ISSN 2616-7433 Vol. 8, Issue 1: 7-12, DOI: 10.25236/FSST.2026.080102

Application of Centralized and Unified Monitoring in Wind Power Generation

Zifu Zhang, Xiangnan Xu*, Yan Jin

Qian'an IW Power Co., Ltd, Songyuan, Jilin, 131400, China
**Corresponding Author*

Abstract: *The global energy structure transformation and the development of renewable energy have led to a continuous increase in the construction and operation scale of wind farms. The management and operation level of wind farms are related to their economy and reliability. In addition, the wind power industry in China has formed a trend of group and scale development, and the traditional decentralized offline monitoring mode has drawbacks. To solve such problems, the project I am working on is based on cloud native technology, combined with microservices and containerization architecture, to develop a centralized and unified monitoring platform for wind power generation that is elastic, scalable, highly available, secure, comprehensive, and multi terminal supported. It can collect and process data from all wind farms in a unified manner, and is applied to regional command screen monitoring, automated report generation, wind power loss actuarial, multi system integration and other scenarios. It provides support for management decision-making, improves the operational efficiency and benefits of wind power enterprises, and promotes the digital transformation of the wind power industry. The platform will combine artificial intelligence and other technologies to achieve the construction of an intelligent and integrated digital twin system.*

Keywords: *wind power; electricity generation; monitor*

1. Introduction

As an important carrier of wind energy conversion, wind farms play an indispensable role in energy supply[1]. After decades of development, China's wind power industry has gone from scattered small-scale development to high-quality development that combines group, scale, and intensification. Large power generation groups or regional energy companies manage dozens or even hundreds of wind farms, which are distributed in different regions and geographical locations with varying climate characteristics, making operation and management difficult. The traditional monitoring mode of wind farms is based on monitoring systems that operate independently at each station, and manually summarize daily and monthly reports on a regular basis. This decentralized and offline management mode has many drawbacks, which restrict the operational efficiency and benefits of the wind power industry. Based on this, our company relies on cloud native technology and adopts secure and stable enterprise private networks and industrial grade data collection technology to uniformly collect, centrally store, and standardize the massive real-time operation data of wind farms across the entire region. By utilizing microservices, containerization technology architecture, and low code development methods, we aim to create a fully digital management platform for real-time monitoring, intelligent analysis, prediction, and intensive operation. This platform also provides real-time and accurate power generation guidance, performance analysis, and optimization solutions for operators, thereby maximizing the global value of wind power assets and achieving digital transformation of operation management. This will enable the large-scale and efficient operation of the wind power industry.

2. Basic configuration of wind power generation monitoring platform

2.1 Microservice Framework of SpringCloud

The centralized and unified monitoring platform for wind power generation is based on the GRP cluster enterprise digital platform, and its business is based on the microservices architecture of Springcloud, combined with the J2EE technology stack for technical architecture, with high cohesion and low coupling technical characteristics. In the centralized and unified monitoring scenario of wind power generation, there are various business functions, including user registration, data collection, real-time query, report generation, algorithm calculation, fault warning, etc. Each business is set as a clearly defined business module, and different microservices are assigned to communicate and collaborate through lightweight ResTfulAPI. In order to achieve unified scheduling and management of various microservices, the platform sets up a unified API Gateway as the aggregation entrance for external services. All front-end application requests go through this gateway, go through the gateway's routing, load balancing, and permission verification, and then send them to the corresponding microservices. According to microservice architecture, developers can develop new microservice modules that can quickly access the original system using API gateways without the need to readjust the overall architecture, reducing the cost and risk of system upgrades. In addition, components such as service registration and discovery, configuration center, and circuit breaker mechanism in the SpringCloud framework can also enhance the stability and reliability of the platform.

2.2 Elastic Expansion and High Availability Guarantee

The operating environment of wind farms has a very high degree of uncertainty. On the one hand, the amount of operating data of wind farms will continue to increase with the increase of the number of wind turbines and monitoring points. Especially in adverse weather conditions, the operating parameters of wind turbines will suddenly change, and the amount of transmitted data will also increase sharply. On the other hand, the operational analysis and report generation work of the group will occur at specific times, leading to a sharp increase in system traffic. Therefore, the platform requires strong resilience and high availability guarantee capabilities to meet the needs of the scenario. In terms of high availability, the platform's service layer adopts a clustered approach, where nodes in the cluster are completely equivalent and replace each other, with no single point of failure. The platform distributes user requests to each node through a load balancer. When a node crashes due to hardware failure, network interruption, or other reasons, the load balancer will automatically send the request to another node. The platform also has fault detection and automatic recovery mechanisms, which detect the operating status of each node through heartbeat detection, health checks, and other methods. If there are any abnormalities, fault recovery operations will be performed. For the wind power industry, the monitoring platform needs to maintain uninterrupted operation 24/7, otherwise the operation status of the wind farm may experience sudden changes after system interruption, such as equipment failure, power loss, and even safety accidents. The high availability of the platform enables the core monitoring functions to work properly, providing reliable guarantees for the safe operation of wind farms.

2.3 Comprehensive security and multi terminal support system

The wind power monitoring platform involves a large amount of key data, including the operating parameters of wind farms, equipment information, power generation revenue, grid information, and so on. The security of data is related to the important interests of enterprises and the security of the grid. The users of the platform include group management personnel, regional operation and maintenance personnel, on-site personnel, etc. Each user may use the platform in different scenarios, so the platform needs to establish a comprehensive security system and multi terminal support system. The platform provides a complete and standardized REST API interface, all of which use encrypted transmission to ensure the security of data during transmission. The front-end and back-end are completely separated, and a unified authentication and authorization center is built based on the SpringSecurity LHN2 extension to achieve centralized management and authentication of user identities. Multiple authentication methods such as username and password, dynamic password, etc. are used to log in to the system, and after logging in, operational permissions are obtained according to roles and permissions. The platform adopts a front-end and back-end separation approach to separate front-end application development and back-end services, supporting various front-end applications such as web, mobile apps, and mini programs. The web end is mainly targeted at group management and regional operation and maintenance personnel, and can provide complete monitoring, analysis, and management, as well as various modes of graphical display and data processing functions. Mobile apps and mini programs are mainly targeted at on-site workers and mobile office scenarios, providing simple and intuitive functions such as device status inquiry, fault alarm, and work order processing, allowing users to access them anytime and anywhere.

2.4 Containerization and DevOps Support

The platform uses container orchestration tools such as Kubernetes to automatically schedule, scale,

ISSN 2616-7433 Vol. 8, Issue 1: 7-12, DOI: 10.25236/FSST.2026.080102

and manage containers. Kubernetes will automatically schedule containers to appropriate nodes based on service load, resource requirements, etc., and dynamically allocate resources to facilitate effective resource utilization. Kubernetes supports horizontal scaling and rolling updates, which can quickly increase or decrease the number of container instances according to business needs, achieving elastic scaling; When upgrading containers, adopt a rolling update method to replace old versions of containers, prevent service interruptions, and ensure stable system operation.

The platform has a complete CI/CD pipeline, which enables fully automated code development, testing, and deployment. The automated CI/CD process reduces development cycles, improves software delivery quality and efficiency, and can quickly respond to changes in business requirements. For example, when it is necessary to improve wind power prediction algorithms, testing and deployment can be achieved by modifying the code through the CI/CD pipeline, and the improved algorithms can be applied to actual monitoring in a timely manner to improve prediction accuracy. The platform supports the DevOps collaborative work mode, where the development team, testing team, and operations team collaborate through one platform to share resources such as code, test cases, and operations documents, improving team collaboration efficiency and ensuring efficient integration of system development, testing, and operations work.

In response to the real-time, reliability, and scalability requirements of a unified monitoring platform, the GRP platform designs different technical architectures to lay the foundation for the rapid development, stable operation, and smooth development of various monitoring and analysis applications in the upper layer. The architecture is shown in Table 1 below:

Table 1. Functional Modules of the Unified Monitoring Platform

Level	Composition	Function
Application layer	Centralized monitoring, power prediction, equipment health, fault diagnosis, business intelligence	Real time monitoring of new energy, data collection and processing, centralized meteorological management, optimization of operation and maintenance strategies, wind power prediction, video integrated monitoring, expert knowledge base, fault diagnosis, energy efficiency evaluation, economic analysis
Visualization layer	Screen configuration tool, 2D system diagram visualization, data analysis visualization, report statistics visualization	Provide intuitive and clear data display and operation
Intelligent layer	Big data platform and artificial intelligence platform	Intelligent analysis, prediction, diagnosis, etc
cloud platform layer	Cloud storage, cloud deployment, virtualization, containerization, PaaS platform	Provide underlying cloud resource support and technical assurance
Internet of Things Perception Platform	Communication and Data Collection	Realize data transmission between devices, platforms, and platforms
Device layer	Wind turbines, transformer boxes, meteorological monitoring instruments, combiner boxes, inverters, intelligent photovoltaic controllers, collection station equipment, etc	Core equipment for wind/photovoltaic power plants

3. Application of Three Monitoring Platforms in Wind Power Generation

3.1 Regional Command Screen and Remote Centralized Monitoring

The regional command screen mainly includes key performance indicators (KPIs) for the operation of the entire wind farm and photovoltaic power station, which are dynamically visualized and reflected to the management to perceive the overall operational status of the wind farm. The indicators displayed

ISSN 2616-7433 Vol. 8, Issue 1: 7-12, DOI: 10.25236/FSST.2026.080102

on the large screen include power generation indicators, equipment status indicators, resource and environmental indicators, operation and maintenance management indicators, etc. The power generation indicators display the total power generation, cumulative power generation, planned power generation, wind farm power generation ranking and other indicators of the entire group, which facilitates management personnel to grasp the overall power generation efficiency and the power generation situation of each station; Equipment status display includes statistics on the operating status of major equipment such as fans, box transformers, and main transformers, as well as indicators such as average equipment availability, number of defective work orders, and processing progress. The resource and environmental indicators display meteorological data such as average wind speed, wind power density, and ambient temperature, which facilitates management personnel in predicting power generation and adjusting operations; The operation and maintenance management indicators display indicators such as the number of work orders, completion status of inspections, and timely failure rate. The regional command screen can be combined with Maximo asset management system to display real-time information such as important equipment defect work orders, processing progress, timeout alarms, etc. If the fan malfunctions, the large screen will automatically display information such as the fan's location, fault type, alarm level, and associate it with the corresponding work order. The management can check the fault handling situation at any time and coordinate resources to solve major problems. The regional command screen provides one-stop decision support for management, allowing them to quickly make operational decisions based on real-time and comprehensive data, improve resource allocation, and enhance operational efficiency.

3.2 Automated Reporting and Multidimensional Trend Analysis

The automated reporting system is a visual and configurable reporting tool based on the platform, which has the functions of customizing, generating, and distributing reports. It eliminates the need for manual statistics and report preparation, and can effectively improve the timeliness of report data submission. Users can design various report templates according to their management needs. The report templates can be dragged and dropped, and the report structure, data sources, statistical caliber, display format, etc. can be configured through a graphical interface. The sources of report data include various data from real-time and historical databases, including power generation, utilization hours, equipment failure frequency, downtime, on-site electricity consumption rate, revenue and cost, etc. Users can set the cycle of the report, and can choose to generate it according to fixed periods such as daily, monthly, and yearly. They can also set a threshold for power generation, and the report will be automatically generated when the power generation reaches the threshold.

In addition, equipment statistical reports mainly refer to reports on equipment operation status, equipment health status, equipment operating time, number of failures, downtime, average time between failures, availability rate, and other factors. The economic indicator report mainly refers to reports such as on-site electricity consumption rate, unit power generation cost, power generation income, investment return rate, etc. Production reports support report formats such as PDF, Excel, Word, etc. Users can preview and export reports online. The system provides automatic email distribution function, setting parameters such as email recipient and sending time. The system will send the report to the designated email on time, making it convenient for relevant personnel to obtain data. The automatic reporting system fundamentally liberates human resources, avoiding errors and inefficiencies that may arise during manual statistical processes. Operations managers can focus on data interpretation and decision-making[2].

3.3 Actuarial and Analysis of Wind Power Loss

The core of wind power loss actuarial is the theoretical power calculation model of wind turbines, which solves the problem of the disconnection between third-party predicted data and actual on-site working conditions by combining physical mechanisms and data-driven approaches. In terms of physical mechanisms, based on the principles of meteorology and fluid mechanics, a high fidelity physical simulation chain is established. Based on Anderson's "Fundamentals of Aerodynamics" blade momentum theory, the wind turbine blades are divided into several microelements along the spanwise direction, and the aerodynamic lift and drag on each microelement are obtained. Finally, the aerodynamic power and axial thrust captured by the entire wind turbine are integrated to achieve the conversion of wind energy to mechanical energy; In response to the low resolution of NWP grid data and the neglect of local terrain, the model combines CFD technology to simulate the steady-state or unsteady state of the complex flow field in the wind farm area using precise digital elevation models

ISSN 2616-7433 Vol. 8, Issue 1: 7-12, DOI: 10.25236/FSST.2026.080102

and surface roughness data. The flow acceleration factor and bias angle of NWP macroscopic wind speed are calculated and corrected to the "effective wind speed" that better characterizes the actual inflow conditions of the wind turbine. Input the effective wind speed corrected via CFD technology and the on-site air density calculated from on-site air temperature and pressure into the standard power curve provided by the wind turbine manufacturer. Adjust the standard power curve for on-site air density, then combine the adjusted curve with real-time operational data from the wind turbine SCADA system to perform the theoretical power calculation.

In terms of data-driven approach, when the system experiences stable historical data covering different climate conditions for more than one year, the model calculation will gradually shift towards data-driven approach, utilizing statistical learning to explore the underlying patterns of historical data. Aiming at the seasonality, trend, and autocorrelation of wind power time series, an autoregressive integrated moving average model (ARIMA) is adopted. For data with stationary sequences and the need to flexibly capture recent changing patterns, the adaptive quadratic exponential smoothing method with smoothing coefficients is adopted, and the smoothing coefficients are dynamically adjusted according to the characteristics of sequence changes to adapt to the non stationarity of wind power; Using NWP forecast data and wind turbine status parameters as independent variables, and actual wind turbine power generation as the dependent variable, a multiple linear regression or machine learning regression model is developed to quantify the comprehensive impact weights of different environmental factors and operating parameters on wind turbine output and capture nonlinear relationships. In response to the time-varying performance of wind turbines, the CKF algorithm is used to real-time integrate the latest wind turbine power observations, dynamically adjust model parameters or system states online, and enable the prediction system to have online learning and adaptive capabilities. For wind turbines with few operations, temporary sensor failures, or missing data, the discrete GM (1,1) grey prediction model is used, which only requires a small amount of recent data to predict the trend of the power series and compensate for the deficiency of small sample poor information[3].

3.4 Multi system integration and single sign on

Single sign on is based on AAD domain services and has built a unified identity authentication management center to manage and authenticate user identities. All business systems of Wind Power Group, monitoring platform, Maximo asset management system, grid connection assessment, early warning and analysis system, Dahua video monitoring system, etc. are connected to the unified certification center. Users are registered in the system, and administrators assign roles and permissions according to their positions and responsibilities. Roles and permissions can be designed in a refined way to achieve permission control based on functional modules and data ranges. Users can enter their username and password through a unified login interface, complete one authentication, and enter the authorized application system without the need for multiple logins. The single sign on function uses multiple security authentication methods, such as password encryption transmission, dynamic password verification, login log auditing, etc. If the management of the group logs into the monitoring platform, they can directly click to enter the Maximo asset management system to query equipment spare parts information, or access the grid connected assessment warning analysis system to query AGC/AVC performance indicators, without the need to re-enter login information.

The multi system integration function breaks through the isolation of business systems, realizes the interaction of data from different systems, connects business processes, integrates the platform with Maximo asset management system, and achieves real-time synchronization of data such as work orders, defects, spare parts inventory, etc. When a certain wind turbine malfunctions on the monitoring platform, a Maximo system defect work order can be automatically generated, consisting of information such as the faulty wind turbine number, fault type, fault description, fault time, etc. The operation and maintenance personnel can view the work order allocation and processing status through the monitoring platform. After the fault is resolved, the work order status can be viewed through the monitoring platform, and the status information is synchronized in real time to the Maximo system, achieving full process management of fault handling. At the same time, the spare parts inventory data of the Maximo system is synchronized in real time. When replacement of spare parts is required for fault handling, the operation and maintenance personnel can query the inventory status and storage location of spare parts through the monitoring platform to achieve timely spare parts allocation and save fault handling time.

The platform and grid connected assessment and warning analysis system have achieved monitoring and warning of AGC/AVC performance indicators. The grid connected assessment warning

ISSN 2616-7433 Vol. 8, Issue 1: 7-12, DOI: 10.25236/FSST.2026.080102

analysis system synchronizes the AGC operation rate, AVC qualification rate, power regulation response speed and other indicator data of the wind turbine to the platform. The platform sets corresponding warning values, and when the warning values are exceeded, the platform automatically alarms. In addition, it has achieved linkage with the Dahua video surveillance system. The platform can call the video stream of Dahua Video Monitoring System through the interface, and embed real-time video images of key locations of the wind farm in the monitoring interface, such as the wind turbine nacelle, booster station control room, equipment storage location, etc. Users can access video footage of key locations to understand the on-site situation of the equipment while viewing its operational status.

4. Conclusion

The centralized and unified monitoring platform for wind power generation is built on a cloud native technology system, which solves many problems in the operation and management of wind power groups in the past through technical architecture, data collection, storage, and application functions. It provides strong support for the digitalization and lean management of wind power groups and has certain application value and demonstration significance. In the future, with the continuous development of technologies such as artificial intelligence, big data, and digital twins, wind power monitoring platforms will also move towards intelligence. On the one hand, deep learning algorithms are introduced to improve the accuracy of wind power prediction, early warning of equipment failures, and life prediction. On the other hand, enhancing normative analytical capabilities enables the system to progress from ‘describing current conditions’ and ‘analysing past performance’ to ‘forecasting future trends’ and ‘facilitating proactive decision-making’. This approach recommends optimal maintenance strategies and power generation scheduling plans, thereby establishing an integrated intelligent wind power operation digital twin system encompassing monitoring, regulation, control, maintenance, and optimisation.

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