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Research on generation and pumping coordinated control function of AC excitation variable speed pumped storage unit

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Abstract. For the problem of coordinated control of active power and speed in AC excitation variable speed pumped storage unit, the principle of variable speed pumped storage unit is analyzed, the coordinated control strategies, primary frequency regulation control strategies, and coordinated control modes for variable speed unit are proposed, and the coordinated control strategies and control modes are verified by the RTDS simulation test platform, finally, flexible control strategies suitable for different application scenarios are provided.

1 Introduction

Pumped storage power stations have functions such as peak shaving, valley filling, frequency regulation, phase regulation, and emergency backup, playing an important role in ensuring the safe and stable operation of the power grid and improving the capacity of new energy consumption.

Compared with conventional pumped storage units, variable speed pumped storage units have the advantages of adjustable active power and speed under pumping conditions, higher operating efficiency under generating conditions, fast power regulation speed, and meeting the requirements of continuous, fast, and accurate frequency regulation and load regulation of the power system[1].

There are two types of variable speed pumped storage units, one is AC excitation variable speed pumped storage units, and the other is full power variable speed pumped storage units. AC excitation variable speed pumped storage units are suitable for large capacity pumped storage units, and full power variable speed pumped storage units are suitable for small and medium-sized pumped storage units[2]. This article mainly researches the coordinated control function of AC excitation variable speed pumped storage units. AC excitation system can regulate the active power and speed of the unit, and the speed control system can also control the opening of the guide vanes to regulate the active power and speed of the unit, there is mutual influence, and the coordinated controller needs to be set

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up to uniformly coordinate and allocate various control objectives[3]. The coordinated controller is the link between computer supervisor and control system, speed controller, and AC excitation system of the variable speed pumped storage unit, playing a bridging role in the control of the variable speed pumped storage unit.

This article research on the power generation and pumping coordinated control strategies, primary frequency regulation control strategies, coordinated control modes, and application scenarios of different control modes for the coordinated control unit of variable speed pumped storage units. A real-time digital simulation platform (RTDS) is built to verify the coordinated control strategies and control modes through simulation experiments.

2 Principle of variable speed unit

The structure of the AC excitation variable speed pumped storage unit is shown in Figure 1, mainly mainly composed of pump turbine, generator motor, governor, AC excitation system, monitoring system and unit coordinated control device. When the unit is running, the mechanical speed of the rotor is N2, and the three-phase AC power supply connected to the rotor winding will generate a rotating magnetic field relative to the rotor, and the rotating speed is Nm; The stator is connected to the power grid to form a rotating magnetic field in the air gap of the unit, and this rotating speed is called synchronous speed N1. Therefore, the stator rotation speed N1 is the superposition of the rotor mechanical rotation speed N2 and the rotor rotating magnetic field rotation speed Nm, that is, N1=N2+Nm. Because N1 is a synchronous speed, that is proportional to the grid frequency and is a constant value, the rotor mechanical speed N2 can be changed by adjusting the rotor rotating magnetic field speed Nm[4-5].

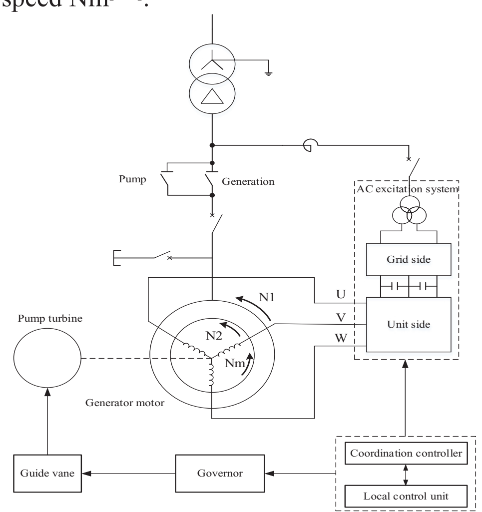

Fig. 1. Structural diagram of AC excitation variable speed pumped storage unit.

3 Research on coordinated control strategy

The coordination of active power and speed of variable speed pumped storage units is an important condition to ensure the stable and efficient operation of the units, but there are coupling problems when adjusting the active power and speed. For example, when the governor controls the opening of the guide vane to adjust the active power of the units under power generation conditions, the speed of the units will also change accordingly, and when the electromagnetic speed of the units is adjusted by AC excitation, the active power of the units will also change accordingly. How to solve the coupling between the active power and speed is one of the control difficulties[6].

Ac excitation controls the rotor three-phase AC power supply to adjust the active power and speed of the unit, which is is an electrical quantity control with fast speed. Governor controls the opening of the guide vane to adjust the active power and speed of the unit, which is a mechanical quantity control with slow speed. Based on the above characteristics, the coordinated controller is set up to uniformly distribute the active power and speed control objectives of the unit. As shown in Figure 2, the coordinated control strategy is: according to the active set value and working head of the unit, the unit speed and the guide vane opening are decoupled and calculated based on the operation characteristic curves of the variable speed unit, and sent to the AC excitation system and the governor for regulation, thereby achieving decoupling and coordinated control of active power and speed[7].

The variable speed pumped storage unit has flexible primary frequency regulation performance in both power generation and pumping conditions[8]. If the primary frequency regulation of variable speed pumped storage unit is still completed by the governor, the decoupling coordinated control of speed and power will be affected when the governor works in power mode. Secondly, if the governor works in opening mode or speed mode, the primary frequency regulation cannot be completed by the governor[9]. Therefore, the primary frequency regulation also needs to be uniformly decoupled and distributed through the coordinated controller. As shown in Figure 2, the control strategy is: firstly, according to the deviation between the unit frequency and the rated 50Hz, the effective frequency difference Δf is obtained by subtracting the artificial frequency dead zone, and then the primary frequency regulation power adjustment ΔP is obtained by dividing it by the adjustment coefficient Ep, which is superimposed with the active set value P to obtain the final adjusted active set value P_set. Then, the unit speed and guide vane opening are decoupled by the coordinated controller, and then are calculated and submitted to the AC excitation system and governor for regulation.

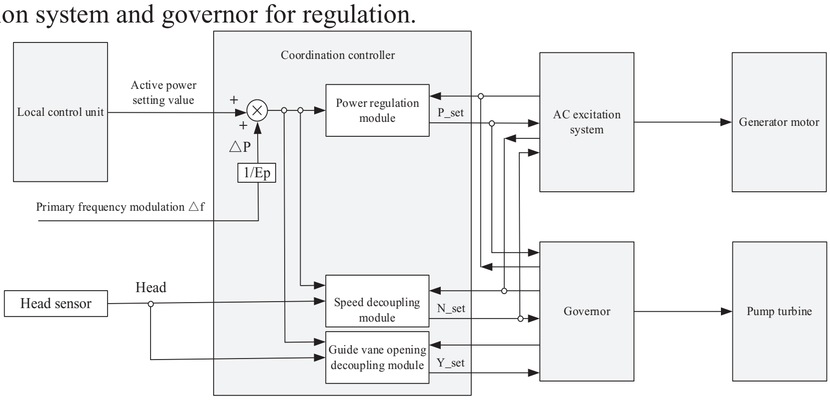

Fig. 2. Schematic diagram of coordinated control for variable speed pumped storage unit.

4 Research on coordinated control mode

According to the different distribution of active power, speed and guide vane opening of the unit by the coordinated controller, there are three control modes of variable speed pumped storage unit: AC excitation control speed and governor control active power, AC excitation control active power and governor control speed, and AC excitation control speed and governor control guide vane opening[3].

4.1 AC excitation control speed and governor control active power mode

This mode is also called fast speed mode. In this mode, AC excitation controls the speed and reactive power, and governor controls the active power. The coordinated controller is responsible for the decoupling calculation of active power setting value and primary frequency regulation, as well as the distribution of unit speed and guide vane opening. The governor adjusts the guide vane opening of the unit according to the set value of active power, and the AC excitation adjusts the speed of the unit according to the speed setting value.

4.2 AC excitation control active power and governor control speed mode

This mode is also called fast power mode. In this mode, AC excitation controls the active power and reactive power, and the governor controls the speed of the unit. The coordinated controller is responsible for the decoupling calculation of active power setting value and primary frequency regulation, as well as the distribution of unit speed and guide vane opening; The governor adjusts the guide vane opening according to the set speed value, and the AC excitation adjusts the electromagnetic power of the unit according to the set active power value. Due to the electromagnetic power of the AC excitation control unit, rapid adjustment of the active power of the unit can be achieved. Generally, about 7% of the active power of the unit can be adjusted within 100 milliseconds, which has good fast response regulation performance.

4.3 AC excitation control speed and governor control guide vane opening mode

In this mode, AC excitation controls the speed and reactive power of the unit, and the governor controls the guide vane opening. The coordinated controller is responsible for the decoupling calculation of active power setting value and primary frequency regulation, as well as the distribution of unit speed and guide vane opening, where the guide vane opening follows the actual speed; The AC excitation receives the speed setting value, and the speed closed-loop mode is adopted to adjust the response; The governor receives the guide vane opening setting value, and the opening closed-loop mode is adopted to adjust the response.

In this mode, there may be a slight deviation in the active power. The coordinated controller needs to superimpose the active power closed-loop adjustment, convert the deviation between the active power setting value and the active power feedback value into the corresponding speed compensation amount, and superimpose it with the speed setting. The AC excitation system will adjust the unit speed to adjust the active power within the allowable range.

5 Simulation test

In order to verify the coordinated control strategy and control mode, a real-time digital simulation platform (RTDS) was built, and the coordinated control strategy and control mode of variable speed pumped storage units were verified by simulation experiments. The simulation model of variable speed pumped storage unit is established in RTDS, The main parameters of the simulation model are: the rated speed of the unit is 428.57r/min, the maximum output power of the unit is 310MW, the maximum input power of the unit is 330MW, the speed range of the turbine is 398.57~412.20r/min, the output power range of the turbine is 124.0~310.0MW, and the head range of the turbine is 385.83~457.36m. The speed range of the pump is 398.57~452.70r/min, the input power range of the pump is 177.73~330.0MW, and the head range of the pump is 404.74~466.56m.

5.1 AC excitation control speed and governor control active power mode

In the mode of AC excitation control speed and governor control active power, the water head is kept constant at 425m, and the set value of active power is adjusted from 175MW to 285MW. The speed is increased from 0.9304p.u (nominal value) to 0.9392p.u, and the guide vane opening is increased from 49.47% to 88.46%. The waveform of active power, guide vane opening and speed changes during the regulation process is shown in Figure 3, where the active power regulation time of governor is 28 seconds, and the speed regulation time of AC excitation system is 32 seconds.

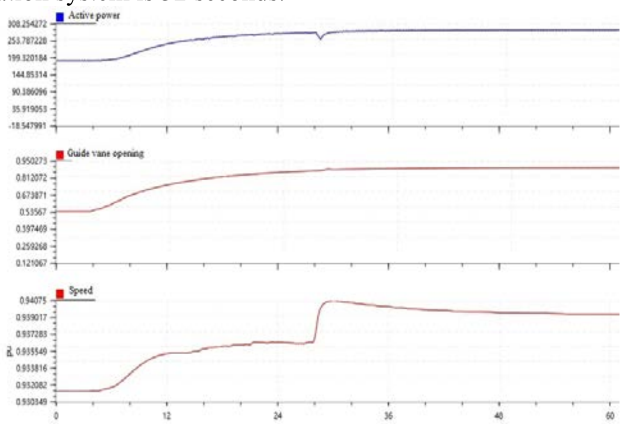

Fig. 3. Simulation waveform of AC excitation control speed and governor control active power.

5.2 AC excitation control active power and governor control speed mode

In the mode of AC excitation control active power and governor control speed, the water head is kept constant at 425m, and the set value of active power is adjusted from 265MW to 285MW. The speed is increased from 0.9315p.u to 0.9392p.u, and the guide vane opening is increased from 77.08% to 88.46%. The waveform of active power, guide vane opening, and speed changes during the regulation process is shown in Figure 4, where the active power regulation time of AC excitation is 0.15 second and the speed regulation time of the governor is 52 seconds.

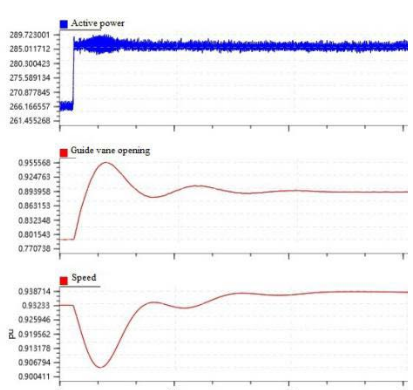

Fig. 4. Simulation waveform of AC excitation control active power and governor control speed.

5.3 AC excitation control speed and governor control guide vane opening mode

In the mode of AC excitation control speed and governor control guide vane opening, the water head is kept constant at 425m, and the set value of active power is adjusted from -265MW to -179MW. The speed is decreased from 0.9853p.u to 0.9568p.u, and the guide vane opening is decreased from 69.32% to 49.74%. The waveform of active power, guide vane opening, and speed changes during the regulation process is shown in Figure 5, where the speed regulation time of AC excitation is 24 seconds and the guide vane opening regulation time of the governor is 26 seconds.

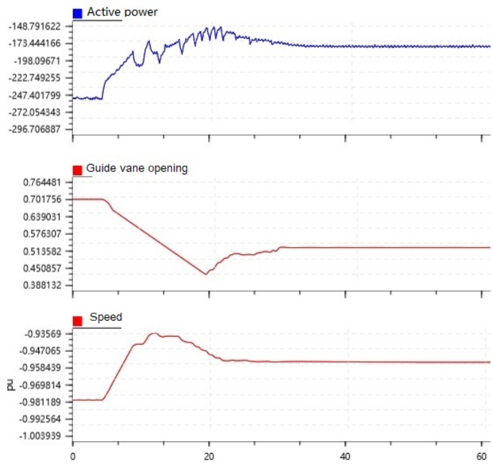

Fig. 5. Simulation waveform of AC excitation control speed and governor control guide vane opening.

6 Application scenario analysis

From the simulation test waveforms of the coordinated control strategy and coordinated control mode of the variable speed pumped storage unit, it is shown that:

(1) AC excitation system control speed and governor control active power mode. When governor conrol active power, the guide vane opening is first activated to change the flow rate, generate the output power of the turbine, and then the generator is converted into electromagnetic power. The process is slow, and the deviation between the mechanical power and electromagnetic power of the unit is small, and the speed fluctuation is also small. It is can be used for wide range active power adjustment, but the active power adjustment time is long. The active power adjustment from 175MW to 285MW is about 28 seconds. Therefore, this mode is suitable for wide range active power regulation in power generation condition.

(2) AC excitation system control active power and governor control speed mode. AC excitation quickly adjusts electromagnetic power to achieve hundred-millisecond level active power regulation. Then, governor adjusts speed to a new balance point. This fast response regulation performance is the advantage of variable speed pumped storage unit, which has good regulation performance for the consumption of new energy in new power systems and the fast response of grid frequency fluctuations. However, the large deviation between the electromagnetic power and mechanical power of the unit in a short time, it will cause significant torque and speed fluctuations of the unit. The load adjustment range should not be too large, and should not exceed ±10%. Therefore, this mode is suitable for

precise and rapid active power regulation in a small range of power generation condition, such as primary frequency regulation.

(3) AC excitation system control speed and governor control guide vane opening mode. According to the characteristics of the pump-turbine unit, the input force of pump is proportional to the third power of the speed, the head is proportional to the second power of the speed, and the flow rate is proportional to the unit speed. Therefore, the pumping condition mainly achieves active power regulation by adjusting the speed through AC excitation, and governor can adjust the guide vane opening with the actual speed, which can adjust active power in a wide range. However, there is a certain error between the model data of the unit operating characteristic curve and the actual operating data, which may cause deviation in active power regulation. It is necessary to adjust the active power to the error range through speed compensation. Therefore, this mode is suitable for the application scenario of active power regulation in pumping condition.

Therefore, AC excitation system control speed and governor control active power mode is suitable for normal active power regulation in power generation condition.When the active power is stable, if there is a significant deviation in the grid frequency (＞0.1Hz), switch to AC excitation system control active power and governor control speed mode for fast frequency compensation regulation, until the frequency compensation regulation is completed, then switch to AC excitation system control speed and governor control active power mode. It can fully leverage the flexible adjustment advantages of the variable speed unit.

7 Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

(1) Compared with conventional pumped storage units, variable speed pumped storage units increase the amount of speed, which brings about the coupling problem of active power regulation and speed regulation. It is necessary to set up a coordinated controller to unify and coordinate the distribution.

(2) The normal active power regulation in power generation condition should adopt the AC excitation system control speed and governor control active power mode. The frequency regulation active power regulation in power generation condition should adopt the AC excitation system control active power and the governor control speed mode, for example, primary frequency regulation, which can achieve rapid adjustment of about 7% active power in hundred milliseconds. Two control modes can be automatically switched according to the application scenarios.

(3) The normal active power regulation in pumping condition should adopt AC excitation control speed and governor control guide vane opening mode. However, there may be deviation in active power regulation, and it is necessary to adjust the active power to the error range through speed compensation adjustment.

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