Analysis of the Influence of Nuclear Power Extraction Steam Heating Reformation on Steam Turbine OPC

Jiaye Shao*, Yuhua Hao, Zhigang Wu
State Nuclear Electric Power Planning Design&Research Institute Co., Ltd. Beijing, China
*Corresponding author’s e-mail: shaojiaye@snpdri.com

Abstract. This article analyzes the influence of the OPC signal transmission, OPC test and OPC action function of the steam turbine before and after the heating renovation of a nuclear power plant, and compares the simulation test of the relevant simulator. The analysis result shows that after the nuclear power plant's heating reformation, the impact on the original steam turbine OPC is not obvious, and it also provides support for the stable operation of the transformed unit, and also provides a reference for subsequent related projects.

1. Introduction
Nuclear energy is a clean, safe, and efficient new energy source, and it is also an important pillar to meet energy supply[1,2]. Due to the slowdown in energy demand in the world today, there are many ways to diversify the use of nuclear energy[3]. Nuclear heating can provide clean heating in most areas, and it can also effectively solve the environmental pollution caused by coal-fired heating. Nuclear energy heating is an important practice for the comprehensive utilization of nuclear energy, and it is also an important strategy for my country to vigorously develop clean energy.

Internationally, nuclear heating is mainly divided into two forms: single nuclear heating and cogeneration[4]. Single nuclear heating is a low-temperature heating nuclear reactor for the purpose of heating, and it operates only during the heating season. Combined heat and power refers to the extraction of a certain amount of steam from the steam turbine or steam pipeline of a large nuclear power plant, and the heating of the surrounding area by means of reheating.

A nuclear power plant carried out a heating reform on Unit 1. The heating steam was extracted from the exhaust pipe of the high-pressure cylinder of the steam turbine. The maximum heating steam volume was about 400t/h, and the heating load was about 4% of the unit's full load. After the transformation, it will have an external heating capacity of about 200MW, and the heating area can cover several million square meters. Due to the heating transformation, the rated parameters of the original steam turbine have also been changed, which has a certain impact on the safety and economy of the entire nuclear power plant. From the perspective of the influence of steam turbines, this article analyzes the influence of the overspeed protection controller function (OPC) of the steam turbine to provide certain favorable support for the safe production and stable operation of the retrofitted unit, as well as for subsequent heating retrofit projects. Reference.
2. Functions and features

2.1. System configuration
The main steam turbine of the nuclear power plant includes a high-pressure cylinder, three low-pressure cylinders and ancillary equipment. The main valves include: the main valve includes the main stop valve (MSV) and the government valve (GV) at the main steam inlet, and the moisture separator & reheaters (MSR) The reheat stop valve (RSV) and intercept valve (ICV) in the downstream connection pipeline. Two main shut-off valves and two regulating valves are combined into one, which are respectively installed on the left and right sides of the ground high pressure steam turbine. Each steam chamber is made of an integral casting body, and each steam path of MSV and GV is connected together inside the steam chamber. The steam turbine system diagram is shown in Fig.1.

![Fig.1 Steam turbine system diagram](image)

2.2. OPC control function
Overspeed protection controller function (OPC) is an important part of the DEH regulation system[5], and is a control function to suppress overspeed. The OPC of the nuclear power plant adopts Load drop anticipator (LDA) design. The protection controller is to prevent the turbine from overspeeding by monitoring the overspeed pre-sensor and quickly closing the GV and ICV.

The nuclear power plant OPC monitors the steam turbine overspeed pre-sensor based on the relationship between the increase in steam turbine speed and load unbalance. The turbine output is represented by the inlet pressure of the low-pressure cylinder, and the generator current represents the generator load. The load unbalance is calculated by the difference between the turbine output (low-pressure cylinder inlet pressure) and the generator load (generator current).

2.3. Operating characteristics

2.3.1 OPC action characteristics
According to the relationship between the speed increase and the load unbalance, when the OPC detects the overspeed prediction, the OPC will act to prevent the steam turbine from tripping over the speed.

(1) OPC normal operating characteristics
If the steam turbine does not accelerate very quickly under the condition of low load unbalance (30% or less), the OPC will act when the speed of the steam turbine reaches 107.5% or above. If the steam turbine accelerates rapidly under the condition of a large unbalance load (30% or more), the
OPC will act when the sum of the steam turbine speed function and the load unbalance function reaches a fixed set value. The characteristics of OPC action are shown in Fig.2 below.

![Fig.2 OPC action characteristics](image)

(a) OPC normal operating characteristics
(b) OPC operation characteristics at parallel off

2. OPC operation characteristics at parallel off

In the case of a unit split, the steam turbine is easily accelerated due to the small load of the steam turbine at this time.

Therefore, in addition to the above cases, in the case of unloading, OPC will act when the load unbalance exceeds 30%. If the load unbalance is 30% or less under the condition of unloading, according to the normal operating characteristics of OPC, OPC will act when the speed of the steam turbine exceeds 107.5%.

2.3.2 OPC logic

- a) When the deviation between generator power and steam turbine power is greater than 30%, OPC will act when the sum of the steam turbine speed function and load unbalance function reaches a fixed set value:
  - b) The generator outlet circuit breaker is off or the main transformer circuit breaker is off, and the low-pressure cylinder inlet steam pressure exceeds 30%. Take two values to do the AND logic (this logic function represents the load rejection in the operation mode above 30%
- c) The speed of the steam turbine exceeds 107.5%:

After the above three conditions a), b), and c) do the "or" logic, and the overspeed test is blocked to do the "and" logic.

3. Impact analysis

Mainly through the three aspects of OPC signal transmission, OPC test influence and OPC action logic, the analysis of the influence of OPC before and after the nuclear power plant heating reformation.

3.1. Analysis of the influence of heating renovation on signal transmission

The OPC signal transmission scheme of the nuclear power plant heating transformation is shown in Fig.3. Three OPC signals are sent to the newly added control system cabinet through DROP Y, and the valve is quickly closed after three out of two logics are implemented in the newly added control system cabinet. Taking into account that the intermediate relay cabinet and DROP Y have signal interlocking with OPC solenoid valves, and the exhaust pipe check valves at all levels of the steam turbine, in order not to affect the safety protection circuit, the intermediate relay cabinet and the DROP Y front-end signal should not be modified.

The OPC signal transmission after the heating transformation does not change the control wiring and control functions in the original cabinet, and meets the requirements of the OPC signal response time of the heating extraction steam check valve and the extraction steam quick-closing valve. OPC signal transmission has no effect.
3.2. Analysis of the influence of heating reform on OPC test

The OPC test is to select and run the "OPC test" on the operation screen after the unit is split and the valve switch is completed, which is equivalent to the OPC test at 100% load unbalance. If the OPC function is normal, the OPC will act for 1 second. By opening the GV and ICV's unloading valve makes GV and ICV completely closed.

Regardless of before or after the heating renovation, the OPC test function cannot be selected during grid-connected operation to prevent misoperation by the operator. Therefore, the heating reform has no effect on the OPC test.

3.3. Analysis of the influence of heating reform on OPC action function

According to the original OPC triggering conditions in Fig.2, the following three aspects are analyzed under heating conditions: turbine overspeed, generator split and load unbalance.

3.3.1 Turbine overspeed

According to the OPC operating characteristics in Fig.2 (a), when the steam turbine does not accelerate very quickly under the condition of low load unbalance (30% or below), the OPC will act when the steam turbine speed reaches 107.5% or above.

The power grid can be regarded as an infinite system. In the case that the steam turbine generator set is not split, the steam turbine will not overspeed. Generator splits generally occur from load rejection to service power or load rejection to idling. Therefore, under heating conditions, the steam turbine generator set is still connected to the grid and the steam turbine will not exceed the speed of 107.5%.

3.3.2 Generator split

According to the OPC action characteristics in Fig.2 (b), under pure condensing conditions, OPC is triggered when the load unbalance exceeds 30% and the unit splits. Since this heating renovation is allowed to be put into the heating system only when the load is above 50%, the splitting of the unit under heating conditions triggers OPC, which has no effect compared to pure condensing conditions.
3.3.3 Load unbalance
Before the heating transformation, when the generator load is at 100% rated power, the load deviation between the steam turbine output and the generator load is 0%. According to logical calculation: the load deviation of 0% is a condition that the steam turbine has a low load unbalance (less than or equal to 30%), and the OPC operates normally, that is, it acts when the turbine speed reaches 107.5% or above.

After the heating reformation, when the generator load is at 96% of the rated power, the theoretical value of the inlet steam pressure of the low pressure cylinder is 0.745MPa.g based on the calculation of the unit's thermal balance, and the ratio of the steam turbine output to the rated value of 0.813MPa.g is 91.6% , The deviation of steam turbine output and generator load is 96%, and the load deviation is -4.4%. This deviation also belongs to the condition that the load unbalance of the steam turbine is low (less than or equal to 30%), and the OPC operates normally, that is, it acts when the speed of the steam turbine reaches 107.5% or above.

Before the heating reformation, the generator load and steam turbine steam load had a deviation of 0%. After the heating reformation, the generator load is 96%, and the inlet pressure of the low pressure cylinder used to characterize the steam turbine load is about 91.6% of the rated pure condensing condition. There is a load deviation of -4.4%. The difference between the second OPC action and the pure condensing condition is that the turbine load characterization value (low pressure cylinder inlet pressure) must first compensate for the initial operating condition steam turbine load characterization value 91.6% and electrical load 96% difference, so the heating condition Because the load deviation is compensated first, and then OPC is triggered, the heating condition should lag behind the OPC triggering time under the pure condensing condition.

4. Simulation test
Based on the above analysis results, the simulation test of the simulator was carried out. This test simulated the transient operating conditions of the nuclear power plant steam turbine unit from load rejection to idling, and simulated load rejection conditions by opening the generator outlet circuit breaker.

The full time of this simulation experiment is 10 minutes, and the data is taken at an interval of 0.1 seconds. Before the heating reformation, the time to simulate the opening of the generator outlet circuit breaker is at 12 seconds. After the heating reformation, the simulation of opening the generator outlet circuit breaker is The time is at the 20th second. In the whole process time, OPC was triggered only once. Before the heating reformation, the OPC action started at 12.15625 seconds and ended at 13.65625 seconds with a duration of 1.5 seconds. In the following 10 minutes, OPC did not act again. After the heating renovation, the OPC action started at 20.8125 seconds and ended at 22.3125 seconds with a duration of 1.5 seconds. In the following 10 minutes, OPC did not move again.

Fig.4 OPC action in simulation test (before heating reformation)
Fig. 5 The change of steam turbine speed during OPC operation (before heating reformation)

Fig. 6 OPC action in simulation test (after heating reformation)
Fig. 7 The change of steam turbine speed during OPC operation (after heating reformation)

Tab. 1 Time comparison table of OPC action and steam turbine speed (before heating reformation)

| Time (s) | Turbine speed (rpm) | OPC_ALM |
|---------|---------------------|--------|
| 12.0625 | 1500.00             | 0      |
| 12.5625 | 1518.48             | -1     |
| 13.0625 | 1536.29             | -1     |
| 13.5625 | 1541.23             | -1     |
| 14.0625 | 1539.15             | 0      |

Tab. 2 Time comparison table of OPC action and steam turbine speed (after heating reformation)

| Time (s) | Turbine speed (rpm) | OPC_ALM |
|---------|---------------------|--------|
| 20.8125 | 1500.00             | 0      |
| 21.3125 | 1520.96             | -1     |
| 21.8125 | 1535.47             | -1     |
| 22.3125 | 1536.26             | -1     |
| 22.8125 | 1533.86             | 0      |

The time period of 0.5 seconds before and after OPC triggering is intercepted from the original data. The comparison table of steam turbine speed and OPC action time is shown in Tab. 1~Tab. 2. The OPC actions before and after the heating reformation are shown in Fig. 4 and Fig. 6. The corresponding OPC action and the change of steam turbine speed are shown in Fig. 5 and Fig. 7. Based on the above chart, it can be concluded that during the OPC operation, the steam turbine did not exceed the speed of 107.5%. Therefore, the simulation results show that the impact of the nuclear power plant heating reform on the OPC operation is only greater than the load unbalance caused by the load rejection condition. Trigger at 30%, and all triggers are once.

5. Conclusion

After the nuclear power plant's heating renovation, the OPC signal transmission of the steam turbine does not change the control wiring and control functions in the original cabinet, and meets the response time requirements of the heating system valves to the OPC signal, so the heating renovation has no effect on the original OPC signal transmission.

Under heating conditions, the maximum deviation between the inlet steam pressure (%) of the low pressure cylinder and the electrical power of the turbine (%) does not exceed 4.4%. This deviation has
no effect on the overspeed and generator split functions of the OPC turbine, and has little effect on the load unbalance function. When the heat supply exits the transient operating condition, the functions of the steam turbine overspeed, generator split, and load unbalance will not be triggered.

References
[1] Xiaobin Li, Hongna Zhang, Kaiyang Qu, Fengchen Li. Analysis of the superiority of nuclear power central heating system[J]. Huadian Technology, 2020, v.42;No.340(11):75-88.
[2] Jianqiang Wang, Zhimin Dai, Hongjie Xu. Research status and prospects of comprehensive utilization of nuclear energy[J]. Bulletin of the Chinese Academy of Sciences, 2019, 34(04):86-94.
[3] Jiangnan Peng, Fuyin Peng. Development Trend of Comprehensive Utilization of Nuclear Energy[J]. China Science and Technology Information, 2019, 598(02):110-111.
[4] Yanrui Li, Yunsheng Bai, Shaoyang Han, et al. Development status and trend analysis of nuclear energy heating[C]// Chinese Nuclear Society 2019 Academic Annual Meeting. 0.
[5] Qing He, Guoqing Li, Lijian Wang, et al. Simulation analysis of steam turbine generator power-load unbalance protection[J]. Thermal Power Generation, 2018, 047(011): 102-108.