ISSN 2522-3488 Vol. 9, Issue 2: 16-20, DOI: 10.25236/IJNDES.2025.090203

Intelligent Early Warning and Monitoring Platform for Power Grid Dispatch: In-depth Analysis of Architecture, Technology, and Development Trends

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Abstract: *With the increasing scale and complexity of power systems, the intelligent early warning and monitoring platform for power grid dispatch has become increasingly critical for ensuring the safe, stable, and economical operation of power systems. This paper provides an in-depth analysis of the platform, elaborating on its conceptual framework and operational significance, reviewing its evolution from rudimentary monitoring systems to advanced intelligent monitoring solutions, and illustrating its current applications through practical case studies. The paper delves into key technologies, including data acquisition and transmission, alarm analysis, alarm visualization, and notification mechanisms. Furthermore, it identifies challenges such as inconsistent information processing standards, information silos, and cybersecurity vulnerabilities, proposing strategies such as standardization, information exchange mechanisms, and enhanced cybersecurity measures. The findings of this study provide robust support for the intelligent transformation of power systems.*

Keywords: *Intelligent Early Warning and Monitoring Platform, Power Grid Dispatch, Information Sharing*

1. Introduction

1.1 Research Background and Significance

The rapid expansion and increasing complexity of power systems have necessitated the development of advanced monitoring and early warning mechanisms. The intelligent early warning and monitoring platform for power grid dispatch serves as a pivotal tool in ensuring the safe, stable, and efficient operation of power systems. By integrating cutting-edge information technologies with power monitoring systems, this platform enables comprehensive, real-time monitoring and control of power grids. It plays a vital role in maintaining power supply quality, preventing operational failures, and enhancing overall system reliability. Research on this platform not only advances the understanding of technological trends in the power industry but also provides theoretical and practical insights for the intelligent upgrading of power systems and the improvement of operational management in power enterprises.

1.2 Domestic and Overseas Research Status

Globally, developed nations such as those in Europe and the United States have taken the lead in the research and application of power grid dispatch early warning and monitoring platforms, leveraging their advanced information technologies and robust industrial infrastructures. The evolution of these platforms can be categorized into four distinct phases:

(1) Initial Phase (Late 1960s to 1970s): Characterized by rudimentary wiring systems that transmitted a limited number of analog signals to regional dispatch centers. This phase was largely devoid of computer integration, offering minimal monitoring capabilities, low data accuracy, and restricted transmission ranges.

(2) Second Phase (1980s): Marked by the integration of monitoring systems into early computer operating systems, which enhanced monitoring capabilities. However, these systems lacked advanced analytical, diagnostic, and alarm functionalities and were not networked, resulting in isolated and closed systems.

(3) Third Phase (1990s):Witnessed significant advancements due to the widespread adoption of

modern computing and communication technologies. Data processing efficiency improved, and systems began to feature open architectures and network functionalities. Despite these improvements, the systems remained limited in their ability to process and analyze large datasets and lacked sufficient intelligence.

(4) Fourth Phase (2000s to Present):Represented a paradigm shift towards fully open systems emphasizing data sharing, transmission, and utilization. Subsystems were equipped with interactive interfaces, and data utilization was maximized. With the rapid advancement of computing technologies, these systems achieved high levels of intelligence in data analysis, processing, and early warning capabilities.

In China, significant strides have been made in the development of intelligent early warning and monitoring platforms for power grid dispatch. State Grid and Southern Grid have spearheaded the construction of smart grids, investing heavily in the research and deployment of advanced power monitoring systems. Domestic research institutions and universities have also contributed significantly, particularly in areas such as big data analytics and the application of artificial intelligence in power systems, driving technological innovation and expanding practical applications[1]. For instance, a platform implemented in a municipal power grid substation control center has demonstrated initial success, leveraging distributed data storage, standardized data processing, parallel batch processing, and data correlation analysis to achieve efficient multi-source data analysis for equipment status monitoring, fault early warning, and maintenance. Nevertheless, certain gaps remain in key technologies and application depth compared to international standards.

1.3 Research Methodology and Innovations

This study extensively analyzes domestic and international academic publications to comprehensively summarizes the research status and development trends of intelligent early warning and monitoring platforms for power grid dispatch. Additionally, the case study method is utilized to examine practical applications, extracting valuable insights and lessons. The primary innovation of this paper lies in its multidisciplinary approach, integrating theories from technology, management, and cybersecurity to propose a holistic set of development strategies for the platform. Furthermore, the study incorporates the latest technological advancements to provide a forward-looking analysis of the platform's future trajectory.

2. Overview of the Intelligent Early Warning and Monitoring Platform for Power Grid Dispatch

2.1 Conceptual Framework and Operational Significance

The intelligent early warning and monitoring platform for power grid dispatch integrates modern information technologies, communication systems, data analytics, and artificial intelligence to enable real-time data collection, intelligent analysis, accurate early warning, and decision support for power grid operations. The platform is characterized by its high level of intelligence, data-driven functionality, real-time responsiveness, comprehensiveness, and openness. Evolving from basic monitoring systems, it has progressed through stages of automated monitoring and preliminary early warning to advanced intelligent monitoring and early warning capabilities. The platform plays a critical role in ensuring the safe and stable operation of power grids, enhancing dispatch efficiency and decision-making, promoting the intelligent development of power systems, and supporting power market operations. A schematic representation of the platform's alarm release workflow is provided in Figure 1.

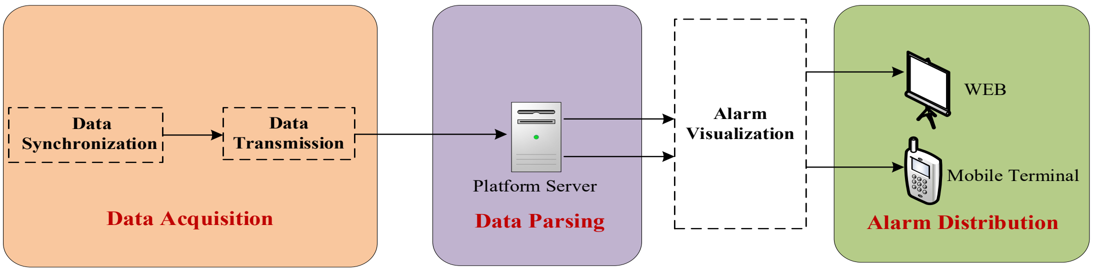

Figure 1. Alarm Release Workflow of the Intelligent Early Warning and Monitoring Platform for Power Grid Dispatch

2.2 Historical Development

The development of the platform can be segmented into several key phases:

(1) Initial Phase: Relied on manual inspections and basic instrumentation, with monitoring systems based on analog signal transmission. These systems provided limited real-time monitoring of electrical parameters and were primarily deployed in small-scale power grids.

(2) Development Phase: The advent of computers and digital communication technologies enabled the digitization of data collection and transmission. Centralized data processing and visualization were achieved through computer systems, and basic early warning algorithms were introduced. These systems were widely adopted, significantly improving dispatch efficiency and accuracy, although their early warning capabilities remained relatively simplistic.

(3) Deepening Phase: The integration of advanced technologies such as artificial intelligence, big data[2], and cloud computing facilitated the real-time collection and deep analysis of massive datasets. Complex and precise early warning models were developed, providing detailed alarm information and decision support. The platform also incorporated adaptive learning and optimization capabilities, becoming a cornerstone of large-scale power grids and smart grid initiatives.

2.3 Current Applications

2.3.1 Case Study: A Municipal Power Company under State Grid

A municipal power company developed a power monitoring platform based on the Isolation Forest algorithm. The platform adopted an advanced, mature, and stable architecture, structured around "one database," "two mechanisms," "three platforms," and "four engines." It significantly enhanced the stability, reliability, and security of the power system, optimized equipment maintenance management, and improved service quality. The platform incorporated a professional security detection engine capable of identifying, alerting, and mitigating harmful database activities in real time[3-4]. It featured a large-screen display for real-time visualization of database security risk events and security indices, providing dynamic security situational awareness. Additionally, the platform utilized big data full-text search technology, achieving second-level response times for queries involving billions of data points. This enabled rapid identification of relevant audit content and supported multi-dimensional search conditions, comprehensive report analysis, and user trend monitoring. The platform demonstrated high accuracy in monitoring and early warning, enabling timely detection and resolution of equipment anomalies or failures, thereby preventing power system disruptions and ensuring operational stability.

2.3.2 Case Study: A Data Research Company

A data research company implemented Long Short-Term Memory (LSTM) networks for power big data analytics, enabling intelligent assessment of power system operational status. The system was developed using the Springboot framework, creating a mobile-accessible intelligent power monitoring platform[5]. The trained LSTM model achieved a mean absolute error of 0.257 for voltage prediction, meeting power grid safety management requirements. Performance testing indicated an average response time of under 1000 ms and a maximum response time below 1500 ms, confirming the platform's robust operational capabilities and suitability for monitoring applications.

3. Key Technologies of the Intelligent Early Warning and Monitoring Platform

3.1 Data Acquisition and Transmission Technologies

Data is the cornerstone of the intelligent early warning and monitoring platform. Data acquisition technologies encompass the collection of operational parameters such as voltage, current, and power, as well as environmental factors like temperature, humidity, and wind speed. Traditional acquisition methods include Remote Terminal Unit (RTU) operations and pulse-based data collection, while modern approaches leverage smart sensors and distributed acquisition architectures. Transmission technologies involve power-specific communication networks, such as Synchronous Digital Hierarchy (SDH) and Optical Ground Wire (OPGW), as well as integrated communication networks like power wireless private networks and 5G. Protocols such as Transmission Control Protocol (TCP) and Secure File Transfer Protocol (SFTP) are employed, alongside redundancy and error correction mechanisms to ensure data reliability. The integration of acquisition and transmission technologies facilitates real-time,

ISSN 2522-3488 Vol. 9, Issue 2: 16-20, DOI: 10.25236/IJNDES.2025.090203

high-efficiency data transfer. Despite current limitations, ongoing advancements promise future breakthroughs in this domain.

3.2 Alarm Analysis Technologies

The platform processes vast amounts of real-time monitoring data (e.g., current, voltage, power, temperature) and employs advanced analytical techniques to enhance the accuracy of equipment status monitoring and the timeliness of fault early warnings. Current systems, while capable of real-time monitoring and intelligent analysis, face challenges such as inaccurate monitoring results, delayed analytical outputs, and data security concerns. Prominent algorithms for alarm analysis include Isolation Forest, Long Short-Term Memory (LSTM) networks, and Density-Based Spatial Clustering of Applications with Noise (DBSCAN). For instance, the Isolation Forest algorithm is utilized for data cleansing and validation, automatically identifying anomalies to reduce error rates.

3.3 Alarm Visualization and Notification Technologies

The selection of a development platform is critical for alarm notification systems. Key considerations include platform stability, reliability, compatibility, and scalability. High-availability architectures, such as cloud-based distributed systems, are preferred to ensure uninterrupted service. Compatibility with multiple communication channels (e.g., SMS gateways, email servers, mobile app push services) is essential, requiring support for protocols like Short Message Peer-to-Peer (SMPP). Scalable platforms, such as Ruoyi and Vue, enable independent service upgrades and expansions, accommodating growing business needs and new functionalities. Diverse notification channels, including real-time in-platform alerts, SMS/email notifications, and mobile app pushes, enhance the efficiency of duty personnel.

The key technologies of the intelligent early warning and monitoring platform for power grid dispatching are summarized as shown in Figure 2.

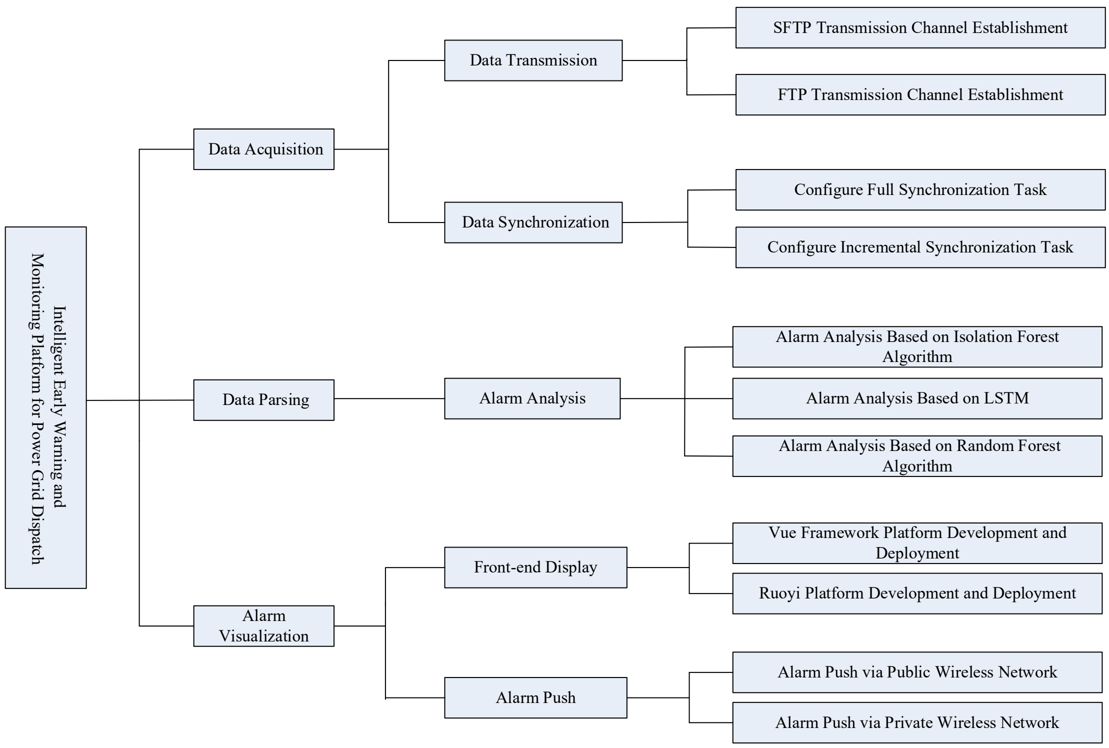

Figure 2. Key Technology Framework of the Intelligent Early Warning and Monitoring Platform for Power Grid Dispatch

4. Challenges and Strategic Recommendations

4.1 Challenges

(1) Lack of Standardization in Information Processing: Inconsistent data formats and structures across

departments hinder data integration and sharing, complicating correlation analysis and reducing operational efficiency.

(2) Information Silos: Limited communication between power dispatch centers and the absence of unified information exchange mechanisms result in isolated systems, redundant infrastructure, and inefficient resource utilization.

(3) Cybersecurity Risks: Vulnerabilities in data acquisition, processing, and storage systems expose the platform to potential cyberattacks, threatening power grid security and stability.

4.2 Strategic Recommendations

(1) Standardization: Establish unified data storage and processing standards, ensuring consistent data formats, structures, and workflows across departments.

(2) Information Exchange Mechanisms: Develop common data formats and communication protocols, fostering cross-departmental collaboration and integrated information platforms.

(3) Cybersecurity Enhancements: Implement robust encryption, intrusion detection, and data backup mechanisms to safeguard data integrity and system resilience.

5. Conclusion and Future Outlook

5.1 Summary of Findings

This study elucidates the conceptual framework, historical evolution, and current applications of the intelligent early warning and monitoring platform for power grid dispatch. It highlights key technologies, identifies challenges, and proposes strategic solutions, offering valuable insights for the intelligent transformation of power systems.

5.2 Future Trends

(1) Intelligent Development: The platform will increasingly leverage artificial intelligence and big data analytics for real-time monitoring, predictive analysis, and decision optimization.

(2) Cross-Disciplinary Information Sharing: Unified information exchange platforms will break down silos, enabling seamless data sharing and collaboration across departments.

(3) Data-Driven Decision Optimization: Advanced data analytics will enhance decision-making processes, improving power system efficiency and reliability.

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