The Adjustment and Analysis of Manual Synchronization Device and the Circuit for the Million Kilowatts Nuclear Power Plant

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Abstract. During the twenty-year-overhaul of the Daya bay nuclear power plant unit 1 and unit 2, the overall transformation of the generator outlet circuit breaker was carried out, in which the synchronization device and the circuit is replacement and adjustment. In order to avoid the failure of non-synchronization, static and dynamic tests are required to verify the reliability of synchronization circuit, and finally it have been proved by test.

1. Introduction

With the rapid development of power grid, a new pattern of power system with 220kV lines as the main power supply network has gradually formed. In order to meet the needs of operation mode, switching operation of 220kV and above lines occurs from time to time, and synchronization operation also occurs frequently in power plants. In order to ensure the stable operation of the system, it is necessary to consider whether the voltage on both sides of the circuit breaker meet the synchronization requirement, in order to avoid the oscillations and impact that may be brought to the power network. Therefore, the integrity of the synchronization device and the synchronization circuit is particularly important.

Generator synchronizing device is an important part of power plant secondary electrical system; it can achieve parallel operation of generating units and grid. The condition of synchronization is that the phase sequence, frequency and voltage between the generator and the power grid system should be the same, so as to ensure the safety and reliability of generators and power grid. The paper take units of Daya Bay nuclear power plant as an example, describes the process and results of simulate synchronization test.

2. Synchronization system

The synchronization device can work in an intelligence way. It can calculate and automatically give command according to the collected electrical parameters, and can compare the voltage and frequency of the generator. Once the synchronization condition is satisfied, the closing pulse can be automatically issued at the appropriate time so that the circuit breaker can close at the best time, when the voltage difference between the two side of circuit breaker is the smallest, and the impact on the generator and grid is smallest. Unit 1 and unit 2 of Daya Bay nuclear power plant are equipped independently with a synchronization device for each one, the manual synchronous device is SYNCHROTACT 5 produced by ABB Switzerland co., ltd. The voltage of the main transformer for the synchronous device is taken from 400kV busbar voltage transformer, which is transferred to the synchronization device after switching by the voltage transformer. The voltage of the generator for the synchronous device is taken from generator outlet circuit voltage transformer, which is use for
3. Difference frequency synchronization

The synchronization for power system can be divided into difference frequency synchronization mode and same frequency synchronization mode according to its characteristics. Difference frequency synchronization refers to the synchronization of the connection lines between the two systems that have been unlinked, and this is the type of the synchronization system for generator outlet circuit breaker of Daya Bay nuclear power plant unit 1 and unit 2. Its characteristic is that the voltage and frequency of power supply on both side of the breaker is not identical. The phase of voltage between the two sources varies constantly due to the different frequencies. So that the difference frequency synchronization needs to catch the synchronization time that is when the voltage and frequency are equal according to the quasi-synchronous conditions and the phase between the two sides of the parallel breaker is 0 degree. The frequency difference and the voltage difference within allowed rage is the two conditions for synchronization. Generally, synchronization need to meet the follow conditions: frequency difference less than or equal to 0.5Hz, voltage difference less than or equal to10%UN, phase difference less than or equal to 30 degrees. In Daya bay, synchronization conditions are as follow: frequency difference less than or equal to0.15Hz,voltage difference less than or equal to4%UN, phase difference less than or equal to 20 degrees, generator frequency should be slightly higher than grid frequency when the generator is connected to the grid.

4. Synchronization device test

Generator synchronizing device and its secondary circuit is relatively simple, in order to ensure the generator synchronizing operation successfully, the static and dynamic test of generator synchronous device is particularly important. The main static test item include appearance and wiring check, phase difference check, voltage difference check, manual synchronous circuit check and automatic synchronous lead time measurement. And the main dynamic test item is generator breaker simulate synchronization test.

Taking unit 1 and unit 2 of Daya Bay nuclear power plant as an example, the static and dynamic test method will be illustrated. We use OMICRON relay protection test instrument to simulate the voltage of generator side and the grid side, then we change the amplitude, frequency and phase of the voltage for the test.

4.1 Voltage difference check.

The generator synchronization voltage setting value of unit 1 and unit 2 of Daya Bay nuclear power plant is 57.7V, and it can adjust, the grid synchronization voltage setting value is 56.7V. The voltage difference in SYNCHROTACT 5 synchronization device is given by,

\[ U_{gc1} = \frac{U_{sc1}U_{gnd}}{U_{szd}} (\pm \Delta U\%) \]  

In Eq.1, \( U_{szd} \) is the setting value for grid voltage, \( U_{sc1} \) is the measured value for grid voltage; \( U_{gnd} \) is the setting value for generator voltage, \( U_{gc1} \) is the regular range for generator voltage; \( \pm \Delta U\% \) is the voltage difference allowed, it is given by,

\[ U_c = U_{gcs} - U_{scs} \left( \frac{U_{gzd}}{U_{szd}} \right) \]  

In Eq.2, \( U_c \) is voltage difference, \( U_{szd} \) is the setting value for grid voltage ,\( U_{scs} \) is the test value for grid voltage, \( U_{gcs} \) is the test value for generator voltage, \( U_{gzd} \) is the test value for generator voltage.

4.1.1 Voltage amplitude increase test

The frequency of voltage of the grid side and generator side is constant, but there is a inherent frequency difference. The allowed voltage difference\( \Delta U \) equal to \( \pm 4\% UN \), generator voltage \( U_N \) equal
to 57.7V, the voltage amplitude in range of \((1 \pm 4\%) U_N\), that is 55.4V to 60.0V. Initialize the voltage as, \(f_s = 50\) Hz, \(f_g = 50.1\) Hz, \(\Delta U = -3.7\) V, \(U_{scs}=57.7\) V, \(U_{gcs}=54\) V the change the generator voltage from 54V to 55.4V, after 3s, measure the state of the command node and confirm whether the closing instruction is sent by the synchronization device, the test result are shown in table blow.

**Table 1. test result 1**

| Name           | Voltage/V | Frequency/Hz | Name           | Voltage/V | Frequency/Hz |
|----------------|-----------|--------------|----------------|-----------|--------------|
| Grid side      | 57.7      | 50           | Difference     | -3.7      | 0.1          |
| Generator side | 54        | 50.1         | Result         | No closing command |

**Table 2. test result 2**

| Name          | Voltage/V | Frequency/Hz | Name          | Voltage/V | Frequency/Hz |
|---------------|-----------|--------------|---------------|-----------|--------------|
| Grid side     | 57.7      | 50           | Difference    | -2.3      | 0.1          |
| Generator side| 55.4      | 50.1         | Result        | The device commands closing |

4.1.2 *Voltage amplitude reduce test.* In this test, reduce the voltage of generator side from 61.4V to 59.96V, after 3s, measure the state of the command node and confirm whether the closing instruction is sent by the synchronization device, the test result are shown in table blow.

**Table 3 test result 3**

| Name           | Voltage/V | Frequency/Hz | Name           | Voltage/V | Frequency/Hz |
|----------------|-----------|--------------|----------------|-----------|--------------|
| Grid side      | 57.7      | 50           | Difference     | 3.7       | 0.1          |
| Generator side | 61.4      | 50.1         | Result         | No closing command |

**Table 4 test result 4**

| Name           | Voltage/V | Frequency/Hz | Name           | Voltage/V | Frequency/Hz |
|----------------|-----------|--------------|----------------|-----------|--------------|
| Grid side      | 57.7      | 50           | Difference     | 2.26      | 0.1          |
| Generator side | 59.96     | 50.1         | Result         | The device commands closing |

4.1.3 *Data analysis of voltage regulation test.* Voltage regulation test is the test that change the voltage amplitude when the voltage frequency of the grid side and generator side is constant, but there is an inherent frequency difference. If there is a voltage difference between the grid side and generator side, reactive power exchange will be carried on when the generator is connected to the grid. If the two side synchronization in a small voltage difference(e.g.4\%UN), there is no influence to the generator and grid system. At the moment when the generator connected to the grid, the voltage adapter sends out a regulation instruction pulse, the length of which is proportional to the current voltage, and the value of the proportional factor \(dU/dt\) can be adjusted according to the voltage regulator. The aim of the voltage adapter is to adjust the voltage difference to the median tolerance zone. The length of the adjustment instruction \(t_pU\) can be calculated according to formula(3).

\[
\begin{align*}
 t_pU &= \frac{\Delta U - \left(\pm U_{max} - |\Delta U_{max}|\right)}{2} \\
 & \times \frac{1}{dU/dt} 
\end{align*}
\]  

Once the voltage is adjusted to the target value, the regulating pulse stops. The length of the adjustment instruction should not be less than a minimum value that can be set. After the adjustment command is given, the system will wait for a pulse time \(tsU\), so as to the voltage value can be
gradually stabilized to the new voltage value, see figure 1.

During the test, the only condition that determines whether the synchronization device can give the closing command is whether the amplitude difference between generator side and grid side is within the set range. From this test, increasing and decreasing the generator voltage manually within the set value, that is less than or equal to 4%UN, the synchronization device will give the closing command. If out of the setting range, that is >4%UN or less than or equal to 4%UN, the synchronization device will not give the closing command.

4.2 Phase difference check

unit 1 and unit 2 of Daya Bay nuclear power plant as an example, use OMICRON relay protection to output the voltage signal with adjustable phase and observe phase angle. When the phase difference is greater than 20 degrees, the synchronization device will not give the closing command. When the phase difference is less than 20 degrees, about 3 seconds later, the closing phase angle is show in figure 2.
It can be seen from the test that the phase difference setting value and the function of synchronization device are correct.

4.3 Simulate synchronization test and the circuit loop check

Simulate synchronization test is a dynamic test, through which the manual synchronization device and the circuit loop reliability are verified.

Simulate synchronization test need to set the isolator off, and unlock the isolator from the generator breaker. Before the test, the unit state is required to be that the steam turbine runs in 3000rpm, and the generator outlet voltage is 26kV, and it has synchronization conditions. All equipment tests have been completed in the start-up stage of the unit.

Since the generator has been stated up and is in no-load operation state when this test is carried out, the risk of this test is relatively high. There is a risk that the turbine vibration will rise due to the turbine running at 3000rpm speed for a long time, and the risk of de excitation for no-load generator, and the risk analysis will not be repeated in this article.

The closing signal of the manual synchronization device is connected in series in the closing circuit of the generator outlet circuit breaker, as shown in figure 3. When the voltage of generator side meet the synchronization conditions, the manual synchronization device will give the closing command, then the outlet circuit breaker will close, this process illustrates the success of the test and the circuit work properly.

![synchronization closing command circuit](image)

**Figure 3** Synchronization closing command circuit

The manual and automatic synchronization are converted by selecting switch, when the switch is selected to “MANUAL”, the manual synchronization will be put into use. When the generator voltage is meet the synchronization condition, the circuit will be switched on while the operator presses the “CLOSE” button.

Though this test, we can verify the rightness of the synchronization device and synchronization
circuit. Before the test, the consistency between the actual wiring and drawing wiring must be carefully checked in order to avoid non-synchronous closing which is caused by the incorrect. Only by the static test and the simulate synchronization test for synchronization device and its secondary circuit and logic circuit for whole system, the success of actual synchronization can be ensure.

5. Summary
Daya Bay nuclear power plant used the synchronization device SYNCHROTACT 5 do synchronization operator in 2015, and set the device parameter value. The synchronization effect is ideal, which shorten the synchronization time and achieves economic and energy-saving benefits.

6. References
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