Research and Design of Safety Early Warning System for Key Equipment of Small Hydropower Units

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Abstract: With the improvement of equipment automation, safety warnings for equipment failures become rather important. This paper develops a small hydropower safety early warning system for several key equipment of small hydropower units. The system can analyze the unit, pressure pipe and governor and provide early malfunction warnings. At the same time, it summarizes the typical equipment failures. The mechanism, through the analysis of mass imbalance faults and the calculation of the counterweight angle, explains its accuracy and has certain practical value.

1. Introduction

With the rapid development of information technology and the rise of computer hardware, big data technology, intelligent power plants, industrial 4.0 and other related concepts are gradually being put-forward [1-2]. Various advanced production equipment is becoming complex. Once the operation status of a certain equipment deteriorates, if not timely repaired and warned, it will bring very serious economic losses to the production line and even the whole enterprise [3]. Any failure of the power plant production process not only directly affects the production and quality of electrical energy, but also may cause equipment damage and personal accidents [4].

At home and abroad, the research on online monitoring as well as analysis and diagnosis of hydropower units mainly focuses on the development and fault diagnosis methods of condition monitoring systems. However, current research results cannot meet the needs of the field [5]. China is one of the countries with the most abundant small hydropower resources in the world. In recent years, small hydropower has been vigorously developed because of its advantages of low investment, short development cycle and no pollution, and has made important contributions to China's energy problems. Most of them were built in the 1970s and 1980s [6] with low automation. Lack of scientific management and evaluation methods, electromechanical equipment is seriously aging and often maintained after accident, causing security risks.

In combination with safety management of small hydropower, this paper studies the state evaluation system which is suitable for key electromechanical equipment of small hydropower, establishes the safety early warning platform, and adopts the method of fault diagnosis based on mathematical model in aspects of multi-equipment integrated state monitoring technology, independent fault diagnosis and state on-line analysis, state maintenance, automatic analysis and evaluation, etc. to solve the state evaluation problems currently faced by small hydropower.
2. System Architecture Design

2.1 System hardware design
The safety early warning system of small hydropower key equipment designed by this paper consists of three parts: data processing system, signal acquisition system and sensor. The data processing system is composed of the main control workstation to complete the real-time monitoring, analysis and diagnosis application. The signal acquisition system contains intelligent data collector and DC power supply device, which is responsible for collecting sensor signals and other data access; the sensor can include measuring vibration, displacement, temperature and other types of equipment, which can be matched according to the needs of the monitoring part, and its structure is shown as below.

![System hardware structure diagram](image)

The unit vibration is measured by a speed sensor, and the servo displacement is measured by a cable sensor mounted outside the piston of the servomotor. The hardware data acquisition device is designed and developed through the PC104 embedded AT96 bus system. Real-time monitoring, data analysis, and system functions are completed through the main control station.

2.2 System software design
The system software is developed by Visual C++ which is object-oriented, the collector-side program is based on real-time embedded programming and the development platform is Borland C++, which is also object-oriented. The system logic structure is divided into three layers:

1) Data collection layer

The data collection layer obtains real-time data from the collector, including the vibration swing size, pressure pulsation size, governor operating state, unit guide vane opening, pressure pipe pressure, unit temperature value and so on. Received data is compressed in real time, then released and stored.

2) Data management layer

Data management layer mainly completes the management logic judgment of real-time data, automatic trend and diagnosis logic, data storage management, and the release of remote APIs corresponding to the background. The relational database is deployed on the central data server and implemented by MSSQL Server system developed by Microsoft Corporation.

3) Background interactive monitoring, analysis, and diagnosis application layer

The application layer mainly refers to the data mining function of the early warning system, including back-end monitoring, analysis, auxiliary diagnosis and so on. It includes a large number of analytical diagnostic modules, the most central of which is the interactive diagnostic module and its maintenance sub-modules.

3. Software Framework Development of System Fault Diagnosis Modules
A complete fault model diagnostic module consists of two modules that are independent of each other: an interactive fault model diagnostic function module running in the backend fault model diagnostic client software module, and an automatic execution logic module running in an application service program deployed on the application server.
3.1 Interactive fault model diagnosis module
The interactive fault model diagnosis module uses reverse reasoning mechanism to realize the fault model diagnosis process combining computer and human interaction. The data extraction, feature extraction and fault parameter matching are automatically completed by computer, while the conclusion and fault cause confirmation as well as fault input are done by human.

3.2 Automated fault model diagnosis module
The automated fault model diagnosis module runs on the analysis center application server which is operated automatically by schedule. Reverse reasoning mechanism is used to complete the fault model diagnosis process automatically by computer, including data extraction, feature extraction & fault parameter matching and conclusion & failure cause confirmation during the diagnostic process. The diagnostic rules for automated fault model diagnosis must be complete and reliable. Characteristic variables, fault models and matching parameters of the fault must be credible and can be expressed by computer formulas.

4. Research on Online Diagnosis Technology of Typical Fault Models
The faults of hydropower units are complex and mostly manifested in various forms [7-8]. Through generalization and summarization, this paper lists the typical fault characteristics of hydropower units and analyzes their fault mechanisms.

4.1 Hydraulic imbalance failure mechanism
The hydraulic imbalance force is caused by the uneven distribution of the flow along the circumference. The hydraulic imbalance caused by the irregularity of the roundness of the runner chamber mainly leads to changes of the swing frequency, the blade frequency and the multiple frequency of the tectum radial vibration, and linearly increases as the unit flow increases.

4.2 Electromagnetic tension unbalance failure mechanism
The electromagnetic unbalance force is mainly caused by the fact that the rotor of the generator is not round, the geometric center of the rotor is inconsistent with the center of rotation, etc. The obvious feature is that the unbalanced force is proportional to the excitation current, and the electromagnetic unbalance force reaches maximum when the generator is no-load. The unit swing vibration increases as the excitation increases.

4.3 Thrust head loosening failure mechanism
The looseness of the thrust head means that there is a gap between the inner hole of the thrust head and the journal. When the thrust head is loose, the vibration and swing characteristics of the unit are as follows: the dynamic axis attitude of the unit will suddenly change, and the vibration and swing of the unit will be large and small randomly, showing an unstable state. Moreover, the looseness of the thrust head may also make the crew difficult to drive. The looseness of the thrust head will cause a sudden change of the axis attitude, the unit swing and vibration, especially at the moment when the thrust bearing load changes such as the process of increasing the speed during boot and load changing. During these changes, the measured value of the swing and radial vibration of the unit will abruptly change, and the phase of the 1X component will also abruptly change.

4.4 Generator quality imbalance failure mechanism
The unbalanced force of a rotating machine refers to the mechanical imbalance force of the rotating part, which is an asymmetrical centrifugal force caused by the asymmetry of mass distribution in the rotating part of the rotating machine. For hydroelectric generating sets, mass imbalance is a problem that generators often encounter and is the easiest to determine. A rigid shafting system is used for a lower-speed hydro-generator set, which can approximatively regard the rotor shafting system as a rigid-rotor system with a single-plate structure, so the rotor mass imbalance can be approximatively described. The
swing and vibration changes caused by the mass imbalance are close to the square of the rotational speed, and the frequency of the change component must be the rotational frequency (1X).

4.5 Governor fault model
The system designed and developed for the governor system is mainly for the analysis of oil leakage and air leakage, including oil leakage outside the system, internal oil leakage and air leakage failure. It is mainly judged by the oil speed of the pressure cylinder.

4.6 Pressure steel pipe model
The system designed and developed for the pressure steel pipe system is mainly for the analysis of the hydraulic pressure and temperature change of the pressure pipe. The dynamic water pressure parameter mainly reflects the change of the flow pulsation pressure inside the pressure steel pipe and the expansion joint. The water pressure change is particularly prominent in the process of flushing, emptying, closing and opening the valve in the pressure steel pipe. Changes of dynamic water pressure directly affect the acceleration amplitude of stress and vibration of the component tested. The thermal expansion effect caused by the temperature change will cause the telescopic displacement of the pressure steel pipe. It is important to analyze the temperature effect on the operating state of the valve body by monitoring the temperature of the pressure steel pipe and telescopic section adjacent to the valve body as well as analyzing the relationship between the valve body, the pressure steel pipe and the telescopic control parameters with the temperature change.

4.7 Analysis of typical faults
Generally speaking, for hydro-generator sets, mass imbalance fault is a common fault. Here is an analysis for a unit with a mass imbalance fault in a power station, and the unit’s swing data in the +X+Y direction of lower bearing swing is shown in Table 1 below. The swing value increases continuously with the increase of the rotational speed, and the phase angle is basically unchanged, which can basically be judged as the mass imbalance fault.

| Measuring point                        | 50%nₑ   | 75%nₑ   | 100%nₑ  |
|----------------------------------------|---------|---------|---------|
| Lower bearing swing +X                 |         |         |         |
| Peak-to-peak value (μm)                | 109     | 187     | 250     |
| Amplitude (μm) ⊙ Phase (°C)            | 93 ⊙ 282| 176 ⊙ 282| 234 ⊙ 277|
| Lower bearing swing +Y pass frequency (μm) | 86      | 154     | 202     |
| Lower bearing swing +Y                 |         |         |         |
| Amplitude (μm) ⊙ Phase (°C)            | 80 ⊙ 190| 144 ⊙ 184| 176 ⊙ 179|

Through integrated and systematic judgment, calculation and analysis, suggestions based on the fault will be proposed: rotate counterclockwise by 150 degrees along the position of the key phase and try to counterweight the unit at the lower web of the generator rotor. Turn on the unit after counterweight and check the results. The counterweight results are shown in Table 2.

| Measuring point                        | 50%nₑ   | 75%nₑ   | 100%nₑ  |
|----------------------------------------|---------|---------|---------|
| Lower bearing swing +X                 |         |         |         |
| Peak-to-peak value (μm)                | 91      | 93      | 121     |
| Amplitude (μm) ⊙ Phase (°C)            | 16 ⊙ 244| 34 ⊙ 235| 30 ⊙ 201|
| Lower bearing swing +Y pass frequency (μm) | 30      | 64      | 106     |
| Lower bearing swing +Y                 |         |         |         |
| Amplitude (μm) ⊙ Phase (°C)            | 25 ⊙ 160| 54 ⊙ 154| 100 ⊙ 119|
5. Conclusion
This paper analyzes and studies the status of small hydropower units and summarizes the cause as well as the mechanisms of some unit faults. On this basis, a set of safety warning system for key equipment of small hydropower units is developed, which can mainly be used for equipment fault diagnosis and analysis of small hydropower units, pressure pipes, governor and its auxiliary machines. Through the analysis of the field measured data, test and analysis of the typical mass imbalance fault data of the hydropower unit, the system can effectively and accurately analyze the cause of the fault and correctly find the counterweight angle. In the future, the function of the small hydropower early warning system can be further increased, and the analysis and early warning of the power station can be carried out more effectively.

Acknowledgments
Research and Application Demonstration of Safety Early Warning System for Key Equipment of Small Hydropower Units in Guizhou Power Grid, Project No.: 066600kk52170083

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