A condition based maintenance system for important auxiliary equipment of thermal power unit

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Abstract—Through the research and development of key technologies of condition-based maintenance for power generation equipment, a set of important auxiliary equipment condition-based maintenance system for thermal power unit has been developed, which realizes the functions of integrated display of equipment-related data, equipment modeling configuration tool, equipment condition monitoring, equipment deterioration trend warning, equipment fault diagnosis, equipment health status evaluation, maintenance decision-making and so on. By studying the comprehensive assessment model of health state of power generation equipment, the equipment can be analyzed and evaluated scientifically and comprehensively, and the health state of equipment can be controlled step by step, thus improving the reliability of equipment operation.

1. Introduction

With the development of China's power industry, the number and capacity of thermal power generation equipment have increased significantly, the maintenance task has become more and more heavy, and the cost of funds has also increased. Most generator units in China have adopted fixed cycle regular maintenance and post maintenance for a long time [1]. To a certain extent, there is the problem of over repair or disrepair of equipment, resulting in a huge waste of resources, which not only affects the normal operation of system equipment, but also brings hidden dangers to safety production. At this stage, the monitoring and maintenance management of some equipment of thermal power units are disconnected from each other, and the equipment condition detection systems are independent of each other and lack of information sharing, thus forming the problem of "information island" [2]. In order to overcome the above problems, a comprehensive condition based maintenance platform for thermal power unit equipment is developed in this paper.

From the early 1990s to the early 21st century, China's power industry absorbed foreign advanced experience and conducted appropriate exploration and pilot application of condition based maintenance technology [3]. Although it has achieved certain results, the condition based maintenance technology in this period is still in its infancy, and the monitoring and fault diagnosis technology related to condition based maintenance cannot meet the requirements for correct quantitative and positioning of equipment faults, and lack of corresponding experience and technical standards, and its practicability is lacking. Therefore, the condition based maintenance of some power plants is only a
named state, the actual implementation is not strong, and the effectiveness and superiority of equipment condition based maintenance technology have not been well demonstrated. In recent ten years, with the rapid development of Internet of things sensing technology, data mining technology, equipment monitoring and fault diagnosis technology, patrol inspection technology and artificial intelligence technology, the function and system of condition based maintenance system of thermal power units are becoming more and more perfect, and the practical technology of condition based maintenance is becoming more and more mature.

Condition based maintenance in a narrow sense is a predictive maintenance based on equipment condition monitoring and fault diagnosis. Based on the current actual operation state of the equipment, it adopts advanced condition monitoring and fault diagnosis methods to judge the status of the equipment online and in real time, identify the early symptoms of the fault, and evaluate the risk, so as to realize appropriate and necessary maintenance time adjustment and maintenance project decision-making. It must be pointed out that years of practice has shown that it is difficult to completely rely on narrow condition based maintenance in power generation equipment. Therefore, this paper aims to develop a condition based maintenance system for important auxiliary equipment in power plant, which takes on-line real-time condition monitoring as the core and integrates regular maintenance, predictive maintenance and fault maintenance. Through the establishment of a powerful data integration, data analysis and fault diagnosis platform, the comprehensive state management of important equipment in the power plant can meet the urgent needs of relevant personnel to comprehensively master the health state of equipment, which has good guiding significance and practical value for the implementation of condition based maintenance of power generation equipment.

2. System Structure

The related applications of the condition based maintenance system are centrally deployed on the cloud servers of the existing hybrid cloud platform of the power generation group. The cloud platform consists of real-time database servers, relational database servers, application servers, WEB servers, interface front-end servers and other cloud servers. The system display uses browser/server (B/S) mode, which power plant users can access through the browser. The network topology diagram of the system is shown in Fig.1.

![Fig.1 System Network Topology](image)

2.1. System development and application platform

Server uses Windows 2008 Sever as operating system and MS SQL SERVER as database service. Visual Studio 2012 (C#) is used as the server-side application software development platform. Using
Tomcat to provide WEB services, web page making uses FineReport, JAVA technology and other tools.

2.2. Database platform
This system uses SQL Server relational database and Haixun real-time database. Server-side applications collect data from the real-time database of Haixun on-line, and make real-time calculation based on the system configuration information of the acquired SQL Server, and write back the calculation results to the real-time database of Haixun or SQL Server.

SQL server is mainly used to store system related configuration information and some real-time calculation results. The system configuration information is divided into five categories: system management, equipment account, equipment condition monitoring, equipment condition evaluation and maintenance decision approval. The system management configuration information includes organization table, user role information, etc; Equipment account configuration information includes equipment static parameters, equipment real-time data configuration table, equipment defect record table, equipment manual input data configuration table, etc; Equipment condition monitoring configuration information includes equipment early warning group correspondence table, early warning model configuration table, vibration monitoring configuration table, etc; Equipment status evaluation configuration information includes equipment status scoring method evaluation configuration table, equipment status configuration evaluation configuration table, etc. The real-time calculation results mainly include equipment status evaluation result table and alarm information table. The update frequency is once per minute.

Haixun database mainly provides background computing program real-time data reading storage, as well as historical data reading functions. Background computing program uses real-time data reading interface to process and analyze the current equipment operation data, and saves the calculation results for display of WEB pages and query of historical results. The real-time database accumulates a large amount of historical operation data, which is the basis and premise of establishing the equipment condition monitoring model. By calling the historical data reading interface and combining the data mining method, the equipment status early warning model is established, and the real-time calculation results are saved to realize the equipment status monitoring.

3. System Main Functions
The condition based maintenance system of power generation equipment realizes the monitoring, comprehensive evaluation and maintenance decision-making of the health status of power generation equipment, improves the safety and reliability of power plant equipment and reduces maintenance consumption. The system functions include four modules: account management, equipment status detection, equipment status evaluation and maintenance and report. Equipment account management flexibly displays and updates equipment status, and realizes the whole life cycle management of equipment, including equipment status display, account modification, account query and maintenance decision approval query. Equipment condition detection, equipment condition evaluation and maintenance are the core functions of the system.

3.1. Equipment condition monitoring
(1) Early warning of equipment failure
The auxiliary equipment early warning function developed based on multivariable state estimation model[4–5] includes equipment current operation parameter similarity monitoring, equipment multivariable parameter early warning and equipment trend early warning. The historical trend of the overall similarity of the equipment is displayed according to the similarity of the current operating parameters of the equipment. The closer the similarity is to 1, the more the current operating state of the equipment tends to be normal. Real time track the deviation between the actual value and predicted value of relevant measuring points used in equipment modeling (including expected value, residual, similarity and other parameters), and judge the current deviation to judge whether it is normal state,
continuous monitoring state or abnormal state, so as to realize the early warning of power generation equipment failure and abnormality.

(2) Vibration monitoring and analysis

Vibration analysis is an important technical means of condition based maintenance of auxiliary equipment. Vibration analysis can judge the current health state of the equipment, and predict the time of equipment failure by comparing the current state and historical trend, so as to reasonably arrange the maintenance plan. The system also introduces early fault detection of peakvue signal auxiliary equipment. Compared with traditional vibration signals, peakvue technology can capture the instantaneous stress wave caused by early defects of bearings or gears[6], and improve the accuracy and reliability of vibration analysis.

The system installs the Internet of things online vibration monitoring instrument for important auxiliary equipment of thermal power unit, accesses the vibration signal, peakvue signal and other data, develops the vibration analysis and early warning function, and monitors the equipment vibration in real time. Due to the high sensitivity of peakvue signal, when an alarm occurs to a device, spectrum analysis and waveform analysis can be carried out on peakvue signal to find out the cause of fault.

(3) Offline state parameter manual input

This function mainly implements manual input of offline state parameters for different devices. According to the technical specifications of equipment condition maintenance, manual input and maintenance are required regularly for some indexes that cannot be monitored online. According to the job guide, this function can be used to import data online or with EXCEL, which is the data base for status score evaluation.

3.2. State evaluation and maintenance decision

Based on the on-line vibration monitoring of Internet of things, on-line state monitoring of mechanism model and data mining model, varies kinds of information such as DCS/SIS operation data and manual input data are employed to establish comprehensive evaluation of equipment state with the scoring system. This system have these basic features: standard scoring evaluation and decision-making, scoring standard and decision-making editing, configuration evaluation and decision-making, configuration evaluation logic editing, and management process of maintenance decision-making.

(1) Equipment state evaluation and maintenance decision based on scoring strategy

The equipment state is evaluated based on the "scoring method", and the system displays the overall state of the current equipment, the recommended condition maintenance strategy, and also provides a button to initiate the maintenance decision approval process. The evaluation value of each parameter is calculated according to the deterioration degree and importance of each index and the quantitative evaluation matrix of state quantity, which is displayed with the range of evaluation value in different colors. Based on the evaluation value, the evaluation index of the overall state of the equipment will be obtained through mathematical reasoning method, with which the condition maintenance strategy will be provided for on-site stuff combined with the type of equipment.

(2) Scoring standard and decision editing

This feature of proposed system provides the functions of creating, editing and viewing equipment status evaluation templates, and provides daily reference for operators. The evaluation values of different schemes are displayed for different template scoring standards. At present, the equipment has two scoring templates: one is the main template, which is mainly set based on the basic scoring method; The other is the comprehensive evaluation template, which mainly forms the comprehensive evaluation model of equipment based on the results of basic scoring method model, equipment similarity model and peakvue results of on-line vibration monitoring.

(3) Equipment state evaluation and maintenance strategy

The basic scoring method is used to configure the overall condition evaluation rules of the equipment and formulate maintenance policies. The corresponding rules are shown in Table 1.
| Equipment state evaluation status | Color displayed | maintenance strategy |
|----------------------------------|-----------------|----------------------|
| Evaluation value < =10           | normal blue     | Keep on operating    |
| 10 < Evaluation value < 20      | watchable yellow| Strengthen monitoring, analyze causes, track the deterioration trend of state quantity and take preventive measures |
| 20 < = Evaluation value < 30    | abnormal orange | cause analysis, formulate targeted measures and arrange maintenance in time |
| Evaluation value > =30          | serious red     | Arrange maintenance as soon as possible |

4. System application
A total of 81 auxiliary equipment of two power plants are included in the system in this phase. The functions of integrated display of relevant data of power generation equipment, equipment modeling and configuration tool, equipment status monitoring and early warning, equipment health status evaluation, maintenance auxiliary decision-making and so on are realized, which plays a supporting role in improving the reliability of equipment operation.

4.1. Application of early warning model
Take a forced draft fan (FDF) A in a 300MW power plant as an example. The modeling parameters of the early warning model of forced draft fan A include: generator power, moving blade of forced draft fan A, current of forced draft fan A, outlet pressure of forced draft fan A, inlet air temperature of forced draft fan A, motor coil temperature of forced draft fan A, motor bearing temperature of forced draft fan A and bearing temperature of forced draft fan A.

According to the current monitoring data, the current operation similarity of forced draft fan A is 0.9843, and there is no obvious abnormality in the trend of overall similarity and modeling parameter similarity, as shown in Fig.2. The modeling parameters take the current of forced draft fan A as an example.

![Fig.2 Early warning model of FDF A](image-url)
4.2. Application of scoring method equipment condition based maintenance model

Taking slurry circulating pump 4A as an example, the scoring condition based maintenance model includes motor bearing box temperature, pump bearing box temperature, motor vibration, bearing vibration and reducer vibration. According to the existing monitoring data, the current equipment alarm is abnormal, as shown in Fig.3. According to the analysis of the causes, the offline input motor vibration of 0.073mm exceeds the normal range, resulting in an abnormal state.

| Measuring Method | Degree of Importance | Parameter              | Degree of Detrimentation | Real-time data | Unit | Determination value | Evaluation value |
|------------------|----------------------|------------------------|--------------------------|----------------|------|---------------------|------------------|
| offline          | 3                    | motor vibration        |                          | 0.0730         | mm   | 8                   | 24               |
| offline          | 3                    | bearing vibration      |                          | 0.0020         | mm   | 4                   | 12               |
| offline          | 2                    | reducer vibration      |                          | 0.0700         | mm   | 4                   | 8                |

Fig.3 State details of slurry circulating pump 4A

5. Conclusion

The scientific maintenance management of power plant equipment is an important means of modern production and management, and one of the important measures to ensure the safe and economic operation of power generation equipment. Through the research of this paper, the following conclusions are drawn:

(1) The research and development of condition based maintenance technology of power generation equipment has very important practical significance, and the implementation of condition based maintenance of power generation equipment is imperative.

(2) The comprehensive evaluation model of equipment status based on the results of basic scoring method model, equipment similarity model and vibration on-line monitoring peakvue can realize the early warning of equipment fault and abnormal status, and play a supporting role in improving the reliability of equipment operation.

(3) With the continuous accumulation of equipment operation data and the continuous in-depth development of condition based maintenance, the judgment results of the model can gradually conform to the actual state of the equipment, and the setting of fault limit will be adjusted according to the specific equipment, so as to finally form a set of condition evaluation standards suitable for power plant equipment.

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