Research on Intelligent Monitoring Panel System for Thermal Power Plants in the Context of Big Data

Qipeng Zheng*, Dehai Li, Yuandong Pei, Yanming Yao, Shiliang Jia

Jinchang Power Branch of Gansu Huadian Tenggeli Green Energy Co., Ltd., Jinchang, Gansu 737202, China
Corrnesponding author: 17361627004@163.com

Abstract: *The transformation of the energy structure continues to deepen, with the role of thermal power progressively evolving from a primary power source to a flexible regulating source. This shift imposes higher standards for its operational safety, economy, and flexibility. The traditional monitoring panel model relies heavily on the experience of operators and commonly faces prominent challenges such as heavy monitoring workload, delayed warning responses, and one-sided analysis and decision-making. This paper focuses on the pathway for empowering the intelligent upgrade of thermal power plant monitoring panel systems through big data technology. It begins by analyzing the limitations of traditional monitoring and the characteristics of plant data in the big data context. Subsequently, it constructs a four-layer overall architecture encompassing "data collection, computation & storage, intelligent analysis, and application". The paper then provides an in-depth interpretation of core technologies, including real-time data stream processing, massive historical data mining, predictive equipment health management, and operational optimization with intelligent decision-making. Finally, it prospects the system's application potential in areas like proactive early warning, collaborative optimization, and adaptive control, while discussing the associated challenges and development trends. The research indicates that the intelligent monitoring panel system serves as the core vehicle for the digital and intelligent transformation of thermal power plants, playing a pivotal supporting role in enhancing plant operational efficiency and market competitiveness.*

Keywords: *Intelligent Monitoring Panel; Big Data; Thermal Power Plant; Predictive Maintenance; Operational Optimization*

Introduction

Guided by the "dual carbon" goals, the large-scale grid integration and consumption of new energy power has led thermal power units to gradually undertake more frequent peak-shaving and frequency-regulation tasks. Their operating conditions have thus exhibited characteristics of increasing complexity and diversification. Traditional monitoring panel systems, centered on Distributed Control Systems (DCS) and Plant-level Monitoring Information Systems (SIS), primarily fulfill basic functions of "data monitoring and anomaly alarming." They commonly suffer from prominent issues such as information overload, alarm redundancy, reliance on expert experience for fault diagnosis, and lagging operational optimization[1]. The production and operation processes of thermal power plants generate massive data resources, encompassing DCS real-time operational data[2], SIS historical process data, equipment condition data (including inspection records, vibration monitoring, etc.), and video surveillance data. This constitutes a typical industrial big data application scenario. Leveraging big data technology to deeply excavate the core value of this data is an inevitable pathway for thermal power plants to achieve refined management and intelligent operation. Constructing an intelligent monitoring panel system holds significant practical importance for ensuring the safe and stable operation of generating units, enhancing power generation efficiency, reducing operational costs, extending equipment service life, and improving the work efficiency of operational personnel[3].

This section briefly reviews the development history in areas such as power plant informatization construction (including SIS and Management Information Systems, MIS), fault diagnosis expert systems, and performance calculation & analysis systems both domestically and internationally[4]. It points out that current systems often exhibit a "siloed" application pattern, lacking intelligent analysis and decision-support capabilities based on the fusion of multi-source data from across the entire plant. It also surveys the latest advancements in big data and artificial intelligence technologies within the industrial sector, focusing on their application progress in directions like predictive maintenance and digital twins, as well as exploratory practices within the power industry. This paper will systematically discuss the construction path and implementation methods for an intelligent monitoring panel system in thermal power plants under the context of big data, from three core aspects: architecture design, key technologies, and application scenarios[5].

1. Data Characteristics and Overall Architecture of the Intelligent Monitoring Panel System for Thermal Power Plants

1.1 Analysis of Big Data Characteristics in Thermal Power Plants

Big data in thermal power plants exhibits the typical "5V" characteristics. Firstly, it demonstrates high Volume, generating tens of thousands of data acquisition points per second, with the scale of historically accumulated data potentially reaching terabytes (TB) or even petabytes (PB)[6]. Secondly, it shows high Velocity, as real-time data streams continuously pour in at high speed, demanding millisecond-level response times for data processing. Thirdly, it displays great Variety, encompassing data types that include structured data (such as measurement point data for temperature, pressure, etc.), semi-structured data (such as system log files), and unstructured data (such as video images, audio recordings, equipment maintenance reports, etc.). Fourthly, it involves Veracity concerns, meaning data quality is uneven, presenting issues like noise interference, data gaps, and data drift, which necessitate professional data governance measures to ensure data validity[7]. Fifthly, it possesses low Value density, implying that valuable information is hidden within massive data sets, requiring deep analysis techniques to extract and transform this value.

1.2 Overall Architecture Design of the Intelligent Monitoring Panel System

The Intelligent Monitoring Panel System adopts a layered architecture design, where each level works in coordinated synergy to construct a full-chain intelligent framework encompassing "data, computation, analysis, and application." It specifically consists of the following four layers:

1.2.1 Data Acquisition and Integration Layer

As the system's data entry point, this layer is responsible for the collection and ingestion of multi-source heterogeneous data from across the entire plant. This coverage includes DCS real-time operational data, SIS historical process data, equipment management data, fuel management data, and environmental monitoring data, among others. It employs technologies such as industrial protocol conversion, Application Programming Interface (API) calls, and edge computing gateways to achieve standardized ingestion and aggregation of diverse data types.

1.2.2 Big Data Computing and Storage Layer

This layer serves as the system's "central nervous system." It employs a hybrid architecture design combining real-time and batch processing:

a) A real-time computing platform (e.g., Flink, Spark Streaming) focuses on processing high-velocity, real-time data streams to achieve functions such as real-time identification of abnormal operating conditions and the triggering of intelligent alarms.

b) A batch processing platform (e.g., Spark, Hadoop) concentrates on the offline mining of massive historical data, model training, and trend analysis.

c) A data warehouse/data lake provides a unified data storage repository, enabling centralized management of various structured, semi-structured, and unstructured data. This supplies stable and efficient data service support for upper-layer analytical applications.

1.2.3 Intelligent Analysis and Model Layer

This layer serves as the system's "intelligent core," integrating various algorithmic models and analytical tools. It primarily includes:

a) Equipment health management models, which utilize machine learning algorithms (such as Isolation Forest and Long Short-Term Memory networks, LSTM)[8] to achieve equipment anomaly detection, fault prediction, and Prognostics and Health Management (PHM);

b) Operational optimization models, which leverage technologies like deep learning and reinforcement learning to conduct research on unit performance optimization, combustion efficiency optimization, and auxiliary power rate optimization;

c) Intelligent alarm models, which employ association rule mining to accomplish alarm compression, redundancy filtering, and root cause analysis of faults;

d) Digital twin models, which construct high-fidelity virtual mapping models of generating units to achieve real-time state synchronization between physical entities and virtual models, operational situation prediction, and scenario simulation.

1.2.4 Intelligent Application and Service Layer

This layer addresses the practical needs of thermal power plant operation and management by constructing diversified functional modules:

a: An intelligent alarm and diagnostic center, which achieves alarm classification and prioritization, correlation analysis, and fault root cause tracing;

b: An equipment predictive maintenance platform, which generates equipment health profiles, conducts Remaining Useful Life (RUL) prediction, and provides precise maintenance strategy recommendations;

c: An operational optimization guidance system, which outputs optimal operational parameter setpoints (such as optimal oxygen content, main and reheat steam temperatures, etc.) in real-time to enhance the operational economy of generating units;

d: An intelligent inspection and safety control module, which combines video-based Artificial Intelligence (AI) analytics to enable standardized behavior recognition for operating personnel and intelligent monitoring of abnormal conditions such as equipment leakage;

e: A visualization cockpit, which integrates key operational indicators of generating units to achieve multi-dimensional data drill-down analysis and panoramic situational display.

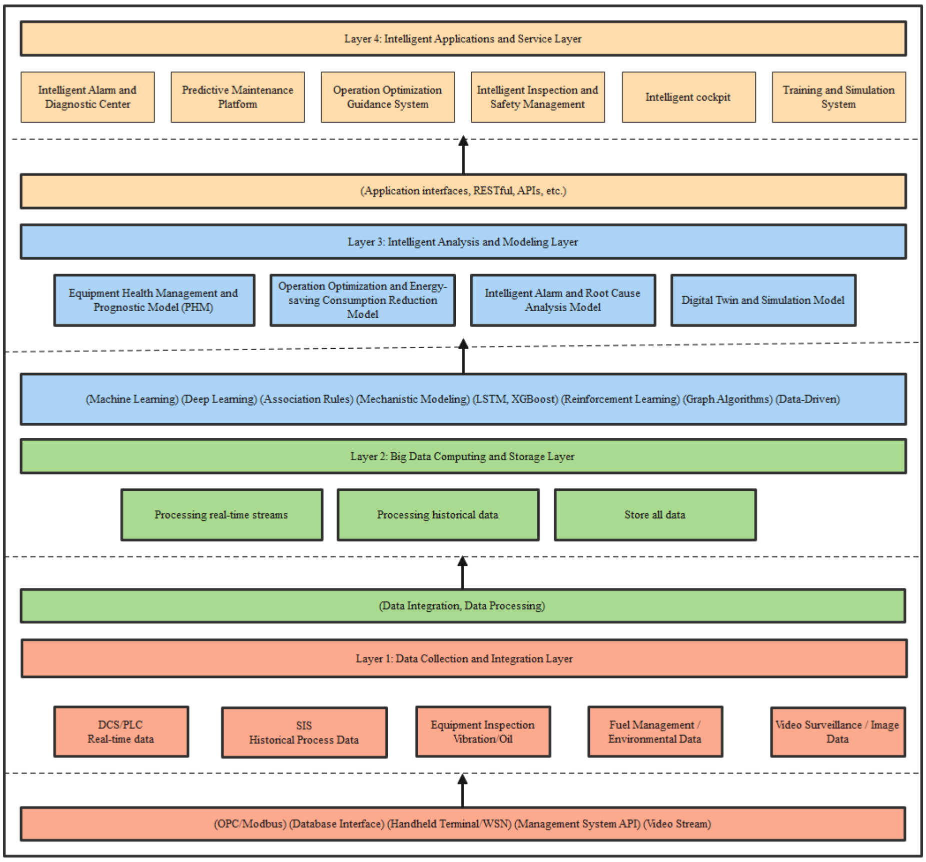

Figure 1 Data Characteristics and Overall Architecture of the Intelligent Monitoring Panel System for Thermal Power Plants

In summary, the integrated control platform for smart power plants, based on big data technology, will become a core supporting tool for the operation and management of thermal power plants. By integrating big data technology, intelligent control technology, and modern monitoring methods, it enables comprehensive perception, precise monitoring, and intelligent management of the entire production process in thermal power plants. This effectively enhances the operational efficiency and safety level of generating units and contributes to promoting the green, low-carbon, and sustainable development of the energy industry. With the continuous iteration and upgrading of big data and artificial intelligence technologies, the integrated control platform for smart power plants will play an even more critical role in the future intelligent transformation of the thermal power industry, serving as a core pillar supporting the power sector's advancement towards greater efficiency and intelligence.

2. Key Technologies of the Intelligent Monitoring Panel System

Driven by both the energy structure transformation and the "dual carbon" goals, the role of thermal power has shifted from a traditional primary power source to a flexible and reliable regulating source. This shift imposes unprecedented high standards for the safety, economy, and flexibility of thermal power unit operation. The traditional manual monitoring panel model relies heavily on the personal experience of operators and faces severe challenges such as excessive monitoring workload, lagging risk warnings, and one-sided analysis and decision-making. Promoting the deep integration of new-generation information technologies like big data and artificial intelligence with thermal power production processes, and constructing an intelligent monitoring panel system, has become an inevitable trend for the high-quality development of the thermal power industry. This paper systematically elaborates on the key technologies, application scenarios, and development pathways of the intelligent monitoring panel system, providing technical reference for the industry's intelligent transformation.

The construction of the Intelligent Monitoring Panel System is a complex systems engineering project that requires the synergistic support of key technologies across multiple domains. Its core technical framework can be categorized into two main directions: data fusion and governance, and intelligent analysis and decision-making. These are further broken down into four key modules: intelligent monitoring, intelligent alarming, intelligent recognition, and intelligent guidance, thereby forming a complete technical chain from "data fusion to decision output."

2.1 Multi-source Heterogeneous Data Fusion and Governance Technology

Data serves as the foundational core of the Intelligent Monitoring Panel System, necessitating the construction of a high-quality data base to support upper-layer intelligent applications. In response to the typical characteristics of thermal power plant data-namely its massive volume, high velocity, diversity, and low value density-technologies such as industrial protocol conversion and edge computing gateways are employed to achieve the aggregation and integration of data from multiple systems, including DCS, SIS, equipment inspection, and video surveillance. On this basis, governance tasks including data cleaning, alignment, and labeling are carried out to eliminate invalid data, correct anomalous data, and supplement missing data. A hybrid storage architecture combining a "time-series database and data lake" is adopted to enable the categorized storage, efficient querying, and management of real-time streaming data and historical batch data. This provides high-quality data input for the intelligent analysis modules.

2.2 Intelligent Diagnostics and Prediction Technology Based on Machine Learning

This technology serves as the core enabling support for transitioning thermal power plants from "reactive maintenance" to "predictive maintenance." It enhances equipment fault warning and operational optimization capabilities by uncovering the inherent correlations within data. Aligned with the practical needs of thermal power plant operation and management, the application of its core technologies can be detailed into the following four aspects:

2.2.1 Intelligent Monitoring

Leveraging data mining and real-time analytics technologies, this module achieves comprehensive, multi-dimensional, and refined monitoring of production process data, thereby laying the foundation for subsequent intelligent analysis. It primarily fulfills four key functions. The first is real-time panoramic monitoring, which involves the real-time collection and dynamic tracking of unit operating status, key parameters (such as temperature, pressure, flow rate), and environmental factors (such as ambient temperature, humidity, wind speed) to gain a comprehensive grasp of the production operation situation.

The second is data pattern analysis, which employs methods like trend analysis and periodicity identification to uncover the inherent patterns within data, enabling accurate assessment of production operational states. The third is intelligent anomaly detection, which constructs a baseline model of normal operating conditions based on historical data; by comparing real-time data against this baseline model, it promptly identifies issues such as parameter exceedances and abnormal trends. The fourth is fault trend prediction, which utilizes historical operational data and fault records to build fault prediction models, thereby achieving early warning of potential equipment failures.

2.2.2 Intelligent Alarming

Building upon the foundation of intelligent monitoring, this module achieves precise management and efficient distribution of alarm information through the construction of intelligent alarm models. Its core functionalities encompass three key aspects. The first is hierarchical and categorical control, which establishes a multi-level alarm system (e.g., red, yellow, blue) based on the urgency and impact scope of the alarm information, thereby assisting operators in prioritizing critical issues. The second is redundant alarm suppression, which utilizes association rule mining to filter out redundant information such as repeated alarms and derivative alarms, thereby addressing the problem of alarm flooding common in traditional systems. The third is multi-channel warning notification, which ensures timely dissemination of alarm information and facilitates rapid operator response through various means such as SMS, email, and system pop-up windows.

2.2.3 Intelligent Recognition

This module adopts an approach that combines multi-level verification with intelligent algorithms to achieve precise fault identification and root cause localization. Its primary implementations include three key aspects. The first is multi-level cross-verification, which enhances the accuracy and reliability of fault identification through multi-dimensional data comparison and the validation of results from multiple models. The second is precise fault diagnosis, which employs machine learning algorithms to conduct in-depth analysis of abnormal data, thereby clarifying the fault type, location, and severity. The third is preventive strategy formulation, which analyzes the patterns of fault occurrences based on diagnostic results and proposes targeted preventive measures to reduce the probability of similar faults recurring.

2.2.4 Intelligent Guidance

This module constructs an expert planning library based on expert experience and data analysis results to provide precise guidance for operational procedures and equipment maintenance. Its core functionalities encompass three key areas. The first is standardized operational guidance, which, by considering unit characteristics and operating conditions, provides normative operational procedures and parameter adjustment suggestions to enhance the standardization of operator actions. The second is full-process task reminders, which establish intelligent reminder mechanisms for critical tasks such as equipment inspection and periodic maintenance to prevent omissions due to human oversight. The third is optimization strategy output, which, based on the analysis of real-time operational data and historical optimal operating conditions, proposes optimization suggestions for unit operation and equipment maintenance, thereby helping to improve production efficiency and reduce operational costs.

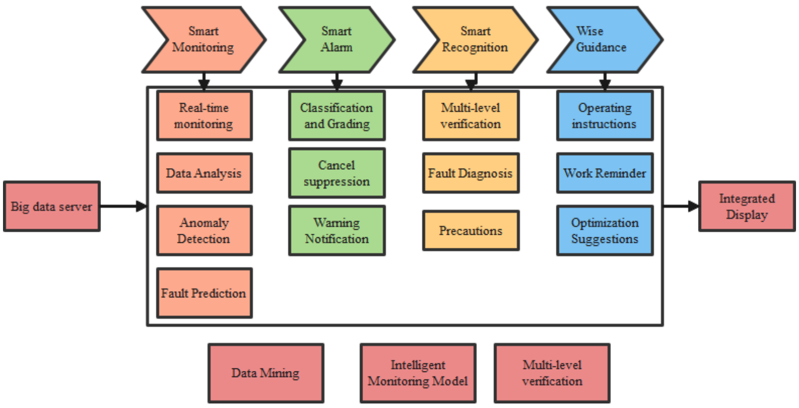

Figure 2 Technical Architecture of the Intelligent Monitoring Panel

In summary, intelligent monitoring, intelligent alarming, intelligent recognition, and intelligent guidance constitute the core technical framework of the Intelligent Monitoring Panel System for thermal power plants. Through the synergistic interaction of these technical modules, the system achieves comprehensive monitoring of the production process, precise early warning of abnormal conditions, efficient handling of fault issues, and scientific optimization of operational management. This effectively enhances the safety, economy, and intelligence level of production and operation in thermal power plants.

Conclusion

With the accelerated pace of intelligent transformation in the thermal power industry, the traditional manual monitoring panel model has become increasingly inadequate for meeting the demands of refined monitoring and management within complex production environments. Conducting research on and applying the Intelligent Monitoring Panel System in thermal power plants holds significant strategic importance for enhancing production efficiency, reducing operational costs, strengthening safety control, and improving environmental performance. This paper conducts research on the Intelligent Monitoring Panel System for thermal power plants within the context of big data, proposing an integrated control platform architecture for smart power plants based on big data, and provides a detailed breakdown and analysis of the functions at each level. The research indicates that the core of intelligent monitoring panel technology lies in the Big Data Intelligent Control Layer. By integrating two key phases-data fusion and data-driven decision-making-and refining them into four core technical modules (intelligent monitoring, intelligent alarming, intelligent recognition, and intelligent guidance), a complete intelligent management and control closed loop is formed.

The intelligent monitoring panel system constructed in this research can effectively enhance the intelligent level of production and operation in thermal power plants, assist in achieving cost reduction and efficiency improvement, and promote corporate digital transformation and high-quality development. It holds significant theoretical reference and practical guidance for the sustainable operation of thermal power plants and the overall intelligent upgrade of the thermal power industry. Future work can focus on further strengthening research in areas such as the optimization of artificial intelligence algorithms and the in-depth application of digital twin technology, continuously improving the system's adaptability and intelligence level to better support the transformation and development of the thermal power industry under the "dual carbon" goals.

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