Experimental Study on On-line Monitoring Technology of Hydropower Station Induced Discharge

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Abstract. In this paper, the water level, tail water level and active power of hydropower generating units are collected and transmitted in real time by using the water level gauge, power collector and other measuring and sensing instruments. Using MATLAB least square fitting simulation algorithm, the three-dimensional surface function of hydraulic turbine characteristics is obtained, and the efficiency of turbine operating point is calculated based on this function. Through the calibration calculation of the background data center, the reference flow of the hydropower station can be obtained on-line in real time, and verified by the comparison test between the reference flow system of the hydropower station and the Nanrui fu911 ultrasonic flowmeter. The results show that the flow measurement data of hydropower station reference flow system and ultrasonic flowmeter have the same change trend, and the flow measurement data of hydropower station reference flow system meet the requirements of class I accuracy class < 9% specified in GB 50179-2015 “Specification for river flow measurement”, which provides an effective method for on-line monitoring of reference flow of hydropower station.

Keywords: Hydropower station; diversion flow; on-line monitoring; experimental study.

1. Introduction

The reference flow of a hydropower station, also known as the working flow of a hydropower station, refers to the amount of water used by the hydropower station to generate electricity through buildings and turbines per unit time. The measurement of unit flow is the basis for real-time monitoring and evaluation of the energy indicators of hydro-generator units [1], and it is also the core of the measurement of hydro-turbine power parameters [2]. The application of on-line monitoring technology for hydropower station flow is of great significance for strengthening the assessment and management of power station technical and economic indicators, realizing the automation of water balance calculation, and improving power generation efficiency.

Online monitoring technology has been applied to monitor unit efficiency, automatic inspection of hydropower station status [3], hydropower station discharge flow [4], power cable line operation monitoring [5], etc., and it is also widely used in hydropower station flow and head monitoring [6]. At present, the on-line monitoring methods used for water turbines, pumps and large pipelines include electromagnetic method, ultrasonic method, and differential pressure method. Among them, the application of differential pressure method to measure flow is relatively simple, the cost of
determining the flow rate is low, and it has almost no impact on the normal operation of the turbine unit [7], but the hydraulic turbine pressure differential coefficient calibration limits the application of the turbine volute differential pressure flowmeter [8]. Most hydropower plants are equipped with flow monitoring equipment such as multi-acoustic ultrasonic flow meters and electromagnetic flow meters. However, due to factors such as high failure rate of equipment and difficulty in accuracy calibration in actual use, the installed equipment is left unused. The economic operation of hydropower plants has caused certain impacts.

Based on the classic fluid mechanics theory, this paper studies the mathematical modeling of the turbine flow rate. Using real-time collected data of the reservoir water level, tail water level and the active power of the generator set, the hydraulic turbine characteristics are three-dimensional curved surface digital simulation to calculate the turbine operation. The efficiency of the operating point is calculated by calibrating and calculating the quoted flow of the hydropower station, which explores new technical methods for online monitoring of the quoted flow of the hydropower station.

2. Turbine Flow Rate

The work of a hydropower station is to convert water energy into electrical energy, and its working parameters mainly include head, flow, efficiency, and electric power [9]. Turbine flow is an important parameter for unit operation efficiency monitoring and economic operation. Determining a reasonable flow of water turbine is the basis for improving hydropower efficiency. The formula for calculating the flow rate of a single unit of a hydropower station, such as the hydrological data compilation specification, and the compilation of water conservancy technical standards are:

\[
Q = N / 9.81H\zeta_1\zeta_2
\]  

(1)

Where \( Q \) is the flow of a single turbine (m\(^3\)/s); \( N \) is the unit's active power (kW), which is collected by the power meter of the hydropower station automation system; \( H \) is the power head of the turbine (m), which is related to the water level, a parameter of tail water level, along-path loss and local loss; \( \zeta_1 \) is the efficiency of the turbine. In this paper, the efficiency of the operating point of the turbine is calculated from the three-dimensional surface digital simulation of the characteristics of the turbine; \( \zeta_2 \) is the generator efficiency, which is a fixed value, and the value is made by the generator Provided by the factory.

3. Turbine Efficiency Simulation

Turbine efficiency refers to the ratio of the output and input power of the turbine, which is one of the basic working parameters of the turbine. In engineering, by collecting data on the reservoir water level, tail water level and active power of the generator set, real-time online monitoring of the flow rate of a single unit of a generator set can be realized. How to accurately monitor and calculate the flow rate of a single turbine in real time is the most critical factor. The efficiency of the operating point.

Turbine characteristic curve is used to express the hydraulic characteristics of water turbine energy conversion and cavitation under different working conditions. It is an important basis for the optimization of hydraulic turbine design, economic operation and digital simulation of hydraulic transition process. These characteristics are the external manifestations of the internal flow law of the hydraulic turbine and are called the characteristics of the hydraulic turbine. The characteristics of water turbines are often obtained through model tests or field tests. The performance parameters of the water turbines obtained from the tests are drawn into different forms of curves, that is, the characteristic curves of the water turbine. The curve contains variables such as turbine speed, flow, output, and turbine efficiency, which depicts the working conditions of the turbine. For example, the characteristic curve of HLA855 turbine is shown in Figure 1 [10]. Digitize the characteristic curve of the turbine, and obtain the relationship between the head, output, and efficiency of the turbine through function calculation.
The digitization of the characteristic curve of the hydraulic turbine model is an important part of the automatic drawing of the operating curve by the computer. As a highly efficient numerical calculation and visualization software, Matlab has good graphics processing capabilities and can easily perform complex operations such as interpolation and drawing [11]. Figure 2 shows the test data of head, output and efficiency of each typical operating point of the hydraulic turbine characteristic curve imported in the Matlab environment, through the “GNU Scientific Library” C language library and the Matlab “curve fitting tool” least square fitting function, Perform interactive calculation and fitting to obtain the three-dimensional surface function of the turbine characteristics. It can be seen from the figure that the three-dimensional surface function of the turbine characteristic fitted by Matlab can express the characteristic curve of the turbine more intuitively. Through the above numerical simulation calculation of the characteristic curve of the turbine, the operating efficiency of the turbine under any head and power can be obtained.

**Figure 1.** Comprehensive characteristic curve of hydraulic turbine unit.

**Figure 2.** Three-dimensional surface function of hydraulic turbine characteristics (x-axis is the head, y-axis is the output; z-axis is the efficiency).

4. Engineering Test Verification of Online Monitoring System for Cited Flow in Hydropower Station

4.1. Overview of Dongshuixia Hydropower Station on the Taulai River

The Dongshuixia Hydropower Station on the Taulai River is located in the upper canyon section of the main stream of the Taulai River in Sunan County, Gansu Province. The powerhouse is about 70 km away from Jiayuguan City. It is the fifth cascade planned and uses water diversion to generate
electricity. The power station is composed of a water diversion hub, a water diversion system and a power plant. The reservoir has a storage capacity of 112,800 m³, a diversion flow of 32.4 m³/s, and a design head of 189 m. The power station hub is located at the Dongshuixia Xiakou, about 4 km downstream of the Jingtieshan mining area, with a total of 3 17.6 MW units installed with a total installed capacity of 52.8 MW and an average annual utilization hour of 4602 h.

4.2. Engineering Test Verification

In April 2017, the “on-line monitoring system for hydropower station citation flow” designed in this paper was installed and debugged at the Dongshuixia Hydropower Station on the Tulai River. In May 2017, it was installed on its 2# unit with the NARI UF- installed in the power station. The 911 large-diameter ultrasonic flowmeter was verified by a comparative test. Figure 3 shows the change of the volute inlet pressure at different times. The change of the volute inlet pressure is within 0.04MP. Figure 4 shows the change of the unit's active power at different times. The unit's active power reaches its maximum value at 13:30 and the unit's active power reaches a minimum at 16:40. The comparison of flow measurement data between the online flow monitoring system and the ultrasonic flow meter of the hydropower station is shown in Figure 5. It can be seen from the figure that the online monitoring system for reference flow of hydropower stations and the ultrasonic flow meter have exactly the same changing trend. The minimum error of the flow measurement data from the online flow monitoring system of the hydropower station and the ultrasonic flow meter measurement data is 0.89%, the maximum error is 3.72%, and the average error is 2.00%.

![Figure 3. Variation trend of volute inlet pressure at different times.](image-url)
4.3. Analysis of Test Results

By analyzing the error between the flow measurement data of the online flow monitoring system of the hydropower station and the flow measurement data of the ultrasonic flowmeter, the reasons are as follows:

(1) The specification error of NARI UF911 ultrasonic flow meter is ±0.5%, but in engineering practice, the error is ±2%.

(2) The calculation method of the hydropower station quoted the flow rate on-line monitoring system for the calculation method of the net head $H$ of the hydraulic turbine is:

\[
H = H_{\text{Gross water level}} - H_{\text{Loss head}}
\]  \hspace{1cm} (2)

\[
H_{\text{Gross water level}} = H_{\text{Reservoir water level}} - H_{\text{Tail water level}}
\]  \hspace{1cm} (3)

\[
H_{\text{Loss head}} = KQ^2 \quad K = 0.053
\]  \hspace{1cm} (4)
(3) The hydraulic turbine efficiency agreement of the hydropower station's reference flow online monitoring system is:

\[ \zeta_1 = \zeta + \Delta \zeta \]  

Where \( \zeta \) is the efficiency of the operating point of the turbine is calculated from the three-dimensional surface digital simulation of the characteristics of the turbine; \( \Delta \zeta \) is the engineering experience value, based on the operating time of the 2# unit of the Dongshuixia Power Station, and the sediment condition of the Taolai River, where the value is -1.5 %.

From the above analysis, it can be seen that there are two main reasons for the deviation of the two flow measurement data: one is the error of the ultrasonic flowmeter itself, and the other is the deviation of the relevant empirical data of the flow rate calibration algorithm of the hydropower station quoted on-line flow monitoring system.

4.4. Test Verification Conclusion

(1) The flow measurement data of the online flow monitoring system cited by the hydropower station has exactly the same changing trend as the flow measurement data of the ultrasonic flowmeter.

(2) The numerical deviation between the flow measurement data of the online flow monitoring system and the flow measurement data of the ultrasonic flowmeter used by the hydropower station is 2.00%.

(3) The flow measurement data of the online flow monitoring system cited by the hydropower station meets the requirements of the first class accuracy level <9% specified in the GB 50179-2015 “River Flow Measurement Specification”.

5. Conclusion

At present, most hydropower plants are equipped with flow monitoring equipment such as multi-acoustic ultrasonic flow meters and electromagnetic flow meters. However, due to factors such as high equipment failure rate and difficulty in accuracy calibration in actual use, the economic operation of hydropower plants is carried out, which cause a certain impact. The online monitoring system for reference flow of hydropower stations is based on classic hydraulic models and fluid theory, based on actual hydropower engineering experience, and based on the digital simulation calculation of hydraulic turbine characteristic curves, which correlates the reservoir water level, tail water level, and unit output power in real time. Collecting data, high-precision real-time measurement of the quoted flow of hydropower stations, explores a new technical approach for online monitoring of the quoted flow of hydropower generating units.

The online monitoring system for reference flow of hydropower stations has been practically promoted and applied in more than 700 hydropower station flow monitoring projects in Gansu, Sichuan, Shaanxi, Qinghai, Xinjiang and other provinces. The overall application effect is good, and it has been well received by hydropower owners. Compared with traditional flow measurement methods, this flow measurement solution has many advantages such as small investment scale, high data calculation accuracy, stable software and hardware systems, open data platform, and resource information visualization. It can be used as the basic module of water resource management of hydropower station or water affairs department at all levels and the rudiment of intelligent water affairs.

In the future development, it is necessary to develop and apply the framework of big data technology to form an online monitoring platform for the flow of hydropower stations in zoning or river basins. HJ/T212-2005 protocol is adopted to share the flow monitoring data of hydropower stations, meteorology, water affairs, environmental protection and other departments in real time through the Internet, so as to realize “resource visualization, equipment checking, business interaction and data sharing”.

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