving and collapse of goaf, the key problem to be solved in this paper is to select the appropriate detection method to evaluate the potential hazard of geological body and reasonably determine goaf.

2. Introduction of detection methods
Called the EH4 of EH4 continuous conductivity imaging system, jointly developed by EMI and Geometrics company, MT and CSAMT is combined with the double source electromagnetic method of geophysical exploration system. With the help of magneto electromagnetic measurement principle, the system is equipped with two magnetic dipole emission sources in orthogonal directions and emits electromagnetic waves of 500Hz to 100kHz to compensate for the weak signal area of magneto magnetic field and man-made electromagnetic interference, so as to ensure that effective signals can be measured at all frequency bands.

The EH4 observations are the time series of the orthogonal electric \(E_x, E_y\) and magnetic components \(H_x, H_y\). Then, the electromagnetic signals in the time domain are transformed into spectral signals by Fourier transform, and then \(E_x, E_y, H_x, H_y\) and finally, the Kania resistivity is calculated \(\rho = \frac{1}{5f} \left| \frac{E}{H} \right| \).
where \( F \): frequency, \( E \): is the electric field, and \( H \): the magnetic field. The penetration depth \( \delta \) (or skin depth) of electromagnetic waves in terrestrial media is related to frequency. Formula for \( \delta = \frac{503 \sqrt{\frac{E}{f}}}{\rho} \).

The high-frequency data mainly reflect the electrical characteristics of the shallow medium, while the low-frequency data mainly reflect the electrical characteristics of the deep medium. By measuring the electric and magnetic fields in a frequency band, the apparent resistivity and phase of Kania are calculated, and then the geological structure and electrical structure of underground rock strata are determined [1]. In view of the EH4 system's characteristics such as high imaging resolution, light weight of the instrument, relatively fast data observation and display, convenient data interpretation, intuitive image, and the ability to receive electric and magnetic fields in two directions at the same time, we chose this system to detect the research area [2].

3. An example of fan station site selection

3.1. Topographic and geological survey of the exploration area

The exploration area belongs to low mountain landform, with high terrain from north to south and low terrain in the middle. The main mountain ranges run in a near east-west direction. The elevation of the ground is +450 ~ +764m, the highest point +785.10m, the lowest point +370.38m, and the relative elevation difference is 414.72m. Under the effect of internal and external geological stress formed different landscape: watershed is composed of the Cambrian strata in southern level, by the Permian and Triassic action in pingdingshan sandstone in northern mountain sandstone secondary watershed, mountains are basically identical with the strike of the strata, and has the feature of south steep north slow, affected by erosion, gully under present wide narrow "V" word. The valleys in the middle and low-lying areas are mostly shaped like "U".

The surface and shallow strata of the exploration area are dominated by mud-rock mixed slope deposits, among which there are a few exposed bedrock areas and laterite areas. Generally speaking, the slope deposits are dominated by rocks with a small amount of soil in the south, and relatively gentle areas in the north are dominated by laterite rocks. The rocks in the exploration area are mainly pingdingshan sandstone with high hardness. The uneven distribution of surface and shallow strata composition and the greater rock hardness bring great difficulties to the pore forming work. In addition, due to the difference of cementation between rock block and soil quality, the reflection wave excitation and reception are affected in the local slope overburden area. There are only small dorsal and syncline in the exploration area at its periphery and boundary.

3.2. Geophysical characteristics of the exploration area

Through statistical analysis of logging data, the formation electrical parameters in the measured area are shown in Table 1.

| Formation       | Lithology             | Average apparent resistivity Ω·m |
|-----------------|-----------------------|----------------------------------|
| Quaternary      | Loess, clay, sand, etc| Between 20 and 40                |
| Permian         | Siltstone, mudstone   | Between 10 and 40                |
| The carboniferous | Sandstone, limestone  | Between 100 and 40               |
| The ordovician  | Limestone etc         | More than 400                    |

It can be seen from Table 1 that the resistivity of the strata from quaternary to Ordovician increases first, then decreases, and finally increases. Magnetotelluric method is used to distinguish the geological structure and strata and determine the abnormal area by distinguishing the electric difference between strata and abnormal geological bodies.

In addition, the survey area is low and hilly and the terrain is complex, which brings some difficulties to the data collection work. Villages and high-voltage lines are far away from the test area, so the electromagnetic environment in the test area is good, which lays a good foundation for EH4 detection.
3.3. Data acquisition

The ground survey area is centered on a fan station, with 3 EH4 survey lines and a total area of 0.3km². The position of the survey line is shown in Figure 1. The blue line in the figure is the survey line L01, L02 and L03, and the points distributed along the blue line are the EH4 data observation point positions.

Fig. 1 Schematic diagram of line setting

The topography in the survey area is complex, and the terrain fluctuates greatly, especially the steep terrain of some measuring points on Line L01, which limits the layout of the preset measuring points. The deviation is carried out along the vertical direction of the measuring line for a certain distance, but the maximum deviation distance is not more than 100m. A total of 3 EH4 measuring lines are arranged around a fan station. The number of measuring points, line length and point distance are shown in Table 2.

| Line | Number of measuring point | Point distance (m) | Line length (km) |
|------|--------------------------|--------------------|-----------------|
| L01  | 25                       | 30/50/100          | 1.2km           |
| L02  | 17                       | 30/50              | 0.5km           |
| L03  | 21                       | 30                 | 0.7km           |

3.4. Geophysical interpretation

After indoor data processing, the resistivity section of the study area was obtained (FIG. 2-4). On the whole, the three sections showed obvious layered electrical structure characteristics, with high resistivity in the shallow part and gradually decreasing resistivity in the deep part, while the resistivity in the deep part was relatively low [3-4].

The resistivity of L01 line is shown in Figure 2. The resistivity of the shallow part (-100m is shallow) ranges from 300 to 460Ω·m. The buried depth of the high-resistivity stratum is deep in the northwest, shallow in the southeast and trending in the northwest. Deep resistivity is low, about 20 to 100Ω·m; The middle (-500 to -300m) has a resistivity of 150 to 220Ω·m. Along the measuring line from 0 to 200m and vertically upward from 0 to -400m, there is a resistivity distortion band with a resistivity of 150 to 460Ω·m.

As shown in FIG. 3, the resistivity of L02 line is characterized by a longitudinal layered structure and transverse non-uniformity at the shallow part. The overall resistivity of -350m shows low resistance, and along the measuring line 350 to 700m the shallow part (-100 is shallow) has a layered high-resistance body. -350m with a relatively high resistivity of 100 to 260$\Omega\cdot m$; There is an electrical inhomogeneous body along the survey line from 0 to 200m and vertically upward from 350 to 450m. The resistivity varies from 140 to 220$\Omega\cdot m$.

As shown in FIG. 4, the resistivity of L03 line is characterized by alternating changes of high and low resistivity layers. -100m gradually changes from high to low resistivity and the resistivity varies from 180$\Omega\cdot m$ to 460$\Omega\cdot m$. -150m to -500m is a thick layered low resistance body with a resistivity of 20
to 80Ω·m; The resistivity from -500m to -700m is from 20 to 100Ω·m, with 3 high-resistance bodies in the middle and discontinuous distribution.

On the whole, the electrical structure of L01 line is relatively complex, and the resistivity distortion zone and relatively low resistivity zone reflect the distribution of faults within the coverage area of the survey line and the area where goaf is likely to exist. Line L02 and line L03 have obvious electrical stratification, reflecting the electrical characteristics of quaternary, Permian and Carboniferous strata.

3.5. Geological interpretation

The study area is mainly sedimentary strata with mudstone and siltstone lithology. Its resistivity varies from 10 to 100Ω·m, showing low electrical resistance. Combined with geological data, the layered electrical structure of the three sections basically reflects the layered stratigraphic structure characteristics of the study area, indicating that the detection data has considerable reliability. On the whole, the overall resistivity of the three sections is relatively high. Combined with the actual reconnaissance data of the survey area, it can be inferred that the electrical properties of the shallow fractures in the study area are reflected [5].

There are resistivity mutants in line L01 along the survey line from 0 to 200m and vertically near -400 (red elliptic region), which is presumed to be the electrical reflection of gob 1 in the coal mine. In addition, there is an electrical distortion zone from shallow to deep in this area, and it is inferred that there is a concealed fault here, which extends to the deep.

Line L02 has an electrical mutation zone from 0 to 200m and vertically upward from -350 to -450m (red elliptic region) along the survey line, which can be inferred as the electrical reflection of the goaf of Coal mine 2. Along the survey line 150 to 350m and from the shallow part to -350m, there is an electrical change zone (red line area in figure 3), which is inferred to be a fault.

3.6. Planar graph analysis

The apparent resistivity section plan refers to the changes of apparent resistivity along a certain horizontal plane, which is mainly used to study the plane morphology and change characteristics of the apparent resistivity of the target layer at different depths, so as to determine the plane range of the geological abnormal body within the detection range of this layer [6-7].

In order to study the development of geological structure near a fan station, four horizontal section maps of -75m, -175m, -350m and -450m were drawn. For the apparent resistivity variation in the slice diagram, different colors are assigned according to the resistivity difference. Generally, the apparent resistivity of the same rock layer does not change much, but when there are geologic abnormal bodies in the rock layer, the apparent resistivity changes obviously.

FIG. 5 shows the three-dimensional squints superposed by sections at different depths. It can be seen from the figure that the electrical distribution in different depths varies greatly, and the -75m section shows that the shallow part is dominated by high resistivity, which is a reflection of the electrical property of the development of structural fractures on the surface. The section of -175m is dominated by low resistivity, indicating that the strata in this layer are mainly low resistivity strata such as mudstone and siltstone. The low-resistivity and high-resistivity sections in the section of -350m are evenly distributed, indicating poor electrical continuity and well-developed structure of the strata near the zone. The electric structure of the -450m slice is complex, and the high, medium and low resistivity bodies are interleaved, which shows the complexity of the electric properties of the stratum in this layer. Combined with the geological data, it can be inferred that there are more geologic abnormal bodies in this layer, and the goaf is distributed in the low-resistivity area in the figure.
4. Conclusions and Suggestions

4.1. The conclusion
The EH4 exploration design is reasonable, and the field construction is carried out in strict accordance with the requirements. Before the construction, sufficient field tests are carried out to determine the processing parameters suitable for this area. Combined with the geological data, the detailed analysis and interpretation of the result data are carried out, achieving the purpose and task requirements of this exploration work. Through this EH4 detection, the electrical structural characteristics within 500m around a fan station were analyzed and evaluated. The two goaf areas were identified, located in the northwest and southeast of the test area respectively, with a straight-line distance of 300 to 400m from a fan station; In addition, a fault is found near the goaf on the northwest side of Line L01 (west of the fan station), and a fault exists in the middle part of line L02 (east of the fan station). The distribution of the rest gob areas has not been found yet in the survey line coverage area.

4.2. Suggest
Restricted by the volume effect on vertical and horizontal resolution and low resistance shielding effect, it is difficult to determine the exact range of goaf. The scope of the identified goaf is not an absolute concept or absolute, the formation stress balance is relative, and the underground goaf and its water-bearing capacity are also constantly changing. It is suggested to strengthen the observation to ensure the safety of the project construction.

Acknowledgments
This paper was sponsored by Natural Science Foundation of Henan(202300410179), Science and Technology Project of Henan Province(202102310544) and key scientific research projects of Henan Universities (19A1700005).
References

[1] Zhang XJ, Meng YH, Li JB, Zhu DY. Application of EH4 Electromagnetic Imaging System in the Exploration of Gold Mine in Guizhou.[J]. Resources Environment & Engineering, 2017, 31(02): 219-222.

[2] Sun HY, Li RC, Wang SM, Lin TL. EFFECTS OF THE CAGNIARD RESISTIVITY ERRORS BY THE ANTENNA AZIMUTH ERRORS IN THE CSAMT MEASUREMENTS[J]. GEOLOGY AND PROSPECTING, 2004(04): 80-81

[3] Kang M, Kang J, Qin J Z. Identification and application of audio magnetotellurics to the hidden structure: A case study of Laoyachen in Zhengzhou, Henan Province[J]. Geophysical and Geochemical Exploration, 2018, 42(01): 61-67.

[4] Wang Z J. The application of electrical method to tracking underground river of reservoir dam area[J]. Geophysical and Geochemical Exploration, 2019, 43(05): 1157.

[5] Li Z L. Application of Audio Magnetotelluric in the Exploration of a Certain Tunnel [J]. ShangDong Land and Resources, 2019, 35(11): 65-70.

[6] Liu Z. Application of Audio Magnetotelluric Method to Detecting Fault Area[J]. Chinese Journal of Engineering Geophysics, 2019, 16(05): 730-736.

[7] Degn Z J, Yang Y B, Yao C L, Jia Y M. The application of integrated geophysical method to the detection of ground subsidence area[J]. Geophysical and Geochemical Exploration, 2019, 43(02): 441-448.