Safety-Oriented Visual Condition Monitoring System of Hydro-Turbine Generator Sets

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Abstract

Intuitive and efficient monitoring system is a reliable guarantee for the security of Hydro-turbine Generator Sets (HGS). A safety-oriented visual monitoring system for HGS was developed. Under the Hydropower station Optimal Maintenance Information System (HOMIS) integrated monitoring platform, combined with equipment engineering 3D visual models and monitoring means, the visual query and the safety inspection of HGS was carried out; while under the “safety monitoring” of the HGS, real-time condition monitoring and real-time alarm was implemented. The system can help maintenance personnel to carry out safety analysis and fault diagnosis of abnormal equipment, which can help them avoid unexpected incidents. The safety-oriented visual monitoring system has successfully been applied in Gezhouba Hydropower Station and prevents safety incidents of HGS.

Keywords: Hydro-Turbine Generator Sets, Condition Monitoring, 3D Visualization, Safety-Oriented

1. Introduction

The safe and stable operation of large-scale Hydro-turbine Generator Sets (HGS) has close relationship with power system safe operation. In order to prevent catastrophic accidents and keep safe and stable operation for HGS, studying the safe and stable operation problem of large-scale HGS, finding out hidden safe operation danger timely, and making effort to improve the equipment monitoring and maintenance level have become serious problems that need to be solved urgently [1].

The application of condition monitoring and fault diagnosis techniques can avoid equipment unexpected downtime, minimize downtime, reduce maintenance costs, extend equipment life. It provides a wealth of valuable information for optimal equipment use and carrying out maintenance, and has great economic benefits. At present, the hydropower stations are equipped with a large number of special detection equipment and on-line condition monitoring systems, which have collected vast amounts of monitoring data. However, on the one hand, the system lacked intuitive tools to help local staff to express their demands visually; on the other hand, even if the people can express their needs, but the system did not process the data and showed a lot of information [2]. It is difficult to organize them effectively and implement fault detection and diagnosis, which cannot guarantee the safety of HGS equipment.

In order to ensure the safety and reliability of HGS equipment, the intuitive and efficient monitoring and analysis system must be provided. In this paper, a safety-oriented visual monitoring system for HGS was developed. Under HOMIS [3] integrated monitoring platform, combined with equipment engineering 3D visual models and monitoring means, the visual query and the safety inspection of HGS was carried out; while under the “safety monitoring” of the HGS, real-time condition monitoring and real-time alarm was implemented; then, the system can help maintenance personnel to carry out equipment status and fault diagnosis of abnormal equipment, which can associate them handle the equipment status and avoid unexpected incidents.

2. System Framework of Visual Condition Monitoring

Through HOMIS data integration [3], the operational data were accessed to carry out the condition monitoring of HGS, in which contain the HGS and auxiliary systems data. The condition monitoring information and security analysis interact with the 3D engineering visual
models [4-6], real-time database and historical database, and the visual monitoring of the HGS were developed. The system framework was shown in Figure 1.

The equipment of the HGS was displayed intuitively in visual environment, and the visual safety inspection, condition monitoring, alarm and security analysis of the HGS was realized. This system can help local staff to access the equipment state and carry out fault diagnosis, and plan the safety maintenance work ahead of schedule.

![Figure 1. Visual condition monitoring of HGS](image1.png)

3. System Approach and Realization

3.1 Visual Safety Inspection

The visual inspection of HGS safety includes equipment inquiry, equipment status inquiry and operating state inspection.

3.1.1. Equipment query

The equipment query contains physical properties and structural characteristics query. The 3D visual model not only includes all the geometric dimensions and structural information of HGS equipment, but also includes the most of the physical characteristics information. This is a great help of geometric characteristics (such as surface area, volume) and physical characteristics automatic calculation (such as quality, the center of gravity, rotational inertia, etc.) and query. The physical characteristics inquiry of hydro turbine’s runner was shown in Figure 2.

![Figure 2. Physical characteristics query of hydro turbine’s runner](image2.png)
3.1.2. Equipment status query

Equipment status query mainly includes sensor placement status and monitoring device status. Sensor placement status is the basis of condition monitoring and security analysis of HGS, which determines the reliability of the monitoring system data. Therefore, the visual display of sensor placement status is very necessary.

The sensor placement statuses usually have working, not installed, and error status. And it can be expressed as a piecewise function $f(s)$:

\[
 f(s) = \begin{cases} 
 1 & \text{working} \\ 
 0 & \text{not installed} \\ 
 -1 & \text{error} 
\end{cases}
\] (1)

The sensor status was mapped in the condition monitoring system. One of the status visual mapping examples was shown as table 1.

<table>
<thead>
<tr>
<th>Status</th>
<th>Visual mapping(color)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working</td>
<td>Green</td>
</tr>
<tr>
<td>Not installed</td>
<td>Gray</td>
</tr>
<tr>
<td>Error</td>
<td>Red</td>
</tr>
</tbody>
</table>

On the basis of status mapping and 3D visualization model of HGS, the equipment status visualization was represented. As an example, the visual representation of sensor placement status of HGS was shown as Figure 3. The sensors placement status was shown clearly: some sensors are working, such as turbine guide vibration, the air cooler temperature; some sensors are not installed, such as head cover noise, and tail water noise; while the sensor in upper guide vibration + Y was broken, so the sensor status was “red”, which reminded the maintenance staff to focus on this sensor.

3.1.3. Operating state inspection

A variety of visual display methods were integrated and monitoring characteristic operating data were coupled displayed in the condition monitoring system based on the HOMIS monitoring data integration and 3D visualization model.

In order to carry out safety inspection of the HGS operating state, combined with the operating characteristics of the HGS, the temperature color mapping technology [7] was used to draw the bar graph of operating state data. The color of the bar graph represents the equipment condition. At the
same time, the bar graphs have implemented the centralized display or independent display, and the height and color of the bar graph vary along with the operating state changes (Figure 4).

3.2 Visual Condition Monitoring

3.2.1. Real-time condition monitoring

The real-time condition monitoring of HGS was launched based on 3D visualization: the equipment model was shown by 3D visual simulation, the operating states were digitized [8]. And various components of the models and motion were moved to the computer screen directly, the real-time condition monitoring information was displayed with the visual model that driven by the real-time data, and the real-time operating state of HGS were simulation displayed.

3.2.2. Real-time alarm

The real-time alarm was made on the basis of threshold analysis. Suppose $C_t$, $C_{\text{min}}$, $C_{\text{max}}$ were the equipment states (or performance indicators) and its lower limit, upper limit respectively, and sometimes, the $C_t$ has the lowest limit $C_{\text{tmin}}$ and maximum limit $C_{\text{tmax}}$. These threshold limits are usually refer to the relevant standards or provisions provided by equipment manufacturers. If:

$$\text{min } C_t \leq C_t \leq \text{max } C_t$$

the equipment is in normal state, otherwise the equipment is failure.

The abnormal states of equipment include alarm level and protection level abnormal, and the relation of states range and safety operating states was shown as Table 2.

<table>
<thead>
<tr>
<th>NO</th>
<th>States range</th>
<th>Operating states</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$[C_{\text{min}}, C_{\text{max}}]$</td>
<td>Normal</td>
</tr>
<tr>
<td>2</td>
<td>$C_t &gt; C_{\text{max}}$ or $C_t &lt; C_{\text{min}}$</td>
<td>Abnormal (alarm level)</td>
</tr>
<tr>
<td>3</td>
<td>$C_t &gt; C_{\text{tmax}}$ or $C_t &lt; C_{\text{tmin}}$</td>
<td>Fault (protection level)</td>
</tr>
</tbody>
</table>

In addition, if the monitoring states data tends to outside the scope of normal threshold and the pace of change is fast, it is believed that the equipment was failure. For the failure equipment, in order to allow users to become familiar with equipment states in natural and intuitive way, the color mapping scheme was adopted based on the staff’s work habits. Combined with bar graph display technology and
equipment threshold, the real-time states were represented in a natural and intuitive environment, and the real-time states alarm was issued.

When the equipment is in normal operating state, the operating state variable (such as temperature data) was displayed with green color; when the equipment is abnormal, the operating state variable was displayed with yellow and prompted the user to concern this state variables; and when the equipment is failure, the equipment is in protection level, and the variable was displayed with red to remind the user to focus on this state variable.

As shown in Figure 5 the real-time monitoring alarm was issued, the upper guide bearing vibration and supporting cover vibration variables displayed with yellow color were up to 400um, and the turbine guide bearing vibration (+Y) variable displayed with red color was up to 516.5um, which exceeded the vibration threshold ([0,400um]) a lot.

3.3 Safety Analysis

In order to carry out equipment safety precautions of the HGS, the visual condition monitoring system provides the “safety analysis” interface based on the 3D visual models and visual condition monitoring data, which facilitates the staff to execute the equipment safety analysis during the condition monitoring process.

3.3.1. Analysis methodology

The visual condition monitoring system imitates a variety of analytical methods used by the analysts, and make safety analysis to HGS equipment with HOMIS conditions associated technology [8]. The safety analysis of HGS mainly includes threshold analysis, correlation analysis [9] and comparative analysis. Firstly, the analyst inspects the 3D visual models, inquiry the operating data and checks the equipment status by making use of threshold analysis. If the equipment was abnormal, the equipment correlation analysis and operating states comparative analysis were employed to find out the abnormal equipment. Then the fault detection and fault diagnosis procedure was launched, the fault tree analysis [8] and model based fault detection methods [10-12] were used to analyze the possible causes of the malfunction. At last, the suspect failed equipment was listed, which can make a reference for the equipment diagnosis decision and maintenance, and avoiding the risk of security incidents.

The operating states comparative analysis was implemented on the similar historical conditions of HGS. In a given period of time, the similar conditions were searched automatically. Then the states parameters were extracted in the similar working condition of the HGS, and the state parameters were compared. With the help of states parameters comparing, the equipment performance was detected. For
example, the vibration data comparative analysis in different time periods can check the stable balance performance of the HGS is in good status or abnormal status.

3.3.2. Case study

In July 2010, the vibration of a HGS increased abnormally in Gezhouba hydropower station, while abnormal noise occurred. The curve of the peak to peak value in 2010-7-20~2010-8-11 was inquired through the Internet, and the vibration data comparative analysis was launched as shown in Figure 6. It can be seen that the vibration increased suddenly on 31, July while the variation was relatively stable before.

![Figure 6. Vibration data comparative analysis](image)

Then the vibration raw data was related automatically by HOMIS and the curve was shown in Figure 7. We can find that there were 4 times rotation frequency obviously in the vibration signals of the upper guide bearing $X, Y$ (a and b in Figure 7) and the turbine guide bearing $X, Y$ (c and d in Figure 7).

![Figure 7. Vibration raw data](image)

Based on the fault detection results and the analysis methods, a preliminary conclusion that the abnormal was caused by the unbalance inflow water of the turbine was made. Then the HGS was shut down and a check was performed. It was found that there was a tree boot (in Figure 8) blocked in the guide vane of $X$ direction of the HGS, which caused the disorder water flow and the vibration fault. The visual monitoring system avoids a structural damage and prevents an accident of HGS.
4. Conclusion

Under HOMIS integrated monitoring platform, combined with equipment engineering 3D visual models, a safety-oriented visual monitoring system for HGS was developed. The visual query and the safety inspection of HGS were carried out; and the real-time condition monitoring and alarm was implemented. With the help of safety analysis of HGS equipment, the local staff can handle the equipment state and avoid unexpected equipment incidents.

The safety-oriented visual monitoring system for HGS has been successfully put into service in Gezhouba Hydro Power station. It is of great significant to the improvement of the equipment safety monitoring and progressive realization of condition-based maintenance for the hydro-turbine generator set equipment.

5. References

