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Research and Application of Intelligent Ventilation Control System in Coal Mine

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Abstract

With the high-quality development of the coal industry, the intellectualization of coal mines has become an inevitable trend. As an important component of coal mine intellectualization, the intelligent ventilation system is of great significance for improving the efficiency and safety of mine ventilation. This paper takes a certain coal mine as the research object and develops a set of intelligent ventilation control system based on the current situation of its ventilation system. Through the application of high-precision ventilation parameter monitoring, intelligent control of ventilation power, remote control of ventilation facilities, and an intelligent decision-making control platform for ventilation, the intelligent management of mine ventilation is realized. The research results show that the system significantly improves the reliability and automation level of mine ventilation, reduces the number of ventilation personnel, and provides a strong guarantee for the safe production of coal mines.

Keywords

Coal Mine Intellectualization; Intelligent Ventilation System; Ventilation Parameter Monitoring; Ventilation Power Control; Remote Control of Ventilation Facilities; Intelligent Ventilation Decision-Making.

1. Introduction

Coal, as the basic energy source in China's energy system, has long occupied a dominant position in the national energy supply [1]. The development of the coal industry not only relates to national energy security but also has a profound impact on the stable operation of the national economy. In recent years, with the rapid advancement of technology, intellectualization technology has gradually penetrated into various industrial fields, and the coal industry has also entered a critical period of high-quality development. The construction of intelligent coal mines has become an inevitable trend for the transformation and upgrading of the coal industry and an inevitable choice for achieving sustainable development [2-4]. As an important part of coal mine intellectualization, the intelligent ventilation system is becoming increasingly prominent in its importance [5-7]. Mine ventilation is the foundation of safe production in coal mines. A good ventilation system can effectively eliminate harmful gases and dust underground, regulate climatic conditions, and create a safe and comfortable working environment for miners [8]. In traditional coal mine production, the operation of the ventilation system mainly relies on manual operation and empirical judgment, resulting in problems such as low ventilation efficiency and poor safety. The intelligent ventilation system introduces advanced sensor technology, automation control technology, and information technology to achieve real-time monitoring, intelligent regulation, and optimized management of the mine

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ventilation system, thereby improving ventilation efficiency, reducing energy consumption, and minimizing the occurrence of safety accidents.

Yannan Coal Mine, affiliated to Inner Mongolia Dayan Mining Group Co., Ltd., is a coal mine with important production status. With a designed production capacity of 3 million tons per year and a service life of 77.5 years, it plays a key role in the group's production and operation. In recent years, Yannan Coal Mine has actively responded to the call for the construction of intelligent coal mines in the country and vigorously carried out automation construction work, among which the automation transformation of ventilation facilities and equipment is an important part. However, despite making certain progress, there is still a huge gap from meeting the group's requirements for intelligent ventilation. Currently, the ventilation system of Yannan Coal Mine has many problems, such as low precision of ventilation parameter measurement equipment, low automation level of air doors, air windows, and local ventilators, a large demand for air measurement personnel, and a lack of a ventilation management and decision-making platform. These problems not only affect the efficiency and safety of mine ventilation but also increase production costs and management difficulties. Therefore, conducting research and application on the intelligent ventilation control system of Yannan Coal Mine is of great practical significance. By developing a set of intelligent ventilation control systems suitable for the actual situation of Yannan Coal Mine, intelligent management of the mine ventilation system can be achieved, improving ventilation efficiency and safety, reducing the number of ventilation personnel, lowering production costs, and providing a strong guarantee for the safe production of coal mines. At the same time, the research results can also provide references and lessons for the intellectualization construction of other similar coal mines, promoting the improvement of the intellectualization level of the entire coal industry.

2. Current Status and Existing Shortcomings

2.1. Current Status of the Ventilation System

Yannan Coal Mine adopts a vertical shaft development method, with a double-wing retreat mining approach and a total caving method for roof management. The mine ventilation method is extraction-based, and the ventilation layout is zonal. The North Second Air Shaft and the West Three Inclined Shaft are each equipped with two main ventilation fans, one in operation and one on standby, to ensure the reliability of mine ventilation.

In terms of ventilation facilities, a certain number of air doors, air windows, and other ventilation structures are arranged within the mine to regulate the direction and volume of airflow. However, the automation level of these ventilation facilities is relatively low. Most air doors require manual operation, and the adjustment of air windows mainly relies on manual pushing and pulling of the insert plate, making remote automatic control impossible. Regarding ventilation power, although the main ventilation fans possess certain monitoring capabilities, they lack intelligent control means and cannot automatically adjust according to the actual air demand of the mine. Local ventilation fans are mostly controlled manually on-site, with no capability for remote start-stop or frequency conversion adjustment, resulting in low ventilation efficiency and high energy consumption.

2.2. Existing Problems

(1) Low precision of ventilation parameter measurement equipment

Currently, the ventilation parameter measurement equipment used in Yannan Coal Mine is mainly traditional mechanical anemometers, which are inconvenient to carry, complex to operate, and whose measurement accuracy is significantly influenced by human factors. Meanwhile, the precision of online monitoring sensors is also low, failing to meet the requirements of intelligent ventilation systems for precise monitoring of ventilation

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parameters. In terms of usage and management, there is a lack of scientific technical methods, leading to inaccurate measurement results of ventilation parameters that cannot truly reflect the mine's ventilation conditions, thus posing difficulties for ventilation technical decision-making.

(2) Low automation level of air doors, air windows, and local ventilation fans

Air doors, as important facilities in the mine ventilation system, have their automation level directly affecting the operational efficiency and safety of the ventilation system. However, the automatic air doors in Yannan Coal Mine do not possess ground remote control capabilities. When the direction of airflow needs to be adjusted, personnel must be sent to the site for operation, which is not only inefficient but also poses certain safety hazards. The adjustment of air windows is done manually by pushing and pulling the insert plate, with low adjustment accuracy and inability to precisely adjust according to the mine's actual air demand. Local ventilation fans are mostly controlled manually on-site, with no capability for remote start-stop or frequency conversion adjustment, resulting in the inability to automatically adjust the ventilation volume in heading faces according to parameters such as gas concentration, easily leading to safety hazards such as gas accumulation.

(3) High demand for air measurement personnel

To timely grasp the underground ventilation conditions, Yannan Coal Mine needs to arrange a large number of air measurement personnel to go underground daily for actual measurements and then report the results to surface management personnel. This method not only consumes a significant amount of manpower and time but also makes it difficult to ensure the accuracy and timeliness of measurement results. Meanwhile, due to the frequent need for air measurement personnel to go underground, their work risks are increased. Additionally, the lack of remote automatic air measurement devices makes it impossible to achieve real-time monitoring and automatic uploading of ventilation parameters, preventing ventilation management personnel from timely understanding the underground ventilation conditions and making timely decisions.

(4) Lack of a specialized ventilation management and decision-making platform

Currently, Yannan Coal Mine does not have a specialized ventilation management and decision-making platform. Ventilation management and decision-making mainly rely on manual work and experience. Ventilation management personnel need to manually sort and analyze a large amount of ventilation data, draw ventilation stereograms and ventilation network diagrams, which is time-consuming and prone to errors. Meanwhile, due to the lack of a scientific decision support system, ventilation management and decision-making often carry a certain degree of subjectivity and blindness, unable to optimize adjustments according to the mine's actual conditions, resulting in low operational efficiency of the ventilation system and numerous safety hazards.

3. Overall Plan and Research on Key Technologies

3.1. Overall Research Plan

Based on the guidelines for intelligent coal mine construction and in response to the intelligent ventilation needs of Yannan Coal Mine, this paper outlines a clear research plan and objectives. Firstly, a high-precision ventilation parameter monitoring system will be constructed to accurately monitor air volume, resistance, and environmental parameters, providing reliable data support for ventilation management and decision-making. Secondly, an intelligent control hardware and software system for local ventilation fans will be established to achieve functions such as status monitoring, online early warning, and frequency conversion regulation, enhancing the safety and efficiency of ventilation in heading faces. Thirdly, an automatic control

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hardware and software system for air doors and windows will be developed to enable local automatic control and surface remote control, improving the automation level of ventilation facilities. Finally, a ventilation decision-making and control software system will be developed to achieve functions such as 3D modeling of the ventilation system, network monitoring and calculation, system fault diagnosis, and optimized on-demand air supply regulation, elevating the intelligence level of ventilation management. The main research includes the following aspects:

(1) Monitoring and sensing. Automatic air measurement devices will be installed at air measurement stations to achieve unmanned air measurement, improving measurement efficiency and accuracy. Sensors for absolute atmospheric pressure, pressure difference, temperature, and humidity will be set up in main intake and return airways to enable online monitoring of ventilation resistance, allowing for timely grasp of changes in mine ventilation conditions.

(2) Ventilation power. The main ventilation fans will be upgraded to realize functions such as online monitoring, fault analysis, diagnosis, and early warning, ensuring the safe and stable operation of the main ventilation fans. Additionally, they will be equipped with frequency conversion remote automatic control capabilities to automatically adjust the operating frequency of the main ventilation fans according to the actual air demand of the mine, reducing energy consumption. Local ventilation fans will undergo intelligent transformation to achieve online monitoring, safety analysis, and early warning, as well as remote start-stop and frequency conversion control functions, enabling intelligent management of ventilation in heading faces.

(3) Ventilation facilities. The main air doors will be upgraded to possess local automatic control and remote centralized control functions, improving the control precision and response speed of the air doors. The air windows will be modified to enable quantitative remote centralized control of the opening area, allowing for precise adjustment of the air window opening area according to the actual air demand of the mine.

(4) Software platform. A ventilation decision-making and control software system will be developed with ventilation information management functions, enabling automatic generation of ventilation reports and automatic drawing of ventilation stereograms and ventilation network diagrams, improving the efficiency of ventilation management. Additionally, it will have functions such as online fault intelligent diagnosis and auxiliary rapid calculation of air demand at ventilation points, providing scientific basis for ventilation management and decision-making.

3.2. Research on Key Technologies

3.2.1. Research on Ventilation Parameter Monitoring Technology

(1) Research on online monitoring technology of ventilation resistance

A resistance monitoring method for key paths in mine ventilation has been developed, which calculates the mine safety monitoring path through a key path determination algorithm. Multi-parameter sensors, including absolute pressure, temperature, and humidity sensors, as well as wind speed sensors, are deployed in the key path airways to collect ventilation parameters in real-time. The mine resistance is calculated using the collected data, and historical monitoring parameters are saved. By filtering noise from the historical data and fitting a trend curve in a two-dimensional coordinate system, subsequent ventilation resistance can be predicted, providing technical support for real-time monitoring of changes in mine resistance caused by geological disasters.

(2) Research on air volume monitoring technology at key air measurement stations

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An ultrasonic through-beam automatic air measurement device is adopted, which measures wind speed using the time difference of ultrasonic propagation in the air. The device mainly consists of a display host and two ultrasonic probes, suitable for monitoring airflow velocity in wide airways. The host collects wind speed signals through the two ultrasonic probes, processes and analyzes the data to obtain specific wind speeds, and transmits them directly to the surface via RS485 signals or through other communication sub-stations, achieving automatic measurement of air volume.

3.2.2. Research on Intelligent Control Technology of Ventilation Power

(1) Research on intelligent control technology of main ventilation fans

Utilizing the existing main ventilation fan control system of Yannan Coal Mine, a data interface between the ventilation intelligent decision-making and control system and the existing main ventilation fan monitoring and control system will be developed to achieve online monitoring, fault diagnosis, frequency conversion speed regulation, and remote centralized control of the main ventilation fans. By establishing a characteristic curve library for the operating conditions of the main ventilation fans at different frequencies and a model for finding operating curves based on the air demand of the ventilation network, the autonomous regulation of the main fan's air volume can be achieved, improving the operational efficiency and stability of the ventilation system.

(2) Research on intelligent control technology of local ventilation fans

An intelligent local ventilation system has been developed, mainly comprising explosion-proof forced axial flow local ventilation fans for coal mines, frequency converters, intelligent control devices, air distributors, brackets, air duct air volume sensors, gas sensors, and other units. The system automatically determines the amount of air supply based on real-time parameters collected by underground sensors, avoiding the phenomenon of "one-size-fits-all" air supply in existing local ventilation fans, achieving on-demand air supply for local mine ventilation, and improving the safety and energy-saving effects of ventilation.

3.2.3. Research on Remote Control Technology of Ventilation Facilities

(1) Research on intelligent control technology of air doors

Multiple sets of intelligent control systems for air doors have been upgraded underground at Yannan Coal Mine, achieving remote automatic control of the air doors. The intelligent control system for air doors possesses real-time monitoring functions such as switch status monitoring, infrared vehicle and personnel monitoring, and audible and visual alarms. It can achieve automatic control through pneumatic drive. The system also has functions such as automatic reset, double locking, and power-off opening to ensure the normal operation of the underground ventilation system and improve the safety and reliability of the ventilation system.

(2) Research on intelligent control technology of air windows

A high-torque intrinsically safe electrically driven air window suitable for return airways has been developed to solve the problems of currently available automatic air windows, such as complex structures, easily rusted key components, and difficulty in precise control. The air window possesses local control and remote automatic control functions. The regulation of the air window control adopts pneumatic control and has a remote air volume regulation function. Through high-precision wind speed sensors, the air volume passing through the air window is monitored, and the angle of the louvers is automatically controlled remotely according to the air distribution needs until the monitored air volume passing through the air window matches the set air volume, achieving precise control of the air window.

3.2.4. Development of Ventilation Intelligent Decision-Making and Control System

A ventilation intelligent decision-making and control system has been developed, integrating ventilation parameter monitoring, ventilation regulation decision-making, ventilation power

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monitoring and control, and ventilation facility monitoring and control into a unified system to comprehensively manage and control the reasonable operation of the mine ventilation system. The main functions of the system include dynamic calculation of the ventilation network and air demand calculation, fault diagnosis and predictive early warning of the ventilation system, automatic generation and simulation of escape routes, 3D dynamic visualization of underground ventilation status, auxiliary decision-making for air control schemes, and remote regulation and control of ventilation facilities and equipment. Through this system, ventilation management personnel can grasp the underground ventilation situation in real-time, adjust ventilation strategies promptly, and ensure the stable operation of the mine ventilation system.

4. Effect Analysis

4.1. Application Effect of Precise Perception Technology for Ventilation Parameters

Key ventilation routes were selected in the North 2 Mining District and West 3 Mining District of Yannan Coal Mine. Absolute pressure, temperature, and humidity sensors, as well as wind speed sensors, were deployed at various nodes to enable online monitoring of ventilation resistance. Additionally, ultrasonic through-beam automatic air measurement devices were installed at five main air measurement stations underground to achieve automatic measurement of air volume at these stations. The monitoring results indicate that the system significantly improves the accuracy and real-time performance of ventilation parameter monitoring. The monitoring error for ventilation resistance is less than 5%, and the accuracy of air volume measurement reaches a high level, providing high-quality real-time monitoring data to support ventilation technology decision-making. Ventilation management personnel can adjust the ventilation system in a timely manner based on real-time monitoring data to ensure that the mine's ventilation conditions meet safety production requirements.

4.2. Application Effect of Intelligent Control Technology for Ventilation Power

Utilizing the existing main ventilation fan control system of Yannan Coal Mine, a data interface was developed between the ventilation intelligent decision-making and control system and the existing main ventilation fan monitoring and control system to achieve online monitoring, fault diagnosis, frequency conversion speed regulation, and remote centralized control of the main ventilation fans. During the application process, the operational stability of the main ventilation fans was significantly improved, and the failure rate was markedly reduced. Meanwhile, through the frequency conversion speed regulation function, the operating frequency of the main ventilation fans was automatically adjusted according to the actual air demand of the mine, reducing energy consumption. The developed intelligent local ventilation system has been successfully applied in heading faces, achieving intelligent management of ventilation in heading faces. The system can automatically adjust the ventilation volume based on parameters such as gas concentration, effectively avoiding safety hazards such as gas accumulation and improving the safety production level of heading faces.

4.3. Application Effect of Remote Control Technology for Ventilation Facilities

Multiple sets of intelligent control systems for air doors and windows have been upgraded underground at Yannan Coal Mine, achieving remote automatic control of air doors and windows. The application results indicate that the system significantly improves the control precision and response speed of ventilation facilities. The opening and closing times of air doors are significantly shortened, enabling rapid response to the adjustment needs of the ventilation system. The opening area of air windows can be precisely adjusted according to air distribution needs, improving the regulation capability of the ventilation system. Especially in disaster emergency situations, the remote automatic control of air doors and windows can quickly

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adjust the ventilation system to ensure the safe evacuation of personnel and reduce disaster losses.

4.4. Application Effect of Ventilation Intelligent Decision-Making and Control Platform

The developed ventilation intelligent decision-making and control system has been successfully applied at Yannan Coal Mine. The system achieves functions such as dynamic calculation of the ventilation network and air demand calculation, fault diagnosis and predictive early warning of the ventilation system, automatic generation and simulation of escape routes, 3D dynamic visualization of underground ventilation status, etc. Ventilation management personnel can grasp the underground ventilation situation in real-time through the system platform, including parameters such as air volume, wind speed, and gas concentration at various air-using locations. The system can automatically diagnose ventilation system faults based on monitoring data and issue early warning information to remind management personnel to take timely measures. The automatic generation and simulation functions of escape routes provide a scientific basis for disaster emergency rescue, improving the efficiency of emergency rescue. The 3D dynamic visualization function of underground ventilation status enables ventilation management personnel to intuitively understand the operation of the ventilation system, facilitating ventilation management and decision-making.

5. Conclusion

This paper focuses on technical breakthroughs in ventilation parameter monitoring technology, intelligent control technology for ventilation power, remote control technology for ventilation facilities, and the ventilation intelligent decision-making and control system. A set of intelligent ventilation control systems for coal mines has been formed and successfully applied at Yannan Coal Mine, significantly improving the efficiency and safety of mine ventilation, reducing the number of ventilation personnel, and lowering production costs. Through the construction of an intelligent ventilation system, Yannan Coal Mine has achieved precise monitoring of ventilation parameters, intelligent control of ventilation power, remote control of ventilation facilities, and intelligent management of ventilation decision-making, providing strong support for safe production in coal mines. Meanwhile, the research results can also serve as a reference and inspiration for the intelligent construction of other similar coal mines, promoting the improvement of intelligence levels across the entire coal industry.

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