Study of Hydraulic Disturbance of Pumped Storage Unit

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Abstract. The analysis of hydraulic disturbance is an important part of the analysis of the hydraulic transient process of a hydropower station. This paper introduces the relationship between the grid-connected operation mode of the power station and the hydraulic disturbance by the power station system, and performs simulation calculations under the same boundary conditions according to the hydraulic disturbance test cases, and predicts the extreme control conditions which provides the basis for the safe operation of the power station. It also provides reference for the design and calculation of similar projects.

1. Preface
A Pumped Storage Power Station has 4 reversible pumped storage units with a single capacity of 300MW, with a total installed capacity of 1200MW. The maximum net head of power generation is 447.0m. The total length of the water delivery system is about 2061.8 m. The water delivery system is mainly composed of the upper reservoir inlet/outlet, diversion tunnel, diversion bifurcated pipe, high-pressure steel branch pipe, tail water branch pipe, tail water bifurcated pipe, tail water surge tank, tail water tunnel, lower warehouse inlet/outlet and other buildings. It adopts a two-hole with four-machine layout and is divided into two hydraulic units. The upstream side of each hydraulic unit uses the "one hole with two machines" form of water delivery, and the downstream side of the unit uses the "two machines with one hole" form of water delivery.

In the case of multiple units sharing one hydraulic unit, if some of the units lose full load or increase the load significantly for some reason, it will cause fluctuations in the pipeline system pressure or the water level in the surge tank, which will affect the water head and load of the normal operation unit. This phenomenon is called hydraulic disturbance \[1\]. Especially for power stations with large single unit capacity and long diversion tunnels, the hydraulic disturbance characteristics are more worthy of attention. The premise of hydraulic disturbance analysis is a reasonable power grid model. According to the actual operation mode of the power station in the power grid, it is more practical to calculate the hydraulic disturbance in a targeted manner. This article combines the grid-connected operation mode of the power station, and analyzes the actual hydraulic disturbance test conditions on site to provide a basis for the safe operation of the unit.

2. Introduction To Grid-connected Operation Mode Of The Power Station
The governor of The Power Station has three adjustment methods: frequency adjustment, opening adjustment and power adjustment. Frequency adjustment is generally used when the unit is under no-load, back-to-back driving or when the unit is operating in an isolated grid, and its tracking target is the frequency setting value. The opening adjustment is generally put into operation when the unit is connected to the grid (non-isolated grid), and its tracking target is the setting value of the governor guide
vane opening. The power regulation is generally put into operation when the unit is connected to the grid (not isolated grid), and its tracking target is the power setting value.

The analysis of the transient process of hydraulic disturbance mainly considers three operation modes: power regulation under parallel connection to ideal large power grid, frequency regulation under parallel connection to ideal large power grid and frequency regulation under isolated grid.

In the power regulation mode, the governor uses the given turbine power as the input signal. When the grid load changes or other units of the same hydraulic unit experience load increase or accident load rejection, the governor system will automatically follow the given power command signal to adjust the guide vane opening to make the output power and load of the unit reach a new balance. In the calculation of hydraulic disturbance of power regulation under parallel connection to ideal large power grid, the governor participates in the regulation, and the disturbed unit runs on the output power.

In the frequency regulation mode, the governor uses the change of the grid frequency as an input signal to adjust the guide vane opening. When the frequency fluctuation is caused by the imbalance between the power grid load and the output power of the unit, the frequency modulation unit will take the network frequency variation as the input signal of the governor. If the network frequency decreases (increases), the unit will increase (decrease) the opening of the guide vane and increase (decrease) the output of the unit, so that the network frequency will increase (decrease) accordingly to restore to the set value. In the calculation of hydraulic disturbance of frequency regulation under parallel connection to ideal large power grid, it is assumed that the unit is incorporated into the infinite power network. At this time, the power network frequency remains unchanged. According to the principle of frequency regulation, the governor will not act, the load fluctuation caused by hydraulic disturbance will be completely absorbed by the power network, and the disturbed unit will operate at equal opening. In this mode, the unit has the maximum over-current intensity. If this working condition can not meet the design requirements, it may lead to the load rejection accident of the disturbed unit due to over-current protection.

During the calculation of hydraulic disturbance in the isolated grid frequency regulation mode, the grid frequency changes and the governor participates in the regulation. Since the power station is incorporated into Fujian Power Grid and has a large capacity, the possibility of adopting this regulation mode is very small, and the influence of hydraulic disturbance on the output of operating units is small under this mode, so this mode is not considered temporarily.

3. Control Conditions Of Hydraulic Disturbance Calculation

The main evaluation index of hydraulic disturbance is output swing. The output of a generator is equal to the product of current and voltage, and its excitation regulation characteristics make the terminal voltage of the generator stable quickly, so the output swing is mainly manifested as the change of current with time. Short-time overcurrent is allowed under accident condition of hydrogenerator. The multiple of overcurrent of stator winding and the corresponding allowable duration are shown in Table 1. The number of overcurrents reaching the allowable duration in Table 1 does not exceed 2 times per year on average \(^2\).

| Multiples of stator overcurrent | Allowable duration/min |
|---------------------------------|------------------------|
| (Stator current/stator rated current) | Stator winding cooled by air | Stator winding directly cooled by water |
| 1.10                           | 60                     |
| 1.15                           | 15                     |
| 1.20                           | 6                      |
| 1.25                           | 5                      |
| 1.30                           | 4                      |
| 1.40                           | 3                      | 2                |
| 1.50                           | 2                      | 1                |
According to the relay protection setting value of the generator motor of the power station issued by Fujian Power Grid and the calculation formula of inverse time protection heat accumulation in the protection device manual, the relationship between the overcurrent multiple of the inverse time limit sub-overload protection and the allowable duration is shown in the table 2 shown.

Table 2. The allowable overcurrent multiples and allowable duration of stator windings.

| Multiples of stator overcurrent | Allowable duration (s) |
|-------------------------------|------------------------|
| 1.25                          | 288.15                 |
| 1.30                          | 231.14                 |
| 1.40                          | 162.87                 |
| 1.50                          | 124.01                 |

Note: Table 1 is the design requirements for overcurrent intensity of electrical equipment, and Table 2 is the power grid's requirements for unit dispatching operation.

4. Hydraulic Disturbance Test

4.1. Load Rejection Test Conditions And Instructions
The main purpose of hydraulic disturbance test is to verify the influence of load rejection of one unit on the other normal unit when two units of the same hydraulic unit are in normal operation[3]. It mainly evaluates the variation of output power of units in normal operation and governor action. Therefore, the analysis in this part mainly compares and analyzes the variation of output power and opening degree of the disturbed units under parallel connection to ideal large power grid (East China Power Grid has a large capacity, which can be considered as an ideal large power grid).

Table 3. Hydraulic disturbance test conditions.

| Test conditions | Test projects | Upper reservoir water level (m) | Load changes | instructions |
|-----------------|---------------|---------------------------------|--------------|--------------|
| TestR1          | 2nd unit dump rated load | 728.63                          | 2set→1set    | 1st unit has a load of 297.3MW, 2nd unit has a load of 226.1MW, 1st unit has load rejection, 2nd unit is operating normally |
| TestR2          | 2nd unit dump rated load | 727.95                          | 2set→1set    | 1st unit has a load of 299.4MW, 2nd unit has a load of 300.50MW, 1st unit has load rejection, 2nd unit is operating normally |

4.2. Comparative Analysis Of Test Results And Numerical Simulation Calculation Results
Using the same boundary conditions as the experimental boundary, the numerical simulation calculation is carried out. The numerical calculation software adopts "The simulation calculation software for the hydraulic transient process of complex systems- Hysim", which is developed by Huadong Engineering Corporation Limited. At present, Hysim software system has passed third-party software evaluation, has applied for software copyright, published 33 special reports on hydraulic transition process analysis, published 11 papers, applied for 5 patents, 8 scientific research projects, internal and external lectures and 9 reports, 3 awards, 3 standardization regulations and guidelines via combined with engineering applications. The software is used in multiple pumped storage power stations. The comparative
calculation and analysis results are shown in Table 4, and the specific results are shown in Figures 1-2.

Table 4. Maximum output power of normal operation unit.

| Test conditions | Measured value (MW) | Calculated value (MW) | Value difference |
|-----------------|---------------------|-----------------------|------------------|
| TestR1          | 288.13              | 304.23                | 15.60            |
| TestR2          | 363.30              | 389.82                | 26.52            |

Note: Modified value of calculation error is determined by "Value difference = Calculation value - Measured value in experiment".

As can be seen from Table 4 and Figure 1-2,

1) The disturbed unit is in the power regulation operation mode, and the guide vanes are reduced or increased according to the increase or decrease in output, and try to maintain the constant output of the disturbed unit.

2) The numerical calculation result is close to the measured result and the calculated value is slightly larger than the measured value. The main reason is that the guide vane opening has a certain hysteresis during the adjustment process, but the numerical calculation of the time-varying law is basically consistent with the measured result. The measured results can be used to predict the extreme controlled conditions.

5. Review Of Extreme Controlled Conditions

The control condition GR1 of hydraulic disturbance that may be encountered in the operation process of the power station is rechecked and calculated, and the calculation error is corrected according to the measured and calculated conditions of hydraulic disturbance tests. The calculation results of extreme controlled condition are shown in Table 5 and Figure 3.

GR1: The design flood water level of the upstream is 743.79m, and the dead water level of the downstream is 266.00m. When the rated output power of the two machines is in normal operation, one unit will dump all the load, and the other unit will run normally.

Table 5. Calculation results of hydraulic disturbance.

| Frequency regulation under parallel connection to ideal large power grid | Power regulation under parallel connection to ideal large power grid |
|---------------------------|--------------------------|
| Maximum output power      | 404.80                   | Maximum output power      | 404.03                   |
| Maximum output power/ Rated output power | 1.349                   | Maximum output power/ Rated output power | 1.347                   |
Note: Since there is no relevant test of frequency regulation under parallel connection to ideal large power grid and the unit guide vane opening is unchanged in this mode, the calculation boundary is simpler and the calculation deviation is smaller. Therefore, the subsequent relevant corrections of the calculation results in this operating mode are temporarily corrected according to the correction values of the actual measurement and calculation results in the power regulation under parallel connection to ideal large power grid.

Figure 3. The output power of the disturbed unit in power regulation under parallel connection to ideal large power grid.

It can be seen from Table 5 and Figure 3 that the maximum output power of the disturbed unit is 404.80MW under the extreme control conditions and the disturbed unit is in frequency regulation under parallel connection to ideal large power grid. After considering the calculation error correction, the maximum output power of the disturbed unit is 378.28MW, the duration does not exceed 30s, and it meets the requirements of overload intensity design and grid operation dispatching.

The influence of hydraulic disturbance on the output of the operating unit is greater than the power adjustment operation mode in frequency regulation under parallel connection to ideal large power grid[4]. The overcurrent intensity of the unit is the highest, which is the control situation of the overcurrent intensity design of the unit. In the calculation of hydraulic disturbance, adequate attention should be paid to the calculation of hydraulic disturbance in frequency regulation under parallel connection to ideal large power grid.

6. Conclusion
Hydraulic disturbance is closely related to the grid-connected operation mode of the power station. A reasonable operation mode of the power station should be considered when analyzing the hydraulic disturbance. Since the overcurrent intensity of the disturbed unit in frequency regulation under parallel connection to ideal large power grid is greater and the duration is longer, it is supposed to calculate the hydraulic disturbance in frequency regulation under parallel connection to ideal large power grid. The power station meets the requirements of overload intensity design and grid operation dispatching under hydraulic disturbance conditions, which can ensure the safety of the project.

References
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