Commissioning practice of no-load stability in low head area for pump turbine

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Abstract. Connect to grid stably is very important for large capacity pumped-storage power station in low head. But it is also difficult because of different units’ characteristic and start ruler. So, it is necessary to find some good ways to deal with it during commissioning period of power station. This paper is based on the stability commissioning practice of a pumped-storage power station with no-load, verifies the feasibility of pump turbine that try to adjust the speed of opening the guide vanes can connect to grid stably in generating condition. This is a successful example to solve the problem that how to connect to grid stably.

1. Overview
Pump turbine is the core equipment of pumped-storage power station. When design the pump turbine, both power generation condition and pumping condition must be taken into account. The runner design is mainly based on the pumping condition, and the power generation condition of the turbine is also comprehensively considered. The relative runner diameter of reversible pump turbine is larger, so the effect of centrifugal force is remarkable, which causes a large descending gradient of inflow velocity along the rotating direction of turbine in high speed zone. And the effect acts on the four quadrant integrated characteristic curve of pump turbine, where the equal opening curve bends obviously. When power generation start-up, the lower the start-up head is, the larger the corresponding no-load opening will be. And the corresponding angle between the equal opening curve and the zero unit torque curve will be smaller. This makes it easier for pump turbine to enter the braking zone under low head condition.

The water flow through the low specific speed pump turbine is driven by its own inertia force into the braking zone. Because of the blocking effect of water flow on the runner, while the flow rate decreases, the speed is also decreasing. Therefore, the opening curve bends to the direction where the unit speed is smaller. If the inertial force does not disappear, the centrifugal force will push the water out of the runner, then the pump turbine enters the reverse pump zone. After that, the speed will rise again, making the equal opening curve bend to the direction where the unit speed is larger. The equal opening curve forms an inverse "S" shape, which is known as the "S" characteristics. The pump turbine starts up in generator operation condition, and when the speed is close to the rated speed, the unit is in no-load condition, the guide vane opening is small. But the water in the runner room is likely to enter the reverse pump zone under the influence of the powerful centrifugal force formed by the high-speed rotation. At this time, the unit speed may fluctuate, leading to difficulties in grid connection.

Therefore, no-load grid connection instability of pump turbine under generator operation condition must be considered, and the corresponding measures must be found.
2. The problem raised

How to deal with the no-load grid connection instability of pump turbine which may occur under generation condition?

At present, the common ways of dealing with the no load instability of pump turbines are:

- asynchronous pre-opening guide vanes
- Opening the ball valves (inlet valve) partially.
- Governor pressure feedback method

The application of above methods requires prior considered during designing. At the same time, the application of different methods has certain pertinence and limitation. In the above methods, the asynchronous pre-opening of guide vane is used to destroy the reverse "S" characteristic of the pump turbine by changing the flow pattern of the turbine, which often brings greater noise and strong vibration and other adverse effects during the adjustment process. Ball valve is generally not used as throttling, and if opening partially, the ball valve is prone to vibration, which will damage the flow surface. The governor pressure feedback method is generally considered to be more effective in stabilizing the low frequency swing. At present, there is no mature experience in both theory and practice in the field of feedback pressure treatment and optimized operation measures in china. So, can we use other simple and feasible methods to improve the stability of no-load grid connection?

Another way to solve the no-load grid connection instability under power generation condition of pump turbine is to regulate the opening law of the guide vanes, and make the unit approach the synchronous speed gradually, avoiding the turbine entering the unstable reverse pump zone. The principle is that, when the starting speed of pump turbine in power generation condition is fast, it may cause relatively large pressure fluctuation in penstock, spiral case and draft tube, and increase the possibility of the unit to enter the reverse pump condition. The relevant literature shows that (Mei Zuyan, page 231), a foreign research institutions has carried out a computer simulation of the opening law of the guide vanes from zero opening to no-load opening, and the time is 3S and 90s respectively. The result shows that when using the slow opening law, the pump turbine did not tend to enter the reverse pump condition, but when using quickly opening law, flow and pressure fluctuation occured. The method above has been verified in practice in the power station described in this paper.

3. Validation test

3.1. The basic parameters of the verification test station

- Design pool level
  - Upper reservoir: 222.8 m
  - Lower reservoir: 14.96 m
- Design normal level (m): 222 m
- Normal operating level(m): 198.0 m
- Dead water level(m): 190 m
- Head / lift
  - Minimum gross head/lift(m): 185.56 m
  - Limit minimum gross head/lift(m): 175.4 m
  - Maximum gross head/lift(m): 220.05 m
  - Rated head under generator mode (m): 190 m
- Unit capacity / rated speed
  - Unit capacity(MW): 250 MW
  - Rated speed(r/min): 250 r/min

3.2. Schematic curve of “S” region in four quadrants characteristic curve of model test
From the above figure, there is an obvious reverse "S" characteristic in the full characteristic curve.

3.3. The main parameters of the first automatic starting up

- The reservoir water level of power station before the test
  - Upper reservoir: 198.1m
  - Lower reservoir: 3.4m

- PID parameter setting for governor
  - Proportional gain Kp: 0.8
  - Integral gain Ki: 0.05
  - Differential gain: 0.01

- The start-up law

Among them, when the frequency is below 48Hz, the governor uses PI regulation law; when the frequency is above 48Hz, the governor uses PID regulation law. Speed recording as following:
It can be seen from the above figure that the unit speed increases rapidly with the opening of the guide vane, and is maintained near 45Hz for a period of time. After that, the speed increases to 49Hz rapidly, and fluctuates near it, showing a trend of divergence. In 525s, it is cut to the manual state to reduce the sensitivity of the speed feedback. Then the unit speed gradually reaches the rated speed and convergence by adjusting the opening to no-load opening slowly.

The dynamic analysis of the starting of the unit shows that the opening law of the guide vanes is lagging behind the expected opening rules.

Based on the above analysis, the opening speed of the guide vane needs to be slowed down furtherly, when the unit speed gets close to high speed.

While the unit speed increases from 35Hz to 48Hz, the opening speed is reduced from 1.0%Y/s to 1.7%Y/s (of which, Y is the no-load opening of guide vane under corresponding head). When the unit speed arrives at 48Hz, the PID regulation is input, and the differential gain will be magnified 15 times, which means that Kd is amplified from the original 0.01 to 0.15.

### 3.4. The main parameters of the second starting up

- The reservoir water level of power station before the test
  - Upper reservoir 197.9m
  - Lower reservoir 3.5m
- PID parameter setting for governor
  - Proportional gain Kp 0.8
  - Integral gain Ki 0.05
  - Differential gain 0.15
- The start-up law

![Figure 3. Speed change curve with guide vane opening](image_url)
It can be seen from the above figure that during the slow opening process of the guide vane, the unit speed rise steadily and the fluctuation is relatively small. When the speed reaches 48Hz, the governor uses a very slow adjusting mode. For a long time, the guide vane opening is kept in a stable state, which is beneficial to reducing the fluctuation and approaching the set value gradually. The result shows that the unit frequency is stable at the rated speed at last, and the automatic startup of the governor under the low water head of the power station is realized. The influence of the reverse "S" characteristic of the pump turbine is eliminated, and the successful grid connection is realized finally.

4. Conclusions and recommendations
According to the starting up regulation practice under generator operation condition in the pumped-storage power station, the conclusions are as follows:
It is possible to realize the starting up, grid connection and stable operation of the pump turbine undergenerator operation condition by adjusting the law of starting up and slowing down the speed of starting. The practice of this power station provides a reference example for the debugging of similar power stations in China.

For no-load grid connection instability of the pump turbine under low head generator operation condition, the three traditional solutions to solve the no-load grid connection under low head may bring adverse effects on the vibration, noise, pressure fluctuation characteristic of the unit. Where possible, the solution to adjust the start-up law should be given priority.

Up to now, the minimum operating head of the power station has reached 186m, which is relatively stable during the operation of the startup of the pump turbine. The fact has proved that the method is effective. But so far, the power station has not yet reached the minimum design head, which requires further tests on the no-load grid connection stability of the turbine under lower water head.

Reference
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