Influence of Hydro Turbine Supervision and Control System on Frequency Characteristics of High Proportion Hydropower System

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Abstract. With the construction of interconnected power grid and the rapid development of clean energy, the frequency problem of power system is becoming increasingly prominent. The problem of ultra-low frequency oscillation affects the stability of system frequency. In order to analyze the frequency regulation characteristics of the system, it is necessary to study the local active power control link and stability calculation model of the hydropower plant computer monitoring system. In this paper, the influence of the local active power control link of the monitoring system on the system frequency small signal stability is studied, and the model is built in the simulation program. Through the simulation of 4-machine-2 regional power grid, the influence characteristics of local active power control on frequency dynamic damping level are verified. In the example of large power grid, the coordination between the local active power control of the monitoring system of hydropower units is comprehensively considered, the suggestion of coordination of multi-level frequency modulation resources to system frequency regulation is put forward.

1 Introduction

The level of dynamic stability characteristics of the power system has gradually changed with the development of the power system^[1-2]. Since the 1990s, the dynamic characteristics and response speed of the prime mover regulation system have been greatly improved. The generator set has a rapid response to the system frequency. After the speed control system measured model is applied to the field of power system stability analysis on a large scale, frequency oscillation problem caused by the changes on the grid operation mode has been improved, especially the ultra-low frequency oscillation that occurs in high-proportion hydropower systems^[3-4]. Research on computer monitoring systems for hydropower plants mainly focused on the application of power plants such as design, installation and commissioning^[5-6]. The current system frequency stability has multiple target requirements. One is that the power grid cannot generate weakly damped or negatively damped frequency oscillations to ensure that the frequency dynamic stability level is high enough; the other is that it has a fast enough primary frequency adjustment capability to ensure the frequency recovery ability after a large disturbance. Under these conditions, it is not enough to just optimize the governor of the hydropower unit. The governor and monitoring system of the hydropower unit needs to be coordinated and controlled. The primary frequency modulation and AGC multi-level frequency adjustment resources need to be coordinated^[7-8].

According to the Power Systems Safety and Stability Guidelines, the frequency stability refers to the ability of the power system to maintain or recover the frequency within an allowable range after disturbances, without frequency oscillation or collapse. In terms of stability classification, frequency stability is divided into small interference stability and large interference stability.

This paper will mainly focus on the influence of the active power control of the hydropower plant monitoring system on the system frequency stability. Through a combination of mechanism analysis and simulation modelling, the coordination strategy of multi-level frequency modulation resources on the system frequency adjustment is proposed.

2 The representation of the monitoring system local active power control affects the grid frequency stability

Since the existing stability calculation program cannot take the local active power control of the monitoring system into account, a comparison of trip test and simulation under the condition of AGC withdrawal from a certain regional power grid can found. The number of

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frequency oscillations in the simulation calculation is 1.0, the oscillation frequency is 0.053Hz, and the frequency can be restored to 49.96Hz after 60 seconds; while the actual grid frequency oscillated 2.0 times, the oscillation frequency was 0.05 Hz, and the frequency was restored to 49.93 Hz, as shown in Figure 1.



Fig. 1. Diagram of power grid frequency and active power curve under filed test and simulation

In High Proportion Hydropower System, the accuracy of the frequency characteristic simulation calculation and the frequency control strategy are challenged. After the test, the stability calculation curve of the generator unit above 50MW in the area was compared with the PMU and the field test action characteristics, and it was finally determined that the deviation was related to the characteristics of the local active control link of the hydropower unit monitoring system. For example, during the low frequency period after the occurrence of system disturbance of a hydropower unit, the monitoring system continues to issue a power reduction command to the unit (mainly the speed control system), and there is an obvious trend of oscillation. This is contrary to the phenomenon that the general unit adjusts the output of the unit upwards after a frequency modulation action after the low frequency, as shown in Figure 2.



Fig.2 Diagram of monitor power setting and unit power

The computer monitoring system is a system in which the hydropower plant uses computers to monitor and control the production process of the generator. It has the ability to adjust the power according to the daily load curve given by the system dispatch, automatically adjust the power according to the set value of AGC, and set according to the power plant operation attendant. Active power value automatically adjusts the power, according to the system frequency control mode, according to the water level control mode and other functions. The monitoring system consists of a power plant control unit and a local control unit (LCU). As the main part of closed-loop regulation of the monitoring system, LCU is mainly responsible for normal start/stop and emergency stop sequence control, the regulation of generator speed and active power, limitation of maximum power and other functions. As an important equipment for power control of hydropower plants, the power and frequency regulation characteristics of the monitoring system and the speed control system acting together on the grid play a very important role in maintaining system stability and improving power quality^[9-10].

3 Frequency stability calculation modeling of local active power control link of hydropower unit monitoring system

The upper computer and lower computer LCU of the monitoring system mainly realize the two major active power adjustment functions of operator power adjustment and AGC power adjustment. When the operator adjusts the power load, he transfers the set power command to the LCU directly through the upper computer man-machine interface, compares the set value with the measured feedback value, and performs the closed loop adjustment according to the deviation power. When the AGC is in action, the monitoring system of the whole power plant or certain generator receives the power adjustment command issued by the dispatching master station AGC. The host computer of the monitoring system receives the power command, and then distributes it to the LCU for execution, and performs the adjustment process through the LCU power closed-loop control and the hydroelectric speed control system. From the production process, the topology of the AGC, monitoring system, and speed control system is shown in Figure 3.

It can be seen that the local active power control link of the monitoring system is the upper-level control system of the speed control system, and they need to work in coordination. There are two main working methods:

When the speed control system is power closed-loop regulation, the power set value analog quantity of the local active control of the monitoring system is directly issued to the speed control system power set point.



Fig.3 Diagram of power / frequency closed loop control system of hydropower station

When the speed control system selects the opening control mode, the monitoring system LCU realizes power closed-loop adjustment. The adjustment deviation is generally output to the speed control system in the form of pulses. The speed control system increases or decreases the opening setting according to the pulse signal, as shown in Figure 4.

Since the most basic and most reliable control method of the current speed control system is the opening mode, most local active power and speed control system of the domestic hydropower unit monitoring system operate in the second mode.



Fig.4 Control mode of surpervison and control system and speed control system under opening control mode

The output of the local active power control of the monitoring system is transmitted to the speed control system through a pulse generator. This part of the model mainly includes a power adjustment pulse width waveform generator, which is used to receive instructions from the power regulator to generate pulses for increasing or decreasing load, forming a given increase or decrease signal of the opening of the control vane. *Ymc_{MAX}* and *Ymc_{MIN}* are the maximum limit and the minimum limit respectively. If the input deviation is positive, it will automatically switch to the increase pulse. And the decrease pulse will be automatically selected if the input deviation is negative. The increase or decrease pulse signal will be sent to the related link of the opening closed loop adjustment of the speed control

system. To form a given reference value Yref of the opening, as shown in Figure 5.



Fig.5 Link of pulse generating

The monitoring system's local active power control sends increase or decrease pulses according to the detected power deviation, and the speed control system increases or decreases the opening setting according to the increase or decrease pulse length.

$$Y_c = Y_{c_c} + T * D \tag{1}$$

In the formula: Y_c is the setting value of the opening degree of the speed control system; Y_{c0} represents the setting value of the opening degree of the speed control system in the previous calculation cycle; T is the increase or decrease pulse time; D is the opening increase and decrease rate of the speed control system.

The calculation process of the above formula (1) can be expressed by the integral link with input limit. The calculation of active power increase and decrease pulse time T is as follows:

$$t1 = K \times (Ps - Pi) \tag{2}$$

$$t2 = t1 + Tgap + TP\min$$
(3)

$$T0 = t2 + TPa\min + TPac \times t2 \tag{4}$$

Where: K is the pulse width factor; Ps is the active power setting value; Pi is the actual measured value of the active power; Tgap is the pulse compensation time; TPmin is the minimum pulse width; TPamin is the minimum pulse waiting time; TPac is the pulse waiting time factor.

The output of the local active power control of the monitoring system is a pulse signal, and the speed control system receives the pulse signal to form the opening adjustment command Yref. Compared with the commonly used electromechanical transient speed control system model, the opening setting command generation part is added. The model of the typical speed

control system control part is shown in Figure 6.



Fig.6 Model of the opening mode of the speed control system after the new opening given



Fig.7 Simulation model of supervision and control system

Based on the main hydropower unit in a certain power grid, the local active control link model of the computer monitoring system for the hydropower generating unit is established as shown in Figure 7. This model can solve the current situation where there is no computer monitoring system local active power control model for hydropower generating units in power system analysis, can fully reflect the normal frequency adjustment process of the units, and improve the power and frequency simulation accuracy of stable calculations.

The model in Figure 7 mainly includes three parts: power setting (including AGC), power feedback measurement, power closed-loop part and pulse generation. Power closed loop part: P_{AGC} , P_1 and P_E are AGC active power setting, local operation active power setting and active power respectively; t_{j1} , t_{j2} , t_{j3} are delay time, ε is natural logarithm; T_{Jr1} , T_{Jr2} , T_{Jr3} are Time constant; *s* is the Laplace operator; J_1 is selected when the speed control system is in the opening mode, J_2 is selected when the speed control system is in the power mode; +DB1 and -DB1 are respectively expressed as positive dead zone and negative dead zone ; K_{Pe} is the power closed-loop proportional coefficient.

In stability calculation, the local active power control model of the monitoring system and the speed control system model need to be used together. The hydropower unit monitoring system is a necessary intermediate link in the mid-term and long-term calculations. It is also the upper-level power closed-loop regulation system of the speed control system in the electromechanical transient calculation. This model has been solidified in the power system stability calculation program PSD-BPA and PSASP. It can basically reflect the action characteristics of the physical equipment of the unit.

4 Study on the mechanism of the local active power control link of the monitoring system affecting the stability of the system frequency small interference

4.1. The influence of the local active power control link of the monitoring system on the mechanical torque damping component

At the level of active power adjustment, the local active power control link of the monitoring system and the speed control system work together to change the mechanical torque by changing the opening of the guide vane of the unit.

From the block diagram of the model in the previous section, the local active power adjustment of the

$$G_{LCU}(s) = -K_{Pe} \cdot \frac{1}{1 + T_{j2}s} \frac{1}{1 + T_{j3}s} \cdot \varepsilon^{-t_{j2}s} \varepsilon^{-t_{j3}s} \cdot \Delta P_{e}$$
(5)

Local active power control of the monitoring system works, and the speed control system does not operate once the frequency is adjusted.

Considering that the frequency change is very small, once the frequency modulation action, the external input signal of the speed control system with opening mode control only has frequency, at this time the speed control system's primary frequency modulation loop can be ignored, the monitoring system performs power closedloop adjustment, the adjustment deviation realizes the unit power adjustment through the actuator of the speed control system and the hydraulic turbine part of the water diversion system, and the mechanical torque increase generated by the local active power control link of the monitoring system can be approximated by equation (6):

$$\Delta T_{M} = G_{LCU}(s) \cdot G_{HGOV}(s) \cdot G_{TW}(s) \cdot \Delta P_{e}$$
(6)

Where: $G_{LCU}(s)$ is the transfer function of the local active power control link of the monitoring system; $G_{HGOV}(s)$ is the transfer function of the actuator of the speed control system:

$$G_{HGOV}(S) = \frac{K_{PE}}{T_C} \frac{1 + T_2 s}{T_2 s^2 + s + \frac{K_{PE}}{T_C}}$$
(7)

 $G_{TW}(s)$ is turbine transfer function of water diversion system:

$$G_{TW}(s) = K_{W} \frac{1 - sT_{W}}{1 + 0.5sT_{W}}$$
(8)

 $G_{CGOV}(s)$ is the transfer function of primary frequency modulation of the speed control system. And there are:

$$\begin{cases} \Delta T_E \approx \Delta P_e = K_1 \Delta \delta + K_2 \Delta E'_q \\ \Delta E'_q = \frac{-K_3 K_4 - K_3 K_5 E_X(s)}{1 + K_3 K_6 E_X(s) + s K_3 T'_{d0}} \Delta \delta \end{cases}$$
(9)

The research on the generator oscillation process proved that the change of ΔE_q can be ignored when studying the dynamic stability of power system^[9-10], Take *K2*=0, at this time $\Delta T_E \approx K_1 \Delta \delta$, and generally $K_l > 0$.

Based on the above derivation, and put $s = j\omega_d$ into equation (5), then get the expression of the mechanical torque produced by the regulating system:

$$\Delta T_{M} = G_{LCU}(s) \cdot G_{HGOV}(s) \cdot G_{TW}(s) \cdot \Delta P_{e}$$

= $G_{LCU}(s) \cdot G_{HGOV}(s) \cdot G_{TW}(s) \cdot K_{1} \cdot \Delta \delta$ (10)

$$\Delta T_{M} = -K_{1}G_{LCU}(s) \cdot G_{HGOV}(s) \cdot G_{TW}(s) \cdot \Delta \delta$$

$$= -K_{1}K_{LCU}K_{HGOV}K_{TW}e^{j(\varphi_{\Sigma})}\Delta \delta$$

$$= -K_{1}K_{LCU}K_{HGOV}K_{TW}(\cos\varphi_{\Sigma} + j\sin\varphi_{\Sigma})(-j\frac{\omega_{0}}{\omega_{d}}\Delta\omega)$$

$$= -K_{1}K_{LCU}K_{HGOV}K_{TW}\frac{\omega_{0}}{\omega_{d}}\sin\varphi_{\Sigma} \cdot \Delta\omega$$

$$-K_{1}K_{LCU}K_{HGOV}K_{TW}\frac{\omega_{0}}{\omega_{d}}\cos\varphi_{\Sigma} \cdot \Delta\delta$$
(11)

In this formula, $\varphi_{\Sigma} = \varphi_{LCU} + \varphi_{HGOV} + \varphi_{TW}$. At the same time, the torque ΔT_M is decomposed^[13]:

$$\Delta T_M = \Delta T_D + \Delta T_S \tag{12}$$

In the formula: ΔT_D is the damping torque and ΔT_S is the synchronous torque.

From (10), (11) and (12):

$$\Delta T_{D} = -K_{1}K_{LCU}K_{HGOV}K_{TW}\frac{\omega_{0}}{\omega_{d}}\sin(\varphi_{\Sigma})\cdot\Delta\omega$$

$$\Delta T_{S} = -K_{1}K_{LCU}K_{HGOV}K_{TW}\frac{\omega_{0}}{\omega_{d}}\cos(\varphi_{\Sigma})\cdot\Delta\delta$$

$$(13)$$

Define D_{GOV} as the additional damping coefficient provided by the prime mover adjustment system:

$$D_{GOV} = K_1 K_{LCU} K_{HGOV} K_{TW} \frac{\omega_0}{\omega_d} \sin(\varphi_{\Sigma})$$
(14)

 φ_{GOV} is the lag angle of the local active power control link of the monitoring system to the input signal($-\Delta P_e$). Because there is always $K_{LCU}K_{HGOV}K_{TW} \ge 0$ and $K_1 > 0$ in normal operation, the positive or negative of D_{GOV} is determined by the positive or negative of $\sin(\varphi_{\Sigma})$. The additional damping coefficient D_{GOV} is not only affected by the characteristics of the prime mover adjustment system and the oscillation frequency, but also directly related to the parameter K1 in the Phillips-Heffron model that characterizes the system. The coefficients $K_1 \sim K_6$ also express their influence on the damping effect of the prime mover regulation system through the influence on the oscillation frequency.

When $\varphi_{\Sigma} \in [0, 180^{\circ}]$, ΔT_M is located in the third and fourth quadrants of the $\Delta\delta$ - $\Delta\omega$ coordinate system, $\sin \pi(\varphi_{\Sigma}) > 0$, $D_{LCU+GOV+TW} > 0$, prime mover provides positive damping. When $\varphi_{\Sigma} \in [0, -180^{\circ}]$, ΔT_M is located in the first and second quadrants of $\Delta\delta$ - $\Delta\omega$ coordinate system, prime mover provides negetive damping, as shown in Figure 8.



Fig.8 Diagram of damping characteristics of surpervison and control system under power closed loop

4.2. The effect of monitoring system's local active power control and primary frequency modulation on mechanical torque damping component

When the monitoring system is controlled by the local active power to adjust the power, the speed control system adopts the opening mode and the primary frequency modulation also works normally. The power closed loop of the monitoring system and the primary frequency adjustment of the speed control system all realize the power adjustment of the unit through the speed control system actuator and the hydraulic turbine part of the water diversion system. The mechanical torque increment produced by the combined action of the monitoring system and the speed control system.

In the Phillips-Heffron model, ΔP_e and $\Delta \delta$ are in basically the same phase. In the complex plane, the vector $\Delta \omega$ is orthogonal to the vector $\Delta \delta$, and the angle of $\Delta \omega$ leading $\Delta \delta$ in phase is 90°. The local active power control of the monitoring system and the primary frequency modulation (frequency closed loop) of the speed regulation system can be analyzed separately, and then the vector addition can be realized by the superposition principle, the torque characteristics of the two can be analyzed at the same time.

When the primary frequency adjustment of the speed control system is considered separately and the input signal of the control system is the speed deviation- $\Delta \omega$, the transfer function of the primary frequency modulation control part of the speed control system is set as $G_{CGOV}(s)$, the mechanical torque increment produced by the adjustment system is:

$$\Delta T_{M} = -G_{CGOV}(s) \cdot G_{HGOV}(s) \cdot G_{TW}(s) \Delta \omega$$
(16)

$$\Delta T_{E} = K_{1} \Delta \delta + K_{2} \Delta E_{q}^{'} \tag{17}$$

For the oscillation frequency f_d , substituting $s = j\omega_d$ into:

$$\Delta T'_{M} = -G_{CGOV}(s) \cdot G_{HGOV}(s) \cdot G_{TW}(s) \Delta \omega$$

= $-K_{CGOV} \cdot K_{HGOV} \cdot K_{TW}(s) e^{j\varphi_{GOV}}$
= $-K_{CGOV} \cdot K_{HGOV} \cdot K_{TW}(s) \cos(\varphi_{CGOV} + \varphi_{HGOV} + \varphi_{TW}) \Delta \omega$
+ $K_{CGOV} \cdot K_{HGOV} \cdot K_{TW}(s) \sin(\varphi_{CGOV} + \varphi_{HGOV} + \varphi_{TW}) \frac{\omega_{d}}{\omega_{0}} \Delta \delta$

When the local active power control of the monitoring system is considered separately and the input signal of the control system is the power deviation ΔPe , as in the previous formula (10).

$$\Delta T_{M}'' = -K_{1}G_{LCU}(s) \cdot G_{HGOV}(s) \cdot G_{TW}(s) \cdot \Delta \delta$$

$$= -K_{1}K_{LCU}K_{HGOV}K_{TW}\frac{\omega_{0}}{\omega_{d}}\sin(\varphi_{\Sigma}) \cdot \Delta \omega$$

$$-K_{1}K_{LCU}K_{HGOV}K_{TW}\frac{\omega_{0}}{\omega_{d}}\cos(\varphi_{\Sigma}) \cdot \Delta \delta$$
(19)

Then when the local active power control of the monitoring system and the primary frequency regulation of the speed regulation system act simultaneously, the mechanical torque is:

$$\Delta T_{M} = \Delta T'_{M} + \Delta T''_{M}$$

= $-K_{CGOV} \cdot K_{HGOV} \cdot K_{TW}(s) e^{i\varphi_{GOV}}$
 $-K_{i}G_{ICU}(s) \cdot G_{HGOV}(s) \cdot G_{TW}(s) \cdot \Delta \delta$ (20)

Decomposed to obtain the mechanical power synthetic torque when the local active power control of the monitoring system and the primary frequency control of the speed regulation system is normally operating, as shown in Figure 9.





The local active power control and speed regulation system of the monitoring system generates a negative damping if the synthetic torque of the primary frequency modulation (frequency closed loop) falls on the positive half axis of $\Delta \omega$ in $\Delta \delta - \Delta \omega$ coordinate system, otherwise it provides positive damping.

4.3. The influence of nonlinear links on the damping of the regulation system

The non-linear links of the monitoring system and the speed control system mainly include dead zone, time delay, and amplitude limiting. They have an impact on the speed, amplitude, and oscillation characteristics in the frequency recovery process. The impact of the pure delay link is the most important. This section mainly analyzes the impact of the pure delay link. The pure delay link can be expressed by equations $(21)\sim(22)$.

$$G_{delay} = e^{-T_{delay}s} \tag{21}$$

$$\varphi_{delay} = -T_{delay} f \cdot 360^{\circ} \tag{22}$$

In the formula, T_{delay} is the delay time. The negative sign indicates that the phase is lagging. This formula shows that the lag phase of the pure delay link is related to the delay time and the oscillation frequency. The delay will change the direction of the mechanical torque in the coordinate system, thereby affecting the synchronization adjustment characteristics and oscillation damping characteristics ^[13].

5 Simulation verification of calculation example

5.1 The basic situation of the calculation example

Based on the power system program PSD-BPA, a model containing four hydroelectric generating units with a single unit capacity of 900 MW was established. Generator 1 and 2 are sent out through the tie line of bus 6 and bus 7, generator 3 and 4 pass the tie line from bus 10 to bus 9 is sent out. Bus 7 has a load of 800MW and bus 9 has 970MW, bus 8 and bus 9 have a tie line of 102.8MW power flow. As shown in Figure 10.



Fig.10 Diagram of 4-generators model

The input disturbance of this calculation example is to adjust the load of bus 7. Considering the frequency characteristics of the two cases respectively where the speed control system's single primary frequency modulation and the speed regulation side primary frequency modulation act simultaneously with the monitoring side power regulation.

5.2. The influence of monitoring system on ultra-low frequency oscillation

Ultra-low frequency oscillation is a dynamic instability problem of active power and frequency feedback control system in the power system. It is manifested in the stable form, the grid frequency has repeated long-period lowfrequency oscillations. Frequency oscillation will not only affect the grid frequency safety, it will also cause the hydraulic system and the servomotor of the generator to repeatedly twitch. In severe cases, it will cause the generator set to trip due to low oil pressure action, which may cause a more serious chain reaction. In this example, four hydropower generators can also take rapid frequency modulation ability into account without the occurrence of equal amplitude or increased amplitude oscillation of frequency. The speed control system parameter configurations of four generators are basically the same, which means they have the same primary frequency modulation performance. Analyze the frequency oscillation risk of the control system under different configuration conditions.

Configuration 1: Four units are only equipped with the primary frequency regulation function of the speed control system, without considering the monitoring system;

Configuration 2: On the basis of Configuration 1, putting the monitoring system power of Units 1 and 2 into operation.

As shown in Figure 11, after considering the monitoring system, the amplitude of the frequency oscillation increases and the vibration period is prolonged, indicating that the local active power control link of the monitoring system provides negative damping, as shown in Table 1.



Fig.11 Diagram of power grid frequency characteristic curve with or without surpervison and control system

Table 1. The damping of ultra low frequency oscillation

Calculation conditions	Oscillation frequency(Hz)	Damping ratio
No monitoring system	0.096	0.057
With monitoring system	0.093	0.044

With the increase of the local active power control magnification of the monitoring system, the worse the damping. When the magnification is Kp=0.2pu, the

damping ratio is 0.057; when Kp=0.25pu, the damping ratio is 0.028; when Kp=0.9pu, the damping ratio is - 0.001. At this time, the power grid frequency presents a negatively damped amplitude oscillation, and the dynamic instability simulation effect of the power grid frequency is shown in Figure 12. The system damping corresponding to the amplification factor is shown in Table 2.



Fig.12 Diagram of power grid frequency characteristic curve under different surpervison and control ratios

f able.2 Ultra	low	frequency	oscillation
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Calculation conditions	Oscillation frequency(Hz)	Damping ratio
<i>Kp</i> =0.2p.u	0.096	0.057
<i>Kp</i> =0.25p.u	0.091	0.028
<i>Kp</i> =0.9p.u	0.086	-0.001

5.3. The influence of monitoring system on frequency recovery

According to the simulation results, when the fault occurs, the grid frequency quickly drops to 49.92 Hz. If the power adjustment function of the monitoring system is not considered, only primary frequency modulation of speed control system, the mechanical power of generator 1 gradually increases, and the electrical power starts to rise from 498MW to 508.6MW in about 50 seconds. The contribution of the primary frequency modulation power is 10.6MW. The corresponding system frequency can be restored to 49.95Hz within 50 seconds after the fault, and basically restored to the dead zone of the primary frequency modulation of the conventional hydropower unit.

If the power adjustment of the monitoring system is considered, after the fault occurs, the primary frequency regulation of the speed regulation system and the local active power control of the monitoring system action simultaneously. At the beginning of the fault, the primary frequency regulation action, the mechanical power of the generator gradually increases from 498MW, reaches to the maximum value of 503.5MW at 30 seconds, after which the mechanical power gradually decreases, about 50 seconds it drops to 501.6MW. At this time, the grid frequency basically floats below 49.92Hz, as shown in Table 3.

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Conditions	30 seconds after fault		50 seconds after fault	
	Power (MW)	Grid frequency (Hz)	Power (MW)	Grid frequency (Hz)
No monitor	8.6	49.934	10.6	49.945
With monitor	5.5	49.925	3.6	49.914

It can be seen that after considering the local active power control of the monitoring system, the power contribution of the primary frequency modulation of the speed control system is weakened by the monitoring system. At the beginning of the fault, the primary frequency modulation action, the generator set has a certain amount of frequency modulation power contribution, but as the power adjustment function of the monitoring system increases, the active power of the generator set will gradually decrease.

Since the unit reference power has not changed during the fault, the steady-state power of the unit is limited to the initial value before the fault, and the grid frequency will also be suspended below 49.92Hz for a long time, which will significantly affect the grid frequency recovery characteristics. The electrical power of generator 1 is shown in Figure 13, and the grid frequency is shown in Figure 14.



Fig.13 Diagram of electrical power recovery curve with or without supervision and control system (black curve indicates no supervision and control, blue curve indicates supervision and control)



Fig.14 Diagram of power grid frequency recovery curve with or without surpervison and control system (black curve indicates no surpervison and control, blue curve indicates surpervison and control)

6 Conclusion

The local active power control of the hydropower unit monitoring system and the speed regulation system work together to realize the direct adjustment of power and speed. The local active power control of the monitoring system affects the rotor movement by changing the mechanical torque, thereby affecting the frequency oscillation damping of the power system, and has a significant impact on the frequency oscillation characteristics of the grid. When the local active power control of the monitoring system and the primary frequency modulation of the speed control system (frequency closed loop) are acting simultaneously, the damping characteristics should be determined based on the mechanical torque vector synthesis caused by the primary frequency modulation of the speed control system and the power adjustment of the monitoring system. If the resultant torque falls on the positive half axis of $\Delta \omega$ in $\Delta \delta - \Delta \omega$ coordinate system, negative damping is provided, otherwise positive damping is provided. The simulation example shows that the active power control of the monitoring system will significantly affect the frequency regulation characteristics of the power grid, and has a greater impact on the frequency dynamic damping. When the amplification factor of the local active power control link of the monitoring system increases to a certain value, the grid frequency presents a negatively damped amplitude oscillation, and the grid frequency is dynamically unstable. Time domain simulation, small disturbance stability calculation and prony analysis are consistent with the theoretical analysis results.

The monitoring system of a hydropower unit is a necessary intermediate link for medium and long-term calculations, and also the upper-level power closed-loop control system of the speed control system in the electromechanical transient calculation. This paper builds a mathematical model of the monitoring system of a major hydropower unit in Southwest China based on actual measurements, which can be used for power system transient and mid- term to long-term stability calculations.

Through the simulation example of large frequency disturbance, it can be seen that when the monitoring system and the speed control system are considered to act together, the power contribution of the first frequency modulation of the speed control system is weakened by the reverse adjustment of the local active power control of the monitoring system, and the active power of the unit will be gradually reduced. And because the unit reference power does not change during the fault, the steady-state power is limited to the initial value before the fault starts. The monitoring system and the speed control system show uncoordinated action characteristics. Therefore, when the power grid suffers a large disturbance, the system frequency will change significantly. When considering the local active power control of the monitoring system and the primary frequency adjustment of the speed control system, conditional blocking can be adopted, or by introducing frequency control in the local active power control of the

monitoring system, to achieve coordination between the two superposition methods. Local active power control of hydropower unit monitoring has an important influence on power system stability calculation, and it is necessary to measured modeling, which is of great significance for accurately grasping the power and frequency dynamic characteristics of power grid under the electromechanical transient state and medium and long-term stable calculation.

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