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RESEARCH ON KEY TECHNOLOGY OF CONDITION MONITORING SYSTEM OF SUBSTATION EQUIPMENT

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Abstract

Substation equipment plays an important role in the power system, and its running state is directly related to the quality of work and life of power users. However, at present, the degree of automation of substation equipment status monitoring is not obvious, many areas still stay in the traditional operation and maintenance mode, this traditional monitoring mode has many adverse risks, easy to pose a threat to the life safety of operators, and even difficult to find substation equipment problems, unable to ensure the stable operation of the power system. At the same time, the system architecture, software structure, and database technology of the condition monitoring system are not mature, and there are still greater challenges. Based on this, the key technologies of the condition monitoring system of substation equipment are studied, such as software and hardware design, database design, *etc.*, and at last, the test research is carried out to better break through the above limitations. The results show that the condition monitoring system of substation equipment designed in this paper has strong feasibility, each module function can run reasonably, and the response time can be kept at about 3 s. The purpose of this study is to improve the intelligent level of condition monitoring of substation equipment and promote the development of substation business.

Key Words

Substation equipment, state detection, design

1. Introduction

Nowadays, with the rapid development of the power grid, the equipment under the jurisdiction of power supply companies at all levels is also increasing, resulting in the past management mode cannot meet the current needs [1]–[3]. In terms of operation and maintenance of power transformation equipment, the monitoring system of power transformation equipment can provide strong support for the status evaluation of power transformation equipment. It can not only reduce the workload of operation and maintenance personnel but also carry out real-time dynamic monitoring of power transformation equipment, and make timely judgement and early warning once anomalies are found [4]–[6]. At the level of local and city companies, the operation and inspection department, safety supervision department, and other business departments can observe all kinds of information of substation equipment in real time through the monitoring system to provide data support for the later development of the power grid, which shows that the condition monitoring system of substation equipment is very important [7], [8]. In this regard, in order to have an in-depth understanding of the condition monitoring system of substation equipment, this paper will design and study the hardware, design a substation equipment monitoring system that meets the current needs step by step, and finally test the function and operation performance of the system module. The results show that it can still maintain a good response state when the number of visitors is changed. It has strong robustness.

2. Hardware Design of Condition Monitoring System of Substation Equipment

The condition monitoring system of substation equipment needs to form a unified transmission architecture system with the current business system. The overall hardware architecture of the condition monitoring system of substation equipment can be divided into two systems: inside substation and outside substation. The substation includes condition monitoring device, sink node, edge IoT agent, and substation-integrated data network switch. Outside the substation, the PMS system server, monitoring database server, and substation equipment monitoring system server are included [9], [10]. The monitoring device is capable of data acquisition, processing, and communication. The transformer equipment produced by different manufacturers has the problem of incompatibility. The condition monitoring device of the transformer equipment in this paper designs a general monitoring device according to the type of the monitored equipment and the

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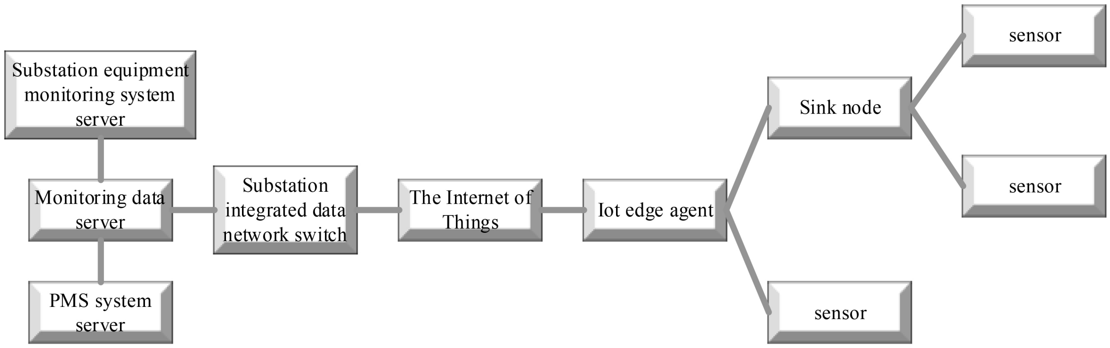

Figure 1. Hardware design of condition monitoring system of substation equipment.

type of monitoring parameters. For example, transformer equipment needs to monitor its top oil temperature index, so the compatibility of different transformer specifications from different manufacturers can be met with the help of the general monitoring device. The monitoring device and the upper-layer sink node can communicate with each other through different communication methods, such as optical fibre, wired, and wireless, according to actual needs. In order to prevent the monitoring loss caused by communication interruption, all types of monitoring devices comply with unified data specifications, that is, monitoring data transmission and processing are completed from the monitoring device. The aggregation node has the ability of information interaction and data processing, and can link the collection and control terminal to complete the collection of attribute information of the perceived object. At the same time, the data processed by customised business applications can be sent to the edge IoT agent. Among them, the edge Internet of Things agent is a device for unified access, real-time calculation, and data analysis of various monitoring devices, which can realise the adaptation of various communication methods and protocol protocols. In general, the hardware design of the condition monitoring system of transformer equipment is shown in Fig. 1.

3. Technical Architecture Design of Condition Monitoring System of Substation Equipment

After analysis, the condition monitoring system of substation equipment will choose Spring MVC as the technical architecture of this system, which has the advantages of strong reuse, low coupling, high maintainability, and open deployment [11]. With the help of the three-layer design of the data access layer, business logic layer, and presentation layer, a variety of software development technologies are organically combined to form a complete system. The specific technical architecture is shown in Fig. 2.

It can be seen that the data required by the business can be displayed according to user requirements, and various graphs can be generated according to different dimensions to realise the visual transformation of the data and help users use the entire system efficiently. In the business logic layer, it can reflect the characteristics of AOC and IOP of Spring architecture, process user requests, CAC

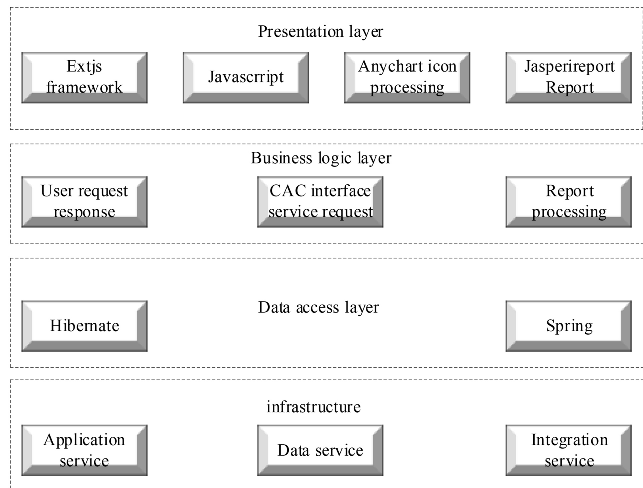

Figure 2. Technical architecture of the condition monitoring system of substation equipment.

interface Service requests, and report processing requests through service, and transmit the processing results back to the presentation layer. In the data access layer, with the help of the NHibernate technology framework, it accepts the call and specific parameters from the business logic layer, contacts with the underlying database, realises the operation of the data or data set, returns the operation results to the business logic layer, and provides database access support for the system.

4. Function Module Design

In the function module design link, this paper mainly designs and studies the key status monitoring module, operation monitoring module, device management module, and system management module, as shown below.

4.1 Status Monitoring Module Design

After the technical framework design of the system is completed, the status monitoring module can be designed, which consists of data acquisition, data processing, and data storage functions. Among them, the data acquisition function is responsible for the collection, processing,

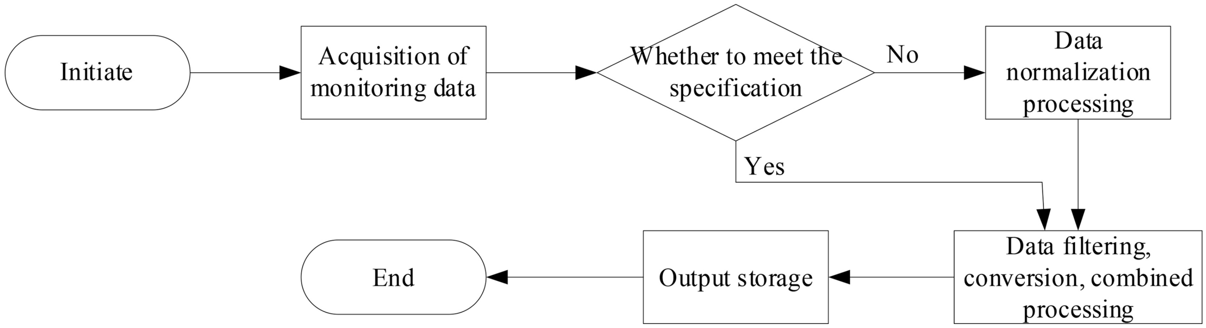

Figure 3. Design of condition monitoring module.

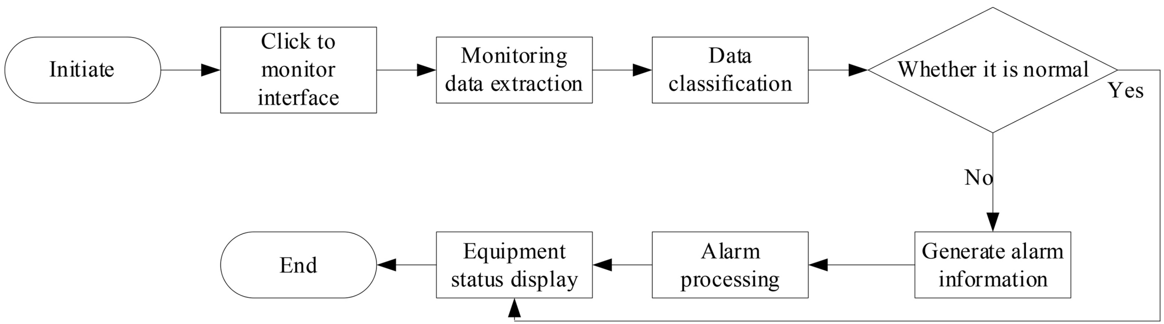

Figure 4. Design of operational monitoring module.

and storage of monitoring data, and the specific status monitoring process is shown in Fig. 3.

4.2 Design of Operation Monitoring Module

The operation monitoring module is composed of status judgement, alarm processing, status display, and data retrieval. The operation monitoring module extracts device monitoring data from the detection database and determines the status of various monitoring parameters of various transformer equipment according to the alarm threshold set in the system. When a parameter is abnormal or in the alarm state, the alarm information is generated. After receiving the alarm information, the operation and maintenance personnel can handle the alarm information, such as alarm information checking, alarm information locating, and alarm information forwarding. Figure 4 shows the operation process of the monitoring function.

4.3 Device Management Module Design

The function of the device management module is to professionally debug and maintain the substation equipment data shared by the PMS system, so as to form the equipment database, and provide a series of basic functions, such as data entry, new equipment entry, delete equipment entry, activate/close equipment, change equipment entry, and retrieve equipment. The device management function is mainly to operate the device data. When the user performs the device management operation, the data generated after the user operation is verified. The verified data will be stored in the device database and finally delivered to the station control terminal, which will further configure the device, while the data that fails the verification will be temporarily stored and wait for the user's further operation. The operation flow of the specific device management function is shown in Fig. 5.

4.4 System Management Module Design

The real-time monitoring system of substation equipment needs to be configured and maintained. The system management module can realise the configuration function of the system itself and monitoring items. The system management functions include maintaining common codes, managing system logs, setting monitoring items, and configuring alarm scripts. The system management function running the process database is shown in Fig. 6.

When a user configures a configurable item, the corresponding configuration data is generated. After verification, the configuration data is stored in the corresponding configuration database and delivered.

5. Database Design

The relationship of the database model of the condition monitoring system of substation equipment is shown in Fig. 7.

It can be seen that the database does not depend on the specific hardware environment and database management system. In the design of the database model, the relationship between various types of data is close and clear, so the design of the status monitoring system of substation equipment is carried out around the relational database, and the status monitoring substations of substations of substations carry out the real-time transmission of

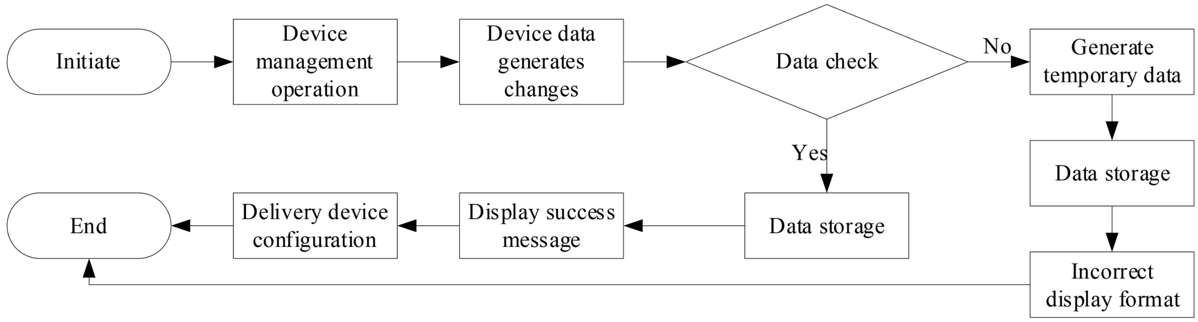

Figure 5. Device management module design.

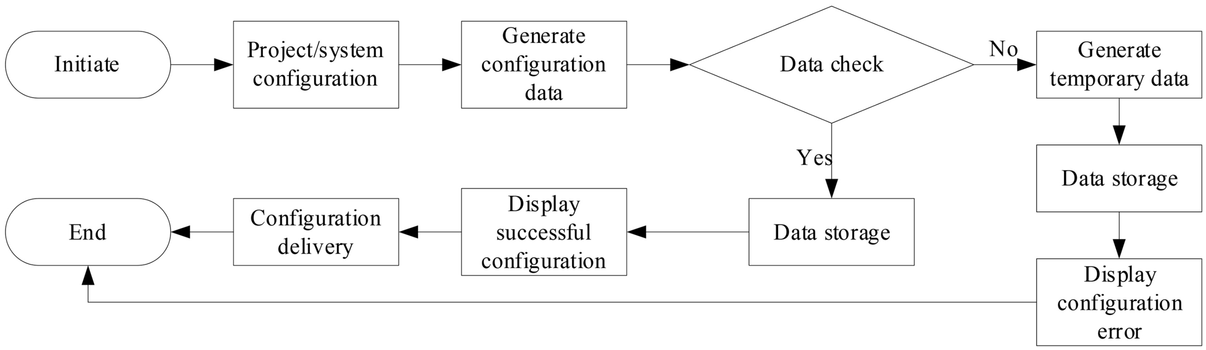

Figure 6. System management module design.

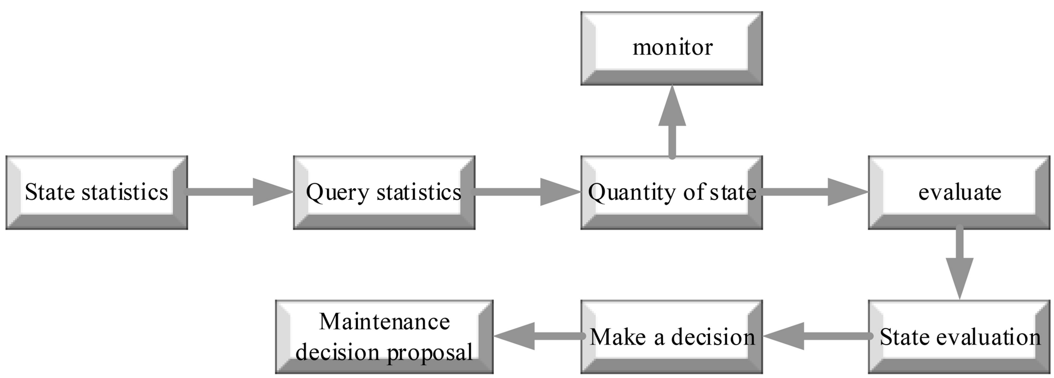

Figure 7. Database model relationship.

information and data through the integrated data network, real-time transmission of status monitoring substation information can be achieved for each substation. On the basis of the unique code of equipment in the production management information system, all data in the condition monitoring information database of substation equipment are identified, which is conducive to other functional components to access the data, saving the trouble of format conversion and improving the access efficiency. Due to the variety of monitoring equipment and monitoring data types, with the continuous operation of the system, the amount of data in the database will increase. If the design of single database and single table is used, the data table space will be confused under the quantisation data, which will drag down the operation of the entire system. In this regard, the database needs to be segmented, subdivided again according to the data table and index content, and processed in layers according to the principle of sub-database and sub-table technology, to ensure that the data can meet the response timing requirements during the operation process, and leave enough space for data expansion. The database is divided according to the time range of data receiving, and then divided according to the type of equipment received and the type of monitoring data, as shown in Fig. 8.

6. System Indirect Port Design

In order to ensure the unobstructed information transmission between systems, port design is carried out. All functions of the condition monitoring system of substation equipment are deployed in the condition monitoring application, which belongs to the subordinate system of the production management system (PMS). The PMS provides

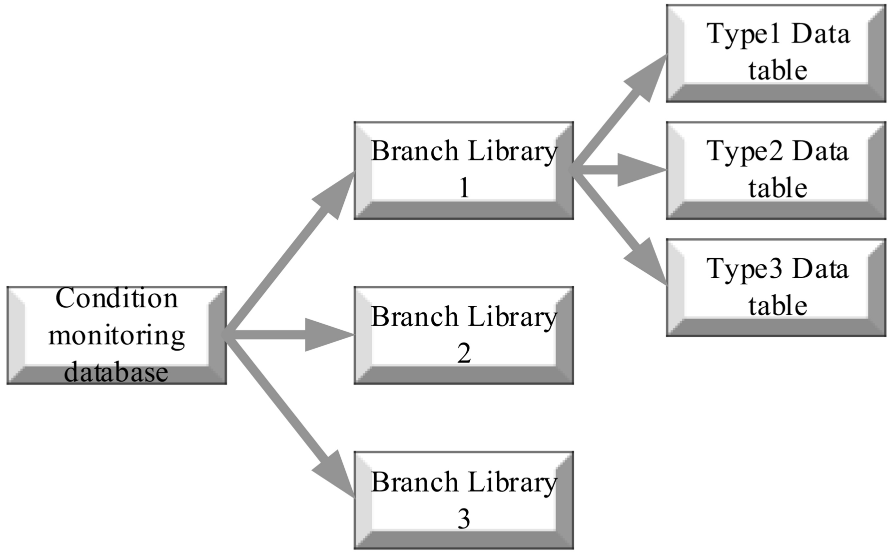

Figure 8. Device type monitoring data type.

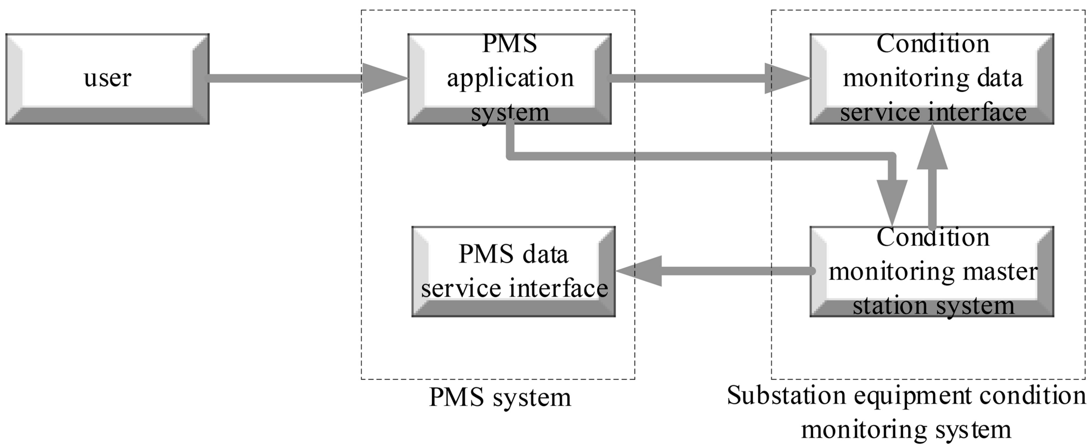

Figure 9. Indirect port design of the system.

the basic data, such as the equipment ledger as well as the main line diagram and physical model of the substation to the real-time monitoring system to generate the monitoring model. Provide monitoring scores to the PMS condition inspection submodule [12]. The service interface adopts the WebService protocol and the call of the service interface. The PMS will inquire the status monitoring data in the master station system and analyse and evaluate the score, and then display it according to the submodule on the page of the equipment defect management submodule and the status evaluation submodule of the PMS. In addition, the master station system will also query the account information under the user's authority in the PMS and process it before displaying it on the page of the master station system. The specific design is shown in Fig. 9.

7. Transformer Equipment Condition Monitoring System Test

In order to test the feasibility of the condition monitoring system design of substation equipment, the login function, condition monitoring function, operation monitoring function, and performance of the system are tested and studied, and the results were shown in Table 1, Table 2 and Table 3, respectively. The specific test situation is as follows.

It can be seen that all functions of the real-time monitoring system of the status of the substation equipment can operate normally and meet the design requirements. In order to ensure that the condition monitoring system of substation equipment can meet the needs of users in terms of performance indicators, the performance of the system is tested, and the test results are shown in Table 4.

It can be found that the system performance is stable, the resource consumption is stable, the response time is within 3 s, and there is no crash or abnormal situation. In addition, the test shows that when the number of concurrent requests is 400, the CPU utilisation of both the application server and the database server can be maintained at about 30%, the maximum memory utilisation of the application server is 35%, and the maximum memory utilisation of the database server is 45%.

Table 1
Test Cases of System Login Function

Serial number	Input and operation instructions	Evaluation criteria	Expected test result	Actual result
A	Enter the wrong username and password.	Whether the system recognises incorrect user names and passwords.	The system displays that the user name and password are incorrect, and asks the user to re-enter the password.	Consistent with expected results
B	Enter the wrong username and password three times.	Whether the system can exceed the number of incorrect login attempts.	The user name or password is incorrect. If the number of times exceeds the limit, try again 10 min later.	Consistent with expected results
C	Enter the user name, password, and check code correctly.	Check whether the system identifies the user type according to the correct user name and performs the corresponding function interface.	Successfully log in to the system main interface.	Consistent with expected results

Table 2
Test Cases of System Condition Monitoring Function

Serial number	Input and operation instructions	Evaluation criteria	Expected test result	Actual result
A	Select a substation equipment by index	Check whether the system can correctly display the status information of the substation equipment	It can display the status information of the selected transformer equipment	Consistent with expected results
B	The query page is displayed to query monitoring type options	Check whether the complete status information of the substation equipment can be queried	The interface data bar can accurately screen out all the status information about the substation equipment	Consistent with expected results
C	The statistics page is displayed. Select a seasonal time range and warning level to collect statistics	Whether the monitoring data is statistical based on the time frame and warning level	It can accurately calculate the status data of substation equipment in a quarter	Consistent with expected results
D	Click the statistics button to view the statistics chart	Ability to generate statistical graphs based on statistical data	Ability to display statistical graphs of data	Consistent with expected results
E	Click the export button to set the path and format of the exported file	Whether statistics can be exported in the correct file format	Ability to export statistics according to established file formats	Consistent with expected results

8. Summary

In general, this paper first designs the hardware system of the substation equipment, such as the condition monitoring device in the substation, the sink node, the edge Internet of Things agent, and the substation-integrated data network switch. PMS system server, monitoring database server, and substation equipment monitoring system server outside the substation. Then, Spring MVC is selected as the technical architecture of the system, and a variety of software development technologies are organically combined to form a complete system with the help of the three-layer design of data access layer, business logic layer, and presentation layer. Secondly, the system function modules are designed, including condition monitoring module, operation monitoring module, device management module, system management module, and database. Through the design of hardware and software modules, the final condition monitoring system of substation equipment is determined. Finally, the feasibility and operation of the design of the condition monitoring system of the substation equipment are tested, and the results show that

Table 3
Run Monitoring Function Test Cases

Serial number	Input and operation instructions	Evaluation criteria	Expected test result	Actual test result
A	Click the menu button to enter the operation monitoring interface	Check whether alarm information is displayed normally	The alarm information of all devices is the same as that designed for the test database	Consistent with expected results
B	Select the desired combination of substation devices and click the monitor button	Whether it has the monitoring function of substation equipment	Ability to display selected transformer devices and status in composite monitoring	Consistent with expected results
C	Select an alarm and enter the alarm handling suggestion	Whether to support alarm processing	The alarm information on the monitoring page is processed. After you click, the alarm handling suggestion is displayed	Consistent with expected results

Table 4
Performance Test Results

Test scenario	Number of visitors	Maximum response time/s	Minimum response time/s	Average response time/s	Maximum number of motors per second	Success rate/%
Functional module testing	100	1.521	1.331	1.422	1952.55	99
Functional module testing	200	2.230	1.856	2.031	1983.66	99
Functional module testing	300	2.412	2.112	2.256	2005.45	99
Functional module testing	400	2.821	2.521	2.653	2026.14	99

the system performance is stable, the resource consumption is stable, the response time is within 3 s, and there is no crash and abnormal situation. In addition, when the number of concurrent requests is 400, the CPU usage of both the application server and the database server can be maintained at about 30%, the maximum memory usage of the application server is 35%, and the maximum memory usage of the database server is 45%. Although the research has made some achievements, there are still some shortcomings. For example, the degree of data exchange is not high, the equipment condition monitoring data can be transferred to the maintenance system in the future to improve the fault location accuracy of the maintenance system, accelerate the maintenance process, and reduce the impact of equipment faults. In the future, according to the construction requirements and overall framework of the power system monitoring platform, on the basis of the existing system construction results, the platform will be deepened and upgraded, and functional modules will be added to improve the shortcomings and improve the integrity of the structure. Through this research, the development of the power industry has been promoted, the monitoring efficiency and quality of the status of substation equipment have been improved, and certain breakthroughs and contributions have been made in the equipment status monitoring technology.

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