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Analysis and optimization of frequency modulation strategy for hydropower units

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Abstract. Analysis the deficiencies of typical control strategies for AGC regulation and primary frequency regulation on conventional hydropower units. The logical relationship between primary frequency regulation and AGC is optimized. A new regulation method is proposed and applied in a hydropower plant. Practice shows that the method can avoid contradiction between AGC load adjustment and primary frequency modulation, and improve the frequency modulation performance of the unit. The optimization finally satisfy the requirements of power grid assessment.

1. Introduction

With the increasing demand for power from industrial production, great changes have taken place in the structure and operation mode of China's power grid. The increasing proportion of wind and solar power generation in the power grid, large-scale grid connection of volatile clean energy and the increasing gap between peak and valley in the electricity market, these lead to the risk of low-frequency fault in the power grid. The security and stability of power grid have become a concern.

The essence of frequency modulation is to control the dynamic balance between the power generated by the generator and the power required by the grid. It mainly includes primary frequency modulation and secondary frequency modulation. Because of the advantages of fast startup-down and fast load-carrying, hydroelectric units has become the main power for ensuring active power balance and frequency stability of power grid[3].

2. Control System Structure of Conventional Hydroelectric Units

Conventional hydroelectric unit control system is divided into three layers, one is the dispatching layer, the other is the monitoring layer, and the third is the governor layer[1]. The dispatching layer is responsible for transmitting the given value of the plant's active power to the monitoring layer. The monitoring layer consists of the upper computer (AGC program) and the lower computer (LCU). The upper computer AGC program receives the set value of the whole plant's active power issued by the dispatch, and distributes the given value of the current active power to each unit's LCU according to the information of the vibration area of each unit and the current water head. The LCU of the unit carries out PID operation on the given and actual values of the active power from the upper computer. In each PID operation cycle, the output pulse width signal decreases gradually, which drives the corresponding synchronous action and recurrence of the increase and decrease active relays. The output contacts of the relays are transmitted to the governor by hard wiring. The governor works in the



open mode. According to the signal of the relay nodes, the guide vane opening and the blade opening of the unit are adjusted to achieve the purpose of regulating the active power of the unit. The structure of the control system is shown in Figure 1.

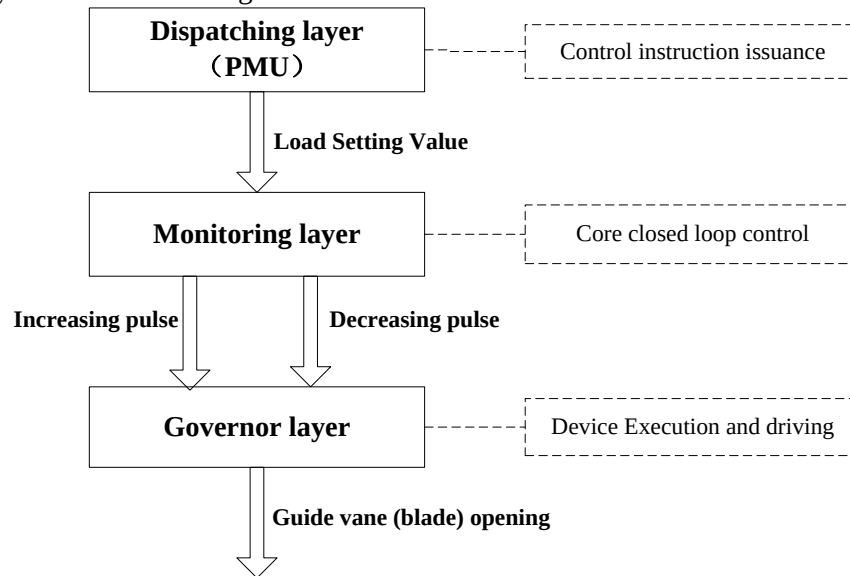


Figure 1. Control System Structure of Conventional Hydroelectric Units

3. Problems and Analysis of Frequency Modulation Strategy for Hydropower Units

3.1. Analysis of AGC Problems for Hydropower Units

The whole AGC regulating system is controlled by monitoring and receiving the given value of active power sent by dispatching, and after AGC operation on the upper computer, the given value of active power is allocated to the LCU of each unit. The active power closed-loop mode is carried out in the LCU PID operation module, and the guide vane opening and blade opening are controlled by regulating impulse (the blade opening of the axial-flow rotating propeller unit needs to be adjusted at the same time). It can be seen that the structure of the whole AGC regulating system is that the monitoring system realizes AGC distribution and LCU active PID control function, while the governor realizes pulse regulation. In this way, there is an intermediate link of LCU active PID control in the whole AGC regulation link, which causes the regulation of active power lagging behind the change of active power. As for the governor, it has actually become a servo system, which only receives the regulating pulse from the monitoring output, converts the regulating pulse into a given opening, and adjusts the opening of the guide vane and the blade of the unit. Regardless of how the active power of the unit changes, the governor is an open-loop link for the active power regulation, which often leads to overshoot when the governor regulates the output of the unit. In addition, the change of the active power of the unit itself lags behind the change of the opening of the guide vane of the turbine. When the LCU PID module in situ is monitored and adjusted, the instructions are already lagged. Because of the change of active power, it is difficult to guarantee the accuracy of AGC regulation[2].

3.2. Analysis of Primary Frequency Regulation for Hydroelectric Units

The target value of power grid for primary frequency modulation is active power, while the governor works in open mode. After primary frequency modulation operation, the governor converts to guide vane opening according to frequency difference, and adjusts the guide vane opening as the target value. Because the guide vane opening and active power exist nonlinearity, and under different water heads, the change value of active power corresponding to the same guide vane opening is also different [2]. Therefore, the primary frequency regulation performance of the governor under the open mode is often difficult to meet the grid assessment requirements.

3.3. Contradictions between Primary Frequency Modulation and AGC Control System

The dispatch sends AGC load instructions to the monitoring system. The monitoring system completes the closed-loop regulation of active power. Once the load deviation exceeds the set dead-time, it adjusts in real time to ensure that the deviation between the actual load value and the given value is within the dead-time range. Primary frequency modulation is that the governor adjusts the opening of guide vane to realize load adjustment according to the frequency deviation of the system. When the governor adjusts the load of the unit due to the primary frequency modulation action, the monitoring system will have load deviation. Because the monitoring system is closed-loop regulation, the deviation caused by the primary frequency modulation load adjustment will be readjusted with the given value, which will lead to the loss of primary frequency modulation function of the unit[4]. As shown in Figure 2.

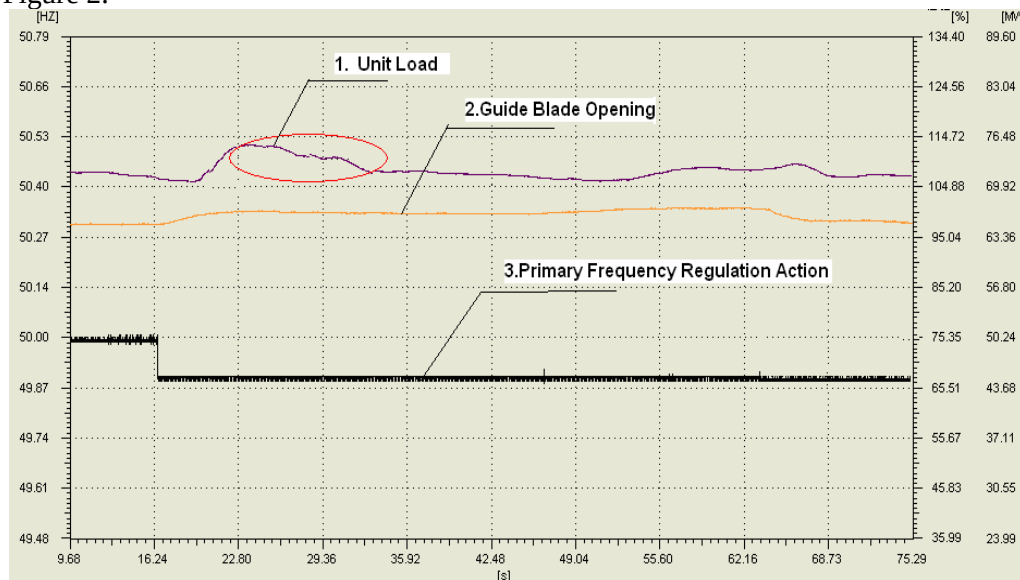


Figure 2. Primary Frequency Modulation Action Curve of a Hydropower Unit

4. The optimization of frequency regulation strategy for hydropower unit

Through the above analysis, if we can avoid the LCU-PID operation module in the AGC regulation system and transmit the given value of active power allocated by AGC to the governor directly, and regulate the active power of the generator set by the governor according to certain control rules, we can avoid the weakness of poor regulation quality at present, that is, the monitoring system will only set the active power according to the results of AGC distribution. The closed-loop regulation of active power is accomplished by the governor, and the PID calculation is carried out directly according to the deviation between the given active power and the current active power, which acts on the guide vane relay and the blade relay in real time. The active power can be quickly adjusted to the target value of active power, thus ensuring the speed of the output of the regulating unit and reducing the active load of the monitoring system. Intersection improves the efficiency of power regulation.

After realizing the power regulation of the governor, the closed-loop power regulation function of the monitoring system can be accomplished by the governor. The target value of the governor power is the superposition of the given active power and the first frequency modulation action. The frequency deviates from the dead zone. The actual power is the superposition of the given power and the first frequency modulation action. The frequency returns to the dead zone, and the real power is restored to the monitoring system. The given power from the upper computer avoids the contradiction between monitoring AGC load adjustment and primary frequency modulation load adjustment.[5]The optimization control system structure of hydropower units is shown in Fig 3.

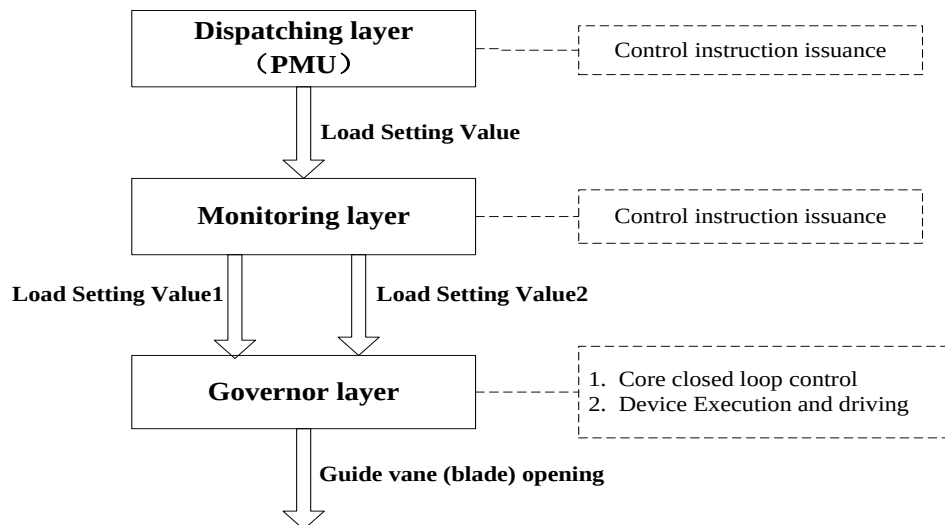


Figure 3. Optimization Control System Structure of Hydroelectric Units

At the same time, We consider the target of power control mode of governor is unit power, the closed loop of PID regulation has include hydraulic turbine and water diversion system. Because of the unsatisfactory runner state, large pressure pulsation often occurs in the low load section, which causes load fluctuation. At this time, improper selection of power dead zone will cause frequent action of guide vane and affect the life of the unit. The load instructions are output from the monitoring system to the governor. If the instruction changes step by step and the magnitude of step is large, the guide vane opening will increase and decrease rapidly, which is not conducive to the safe operation of the unit. So, we suggest that the slope function output be used to optimize the guide vane opening increase and deceleration rate.

As show in Fig. 4, for the same unit, the power regulation process of the ramp output mode is more gentle than that of the step output mode, and the stability time is basically the same as that of the step output mode, which meets the requirements of AGC regulation rate in the guidelines.

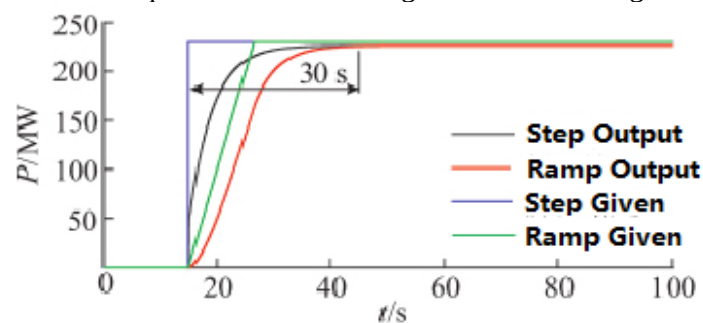


Figure 4. Simulation results of output mode

AGC load control and primary frequency modulation share a set of parameters on power control mode. Because of the different speed requirements of frequency modulation and power modulation in grid-connected operation, the speed of frequency modulation is faster, and the load should be increased and reduced rapidly after the system frequency exceeds the limit. On the premise of meeting the requirements, the speed of AGC load regulation can be slowed down properly to avoid blade damage caused by the long-term and fast action of guide vanes. The speed of primary frequency regulation is obviously faster than that of AGC load response regulation, Variable parameter control is adopted to meet the requirements of primary frequency modulation and AGC control respectively.

5. Effect of the frequency regulation strategy

Taking a 100MW unit as an example, after retrofitting, the AGC regulation rate is above 85 MW/min, which meets the requirements of the two rules in central China region for more than 0.8 PN/min, the regulation accuracy is about 1.5%, and the requirements of the two rules for less than 3%.

On the basis of 50 Hz, the step frequency signals of 0.15 Hz are applied to the governor respectively, and the signals last 60 seconds to check the response behavior of the governor system. The test results show that the average response lag time of primary frequency modulation load is 2.08 s, which meets the requirement of less than 8 s; the average response stability time of primary frequency modulation load (load adjustment range is 90%) is 7.67 s, which meets the requirement of less than 15 s; and the average response time of primary frequency modulation load is 28.0 s, which meets the requirement of less than 30 s.

The test data show that the primary frequency modulation function and the AGC regulation function of some hydropower station can accomplish their respective regulation tasks independently without affecting each other.

6. conclusion

In this paper, the conventional control mode of hydropower units is analyzed and studied, and the existing problems in AGC and primary frequency regulation are analyzed. An improved closed-loop control mode of governor power is proposed, which avoids the contradiction between AGC load adjustment and primary frequency regulation coordination, improves the frequency regulation performance of units, and achieves good results in the application of a unit.

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