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Research and Application of Intelligent Ventilation Control Systems in Coal Mines

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Abstract

The intelligent transformation of coal mines is an inevitable path for the development and transition of the coal industry. As one of the first batch of national intelligent demonstration coal mines, Yannan Coal Mine has undergone an intelligent upgrade and transformation of its ventilation system. This paper introduces the research background, system composition, key technologies, and implementation effects of the intelligent ventilation control system at Yannan Coal Mine. Through intelligent sensing, intelligent control, and intelligent decision-making, the system achieves intelligent regulation of the mine ventilation system, enhancing its stability and safety, and providing significant support for reducing personnel, improving safety, and increasing efficiency in coal mines.

Keywords

Coal mine; Ventilation system; Intelligent; Regulation; Safety.

1. Introduction

As a pillar industry of China's energy sector, the coal industry is advancing towards a stage of high-quality development. With coal mining entering a new era of safety and intelligence, the deep integration of intelligent technologies with the coal industry has driven revolutionary changes in coal mining production methods [1-3]. In recent years, under the dual impetus of national policy guidance and market demand, significant achievements have been made in the intelligent construction of coal mines [4-7]. The level of intelligent mining technology and equipment has significantly improved, with breakthroughs in intelligent fully mechanized mining technology and equipment for large and extra-large mining heights, and the gradual maturation of intelligent mining technology for thin coal seams. Positive progress has also been made in the research and application of intelligent excavation and transportation technologies and equipment. Breakthroughs have been achieved in the development and application of coal mine robots, with various types of robots for underground inspection, detection, and rescue being gradually promoted and applied, effectively replacing humans in dangerous and heavy work, thereby enhancing the safety assurance capabilities of coal mines. Additionally, the continuous improvement of coal mine information infrastructure, with the application of new-generation communication technologies such as 5G, F5G, and WiFi6 in coal mine underground, provides high-speed and reliable information transmission channels for the intelligent construction of coal mines. Meanwhile, the intelligent standard system for coal mines is gradually being established, with a series of standards and specifications for intelligent coal mine construction issued at the national level, providing technical guidance and basis for the intelligent construction of coal mines [8-11].

The ventilation system is an important component of coal mine safety production, and its stability and reliability are directly related to the safe production of the mine [12-14].

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Traditional ventilation systems have issues such as low accuracy in air volume measurement and low efficiency in manual regulation, making it difficult to meet the needs of modern coal mine safety production. Specifically, traditional air volume measurement methods mainly rely on manual measurements, which have problems such as large measurement errors and untimely data updates; traditional ventilation systems mainly rely on manual adjustments of air doors and windows, which have problems such as lagging adjustments and low precision; moreover, traditional ventilation systems lack real-time monitoring and early warning capabilities for key parameters such as gas concentration and carbon monoxide concentration, making it difficult to effectively prevent and control the occurrence of ventilation accidents.

To meet the development needs of coal mine intelligence and improve the level of coal mine safety production, the intelligent upgrade of the ventilation system is imperative [15-16]. By constructing an intelligent sensing system, building an intelligent control platform, developing intelligent regulation equipment, and establishing an intelligent early warning mechanism, comprehensive perception, intelligent analysis, and automatic control of the ventilation system can be achieved, improving the stability and reliability of the ventilation system, effectively preventing and controlling the occurrence of ventilation accidents, and ensuring the safety of miners' lives and the safe production of the mine. Therefore, Yannan Coal Mine actively responds to the national call, combines its own development needs, and carries out research and application of intelligent ventilation control systems, which is of great significance for improving the stability and safety of coal mine ventilation systems.

2. Project Overview

Yannan Coal Mine has a recoverable reserve of 232.608 million tons, and the coal type is lignite. The mine adopts a vertical shaft development method, with a double-wing retreating mining method. The current production level elevation is +350m, and the first mining area is the North II mining area. The layout of the mining area roadways is a combined grouping layout of coal seams. Currently, the resources in the North II mining area are nearing depletion, and full transition to the West III mining area will occur in 2 years. The mine ventilation system uses an exhaust ventilation method with a zonal ventilation approach, with air intake through the main shaft, auxiliary shaft, and West II ventilation shaft, and air return through the North II ventilation shaft and West III inclined shaft. The North II ventilation shaft is equipped with two BD-II-8-№23 explosion-proof counter-rotating axial flow main fans, and the West III mining area is equipped with two FBCDZN№23 explosion-proof counter-rotating axial flow main fans, both configured with one in use and one on standby. The actual air intake volume of the mine is 5652 m^3/min, with an equivalent orifice of 2.47 m^2. The gas level identification results in August 2021 showed that the absolute gas emission rate is 4.32 m^3/min, and the relative gas emission rate is 0.94 m^3/t, classifying it as a low-gas mine. The mining face uses total air pressure ventilation, while the excavation face uses forced ventilation with local fans. The length of the mining face is generally 1200~1400m, usually supplied by a set of fans (2 units, one in use and one on standby). The mine is equipped with comprehensive systems for transportation, ventilation, power supply, gas drainage, dust suppression, fire prevention and extinguishing, monitoring and control, personnel positioning, communication, compressed air self-rescue, water supply and drainage rescue, and emergency refuge.

Although Yannan Coal Mine has achieved certain results in intelligent construction, such as realizing on-site automatic control of underground ventilation doors and remote monitoring of the status of main ventilation fans, there is still a significant gap from the requirements of intelligent ventilation. The specific issues are as follows:

(1) Ventilation parameter measurement equipment. The mine's current wind speed measurement equipment includes traditional mechanical anemometers and online monitoring

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sensors. Mechanical anemometers have issues such as inconvenience in carrying, complex operation, and the need for manual conversion, which cannot meet the requirements of intelligent ventilation for rapid and accurate parameter measurement; although online monitoring sensors can achieve real-time monitoring, their accuracy is low, and there is a lack of scientific technical methods in validity identification, optimal installation location, and coefficient calibration.

(2) Ventilation door control. The existing automatic ventilation doors do not have ground remote control functions, and their disaster emergency control capabilities are insufficient, unable to meet the needs of intelligent mines for remote regulation of ventilation facilities.

(3) Ventilation window adjustment. The mine mainly uses manually operated sliding plate ventilation windows, which lack automatic adjustment capabilities, cannot achieve precise regulation of air volume, and are difficult to meet the real-time requirements of intelligent ventilation.

(4) Ventilation fans. Although the main ventilation fans have frequency conversion adjustment capabilities, they lack remote automatic adjustment functions. Operations such as fan switching and reverse airflow still rely on manual operation, and intelligent control cannot be achieved. The existing mine explosion-proof forced axial flow local ventilation fans are mostly locally manually controlled, lacking remote monitoring and automatic frequency conversion adjustment functions, and have significant limitations in gas emission and dust prevention at the excavation face opening.

(5) Ventilation management and decision-making platform. The mine lacks a dedicated ventilation management and decision-making platform, and ventilation management and decision-making mainly rely on manual work and experience, making it difficult to adapt to the requirements of high-standard management, and cannot achieve intelligent analysis and optimization of the ventilation system.

3. Key Technology Research

The technical research focuses on precise sensing technology for ventilation parameters, intelligent control technology for ventilation power, remote control technology for ventilation facilities, and an intelligent decision-making and control platform for ventilation.

(1) Precise Sensing Technology for Ventilation Parameters

In the North II and West III mining areas of Yannan Coal Mine, a key ventilation route is selected for each area. Absolute pressure, temperature, and humidity sensors are installed at each node, with absolute pressure and temperature-humidity sensors placed at roadway intersections, and wind speed sensors installed 10 meters downstream of the intersections. Real-time monitoring of air pressure, temperature, and humidity at the start and end points of each roadway on the key ventilation routes is conducted. The air density at each node is calculated, and the resistance of each roadway segment is monitored. The total ventilation resistance of the mine is obtained by summing the ventilation resistance of all roadways on the key ventilation routes, enabling online monitoring of ventilation resistance. Real-time monitoring of natural ventilation pressure fluctuations is combined with real-time data on roadway ventilation resistance and air volume to dynamically calculate changes in roadway air resistance. This achieves online monitoring of roadway air volume and resistance.

(2) Intelligent Control Technology for Ventilation Power

Based on the existing main ventilation fan control system at Yannan Coal Mine, a data interface between the intelligent ventilation decision-making and control system and the existing main ventilation fan monitoring and control system is developed. This interface is directly integrated into the intelligent ventilation system platform, enabling online monitoring, fault diagnosis,

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frequency conversion speed regulation, and remote centralized control of the main ventilation fans. By monitoring parameters such as air volume, wind speed, shaft temperature, vibration, frequency, and voltage of the main ventilation fans, data analysis methods are used to deeply explore the operating state characteristics of the main ventilation fans, achieving parameter monitoring, health analysis, fault diagnosis, and predictive early warning for future operating states.

Additionally, the intelligent local ventilation system mainly consists of explosion-proof forced axial flow local ventilation fans, frequency converters, intelligent control devices, air dividers, brackets, air duct air volume sensors, and gas sensors. Its primary function is to automatically determine the required air supply volume based on real-time parameters collected by underground sensors, avoiding the "uniform air supply" phenomenon of existing local ventilation fans and solving the problem of on-demand air supply for local mine ventilation. From the perspective of safety and energy efficiency, the system uses a control system composed of PLC and frequency converters to regulate fan speed in real time, achieving "real-time early warning, human-machine dual control, on-demand air supply, and disaster prevention and mitigation." This ensures efficient and safe local ventilation and automatic gas emission, reducing gas accidents and saving energy.

(3) Remote Control Technology for Ventilation Facilities

The intelligent control system for ventilation doors is equipped with real-time monitoring functions such as door status monitoring, infrared human-vehicle detection, and audible-visual alarms. It can achieve automatic control through pneumatic drive. Remote automatic control ventilation doors are installed at four locations in Yannan Coal Mine: the +267m yard, +236m yard, +213m yard, and +600m return air crosscut.

Remote intelligent automatic adjustment ventilation windows enable remote intelligent adjustment. By remotely controlling micro-adjustment actuators, the airflow area of the ventilation windows is adjusted to regulate air volume, achieving timely and rapid remote adjustment. Automatic ventilation window control systems are installed at 15 locations in Yannan Coal Mine, including the machine-return connecting roadway, machine-track #2 connecting roadway, +267m yard, and 408 lower return air connecting roadway.

(4) Intelligent Decision-Making and Control Platform for Ventilation

The intelligent decision-making and control system for ventilation integrates ventilation parameter monitoring, ventilation regulation decision-making, ventilation power monitoring and control, and ventilation facility monitoring and control into a unified platform, comprehensively managing the rational operation of the mine ventilation system. This platform integrates multiple intelligent functions for mine ventilation management, achieving a comprehensive upgrade of the ventilation system. By integrating mine monitoring data, a dynamic network calculation module for intelligent ventilation is established, enabling real-time monitoring of mine wind speed and resistance, dynamic calculations, and data analysis with support for report export. Additionally, the platform can diagnose the required air volume for key ventilation areas in real time, monitor the air supply-demand status, and develop regulation plans during ventilation anomalies to ensure stable operation of the ventilation system.

Furthermore, the platform features fault diagnosis and predictive early warning functions, including self-diagnosis of ventilation network faults, real-time alarms, dynamic prediction of monitoring points, and three-level early warnings, as well as disaster simulation and escape route calculation, providing strong support for mine safety. In terms of ventilation diagram editing, the platform supports rapid construction of network models, automatic generation of topological structures, and integrated 2D/3D visualization of ventilation status, improving work efficiency. The platform also establishes a ventilation resistance parameter database,

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supporting real-time editing and export, and performs air distribution calculations to ensure algorithm convergence and fault tolerance. Through cross-platform graphical applications, the platform avoids redundant graphic drawing, reducing maintenance costs. Additionally, the platform supports three-level predictive early warnings, dynamically displaying ventilation parameters through a ventilation status map, achieving status rendering and monitoring alarms. Moreover, the platform establishes a key ventilation path resistance monitoring module, calculating the total mine resistance and resistance gradient map, and performing sensitivity and reliability calculations for network branches, enabling focused monitoring. The platform provides remote centralized control modules for local ventilation fans, main ventilation fans, and automatic ventilation doors and windows, supporting one-click operations, frequency conversion speed regulation, and real-time video monitoring, enhancing the convenience and safety of ventilation management. Finally, the platform establishes a unified data reading standard program, integrating data from multiple subsystems to achieve data sharing and comprehensive analysis, providing a comprehensive and intelligent solution for mine ventilation management.

4. Conclusion

This paper conducts an upgrade study on the ventilation control system of Yannan Coal Mine, focusing on precise sensing technology for ventilation parameters, intelligent control technology for ventilation power, remote control technology for ventilation facilities, and an intelligent decision-making control platform for ventilation. These advancements have significantly enhanced the safety and production efficiency of the mine. The research results provide a theoretical foundation and technical support for the intelligent upgrade of coal mine ventilation systems, holding substantial engineering application value.

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