Automatic Voltage Control of Large-scale Synchronous Condensers in UHV-DC Converter Station

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Abstract. Large-scale synchronous condenser can provide a powerful dynamic reactive power for the Ultra high-voltage (UHV) Direct Current (DC) transmission system. The dynamic characteristics of synchronous condenser ensure the reactive power support capability in the case of grid fault. In this paper, the control strategy and deployment of the synchronous condensers in East China Power Grid are presented. Taking converter station as an example, this paper introduces the main architecture of automatic voltage control (AVC) system, and the relationship between host computers and slave computers. In the substation, it describes the mechanism of several control modes, and designs the on-site test scheme of the control modes. After on-site testing, the correct operation of the large-scale synchronous condensers can be guaranteed.

1 Introduction

The energy resources and loads are reversely distributed, and UHV-DC is often used for large-capacity transmission in China.[1] On the one hand, the UHV-DC is injected, the conventional units are shut down to meet the requirements of UHV-DC power absorption and peak shaving. As a result, the reactive power and voltage support capacity of the system is insufficient and the overall regulation ability is reduced. On the other hand, according to HVDC design principles, under normal operating conditions, the reactive power exchange between the UHV-DC converter station and the system is zero, and the UHV-DC does not provide dynamic reactive power to the system. Therefore, in the dynamic process of system fault, UHV-DC needs to absorb a large amount of reactive power from the system.

With the large-scale feeding of UHV-DC, especially in East China Power Grid, multiple UHV-DC commutation failure problems, voltage Stability problems are becoming more prominent.[2-3] The new-generation condenser can provide dynamic voltage support through strong excitation to reduce the risk of commutation failure in the DC system. The sub-transient characteristics of the condenser can be used to suppress voltage fluctuations. The system voltage can be quickly restored. The condenser can improve the static voltage stability margin of the system, improve the system transient voltage stability level and solve various types of voltage stability problems of the receiving power grid. During steady operation state, the condenser can also maintain voltage stability as a means of regional voltage regulation.[4]

In East China Power Grid, with the continuous increase of UHV-DC input power from the outside region, DC input power accounts for a relatively large amount. Insufficient dynamic reactive power compensation and voltage stability problems are prominent, especially in the power grids with dense UHV-DC input and high power receiving ratio. East China Power Grid accepts a high proportion of electricity from the outside region. And if the alternating current (AC) system fails, there is a risk of system voltage instability. The installation of two 300Mvar condensers in each converter station in East China Power Grid will help alleviate the difficulty of voltage recovery during system failures and increase the voltage stability level. The converter station equipped with condensers is conducive to providing an effective technical means for the reactive voltage regulation of the power grid, providing dynamic reactive power support for the local power grid with a high proportion of UHV-DC power feeding, reducing the scope and probability of DC commutation failure when the AC power grid fails, and facilitating the safe and stable operation of the power grid.

In this paper the control strategy and deployment of the synchronous condensers in East China Power Grid are presented. Taking UHV-DC converter station as an example, the on-site test scheme of the control modes is introduced.

2 Deployment strategy of condensers

The main influence of the access and operation control strategy of the condenser on the UHV power grid includes the following aspects: firstly, the condenser can improve the DC multiple feeding short circuit ratio. After the installation of the condenser, the effective short

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circuit ratio of the DC converter bus in East China Power Grid has been improved, and the voltage support ability of the receiving DC power terminal is improved. Secondly, the voltage stability of the DC power receiving system can be improved by adjusting the condenser. After the installation of the condenser, the static voltage stability margin of the power grid has been improved under normal operation mode, N-2 mode and DC blocking mode. The condenser has the function of steady-state leading phase/lagging phase reactive compensation, which can effectively regulate the near area bus steady-state voltage of the converter station. The condenser provides fast dynamic reactive support to the system after failure, which helps the system voltage recovery and DC transmission power recovery. Thirdly, the condenser can improve the commutation failure characteristics of UHV-DC. After adding the condenser, the failure range and frequency of UHV-DC commutation caused by AC fault are reduced. Fourthly, the level of short-circuit current can be increased by the condenser. The auxiliary effect of the condenser on the short-circuit current of the 500 kV Bus in the near area is more significant than that of the 220 kV side. After the short-circuit current control measures are taken, the stable operation of the power grid will not be affected. Finally, the condenser is connected to the near area AVC system, which is uniformly deployed by the dispatching center. The stable operation point of the condenser is set in the appropriate lagging phase operation mode, and the operation control strategy such as the control mode with small static adjustment coefficient or the fixed reactive power control mode is adopted, which can give full play to the dynamic reactive power supporting role of the condenser. Based on the above conclusions, East China Power Grid, as a large-scale receiving power grid, decide to deploy new generation 300Mvar condensers in each UHV-DC transmission converter station.[5]

In order to give full play to the dynamic reactive power function of the condenser, the operation control strategy of the condenser is proposed from the aspects of the participation of the condenser in the system voltage regulation and the coordination of the condensers with other reactive power compensation.

(1) The condenser is connected to the AVC system in the near area, and is uniformly deployed by the dispatching center. Under normal operation mode, the system voltage control and regulation should mainly rely on the original reactive power compensation equipment (shunt capacitor/reactor, etc.). Under extreme conditions, when it is difficult to control and adjust the voltage, the condenser can properly participate in the system voltage control. But it should ensure that it has sufficient dynamic reactive power reserve after fault.

(2) The setting of the steady-state operating point of the condenser should meet the requirements of the condenser's lagging-phase dynamic reactive power reserve after the AC fault. During steady-state operation, it is not recommended to adjust the condenser to send too much lagging-phase reactive power, to ensure that the reactive power output of the adjustable condenser can increase rapidly and quickly after the AC system fault, support the rapid recovery of the AC bus voltage of the converter station, and reduce the occurrence of DC commutation failure.

(3) The steady-state operation of the condenser should be in the lagging phase reactive power output mode. The voltage level of the power grid near the converter station is high, and the transient overvoltage problem is prominent after DC blocking. The leading phase dynamic reactive power requirements of the adjustable condenser are high. Therefore, after the adjustable condenser’s lagging phase dynamic reactive power reserve is met in the AC fault, it is necessary to retain appropriate leading phase power reserve.

(4) The condenser should adopt the control mode with small static adjustment coefficient or constant reactive power control mode. Since the condenser is installed on the high voltage bus of converter station, if it participates in DC reactive power regulation, the dynamic reactive power reserve of the condenser will be frequently called during the switching of HVDC AC filter, and these two control modes can control the reactive power output of the condenser during the operation of reactive power compensation equipment in the converter station.[6]

The excitation system of the condenser is mainly composed of excitation fast voltage loop and excitation slow reactive loop, in which the excitation slow reactive loop can accept the reference value of reactive power from AVC substation. The excitation fast voltage loop of the condenser aims at the stator voltage at the end of the generator and maintains the constant voltage at the end of the generator through excitation regulation. This is the most basic excitation control mode, also known as automatic operation, which cannot be interfered by external system. When the grid fault occurs, it will play a role and provide rapid reactive power support.

The excitation slow reactive loop of the condenser is controlled by the superimposed reactive outer loop. Two types of modes as "local control" and "AVC control" can be adopted to change the steady-state reactive output of the condenser through the slow regulation of the system voltage and the unit reactive power. The on-site test of the control modes is mainly on the reactive power outer loop.

3 Example converter station

The DC rated voltage of UHV-DC Converter Station with bipolar operation is ±800kV, and the rated capacity is 8000MVA. The 500kV AC power distribution device of Converter Station adopts internal GIS equipment and 3/2 circuit breaker wiring. The first-phase project converter station has been built with 4 converter transformer inputs, 4 large group filter inputs, and 10 500kV outlets with a total of 9 complete strings. The other two sets of busbars are connected to 500/10kV high-voltage station transformers. The primary system wiring diagram of the condensers is shown in Figure 1.

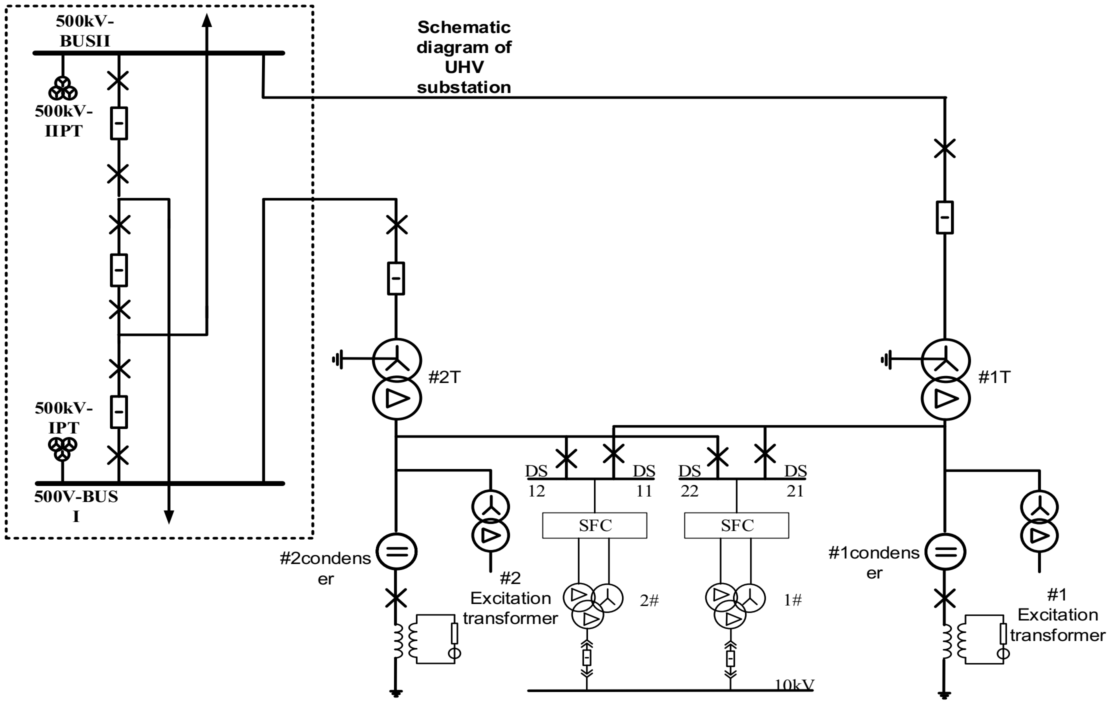

Fig 1. Primary wiring diagram of the condensers

The 2×300Mvar condensers added in this project are connected to two sections of 500kV AC filter busbars via circuit breakers, and 2 circuit breakers are installed.

4 AVC system station framework

The AVC substation is composed of two host industrial control computers, multiple slave computers (the same number as the units), Ethernet switches, the dispatch data network switches, SCADA gateways, unit control system (DCS), auxiliary power PT and etc. as shown in Figure 2. The configuration of the AVC sub-station should meet the requirements of the secondary safety protection of the relevant power monitoring system such as the 2014 Order 14 of the National Development and Reform Commission.

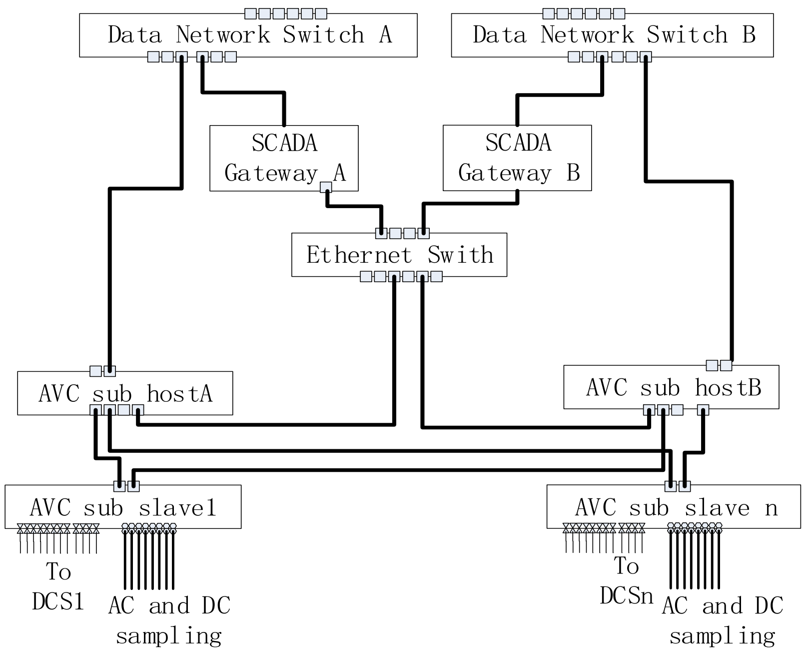

Fig 2. AVC sub-station and related equipment connection

The host computer of the AVC sub-station should be in dual-master operation mode, and the control channel is selected by the AVC master station. The slave computer is controlled by the host computer. The host computer that correctly receives the real-time adjustment instruction from the AVC master station for two consecutive instruction cycles is the master control host computer, which can control the slave computer effectively. The other parallel host computer tracks the master control host computer to forward adjustment instructions, independently calculates, records and generates control information, and its control to slave computer is invalid.

5 Control mode test

The AVC substation uses 4 control modes, switching between modes without interference, the excitation control mode (excitation fast voltage loop) has the highest priority, and the AVC remote control mode has the lowest.

5.1 AVC remote control mode

When the AVC substation runs in the "remote control mode", the AVC substation receives the AVC master station adjustment command. In the "remote control mode", when the system is running normally, the single condenser reactive power output is within a limited range to ensure that the condenser has sufficient dynamic reactive power backup to deal with system failures.

When the excitation system senses that a system fault has occurred and removes the outer loop of reactive power, the reactive output of the condenser is not subject to additional limit. By default, the rated output reactive power of the single condenser is the limit.

5.2 AVC substation local control mode

5.2.1 AVC substation local manual mode

Operator through HMI screen manually sets reactive power output. In this mode condenser does not receive voltage coordination control system commands.

5.2.2 AVC substation automatic mode

Based on 500kV bus voltage, through PI control, the host computer automatically calculates the reactive power command, this mode can receive voltage coordinated control system commands (priority).

5.3 DCS control mode

In this mode, the AVC sub-station is in the tracking state, and the reactive commands of the AVC sub-station follow the DCS commands.

5.4 Excitation control mode

In this mode, the DCS of the condenser is in the tracking state, and the DCS reactive power command tracks the feedback of the forced excitation real reactive power.

6 Test content

Before the AVC system is officially put into operation, the operational control performance of the AVC system needs to be tested. It is necessary to verify whether the condenser and AVC system can correctly receive and execute the AVC adjustment instruction, whether the unit of the converter station meets the safety requirements of the unit when it is put into/withdrawn from the power grid and during the adjustment process, whether the condenser and AVC system give full play to the voltage/reactive power control. The on-site test content of AVC system control is listed.

6.1 AVC system uplink information check

Safe and accurate uploading of substation information is the basis of AVC control.

Table 1. Uplink Information Test Table

TEST CONTENT		TEST RESULT
Up	AVC sub-station local/remote control	
	AVC sub-station on/off signal	
	AVC substation fault signal	
	System failure recovery status signal	
	Can increase or decrease reactive power	
	Bus voltage upper and lower limits	
	Current total reactive power	
	……	

6.2 AVC system Downlink receive information test

In the closed-loop state of the main station and the sub-station of the AVC system and the open-loop state of the output of the sub-station, the main station manually issues a command to adjust the total reactive power of the condenser. Within the upper and lower limits of the total reactive power adjustment, one command is issued with the step of 30Mvar. The reception data of AVC substation from the main station should be checked.

6.3 Dual host mode test

The dispatch center arbitrarily sends instructions to host A and host B computers. Host A and host B computers simultaneously receive instructions. The online host computer executes the instructions. The standby host computer accepts but does not execute the instructions. The online computer and the standby computer can be seamlessly switched.

6.4 Remote/local reactive power distribution principle

Experiment with three reactive power distribution methods of equal capacity, equal margin, and average distribution in the state of remote and local control.

6.5 Switching function test

In the closed-loop state of the AVC system, conduct the On/off test of the AVC system and the switching test of each control mode of the AVC system to ensure that all operations can be carried out normally without causing fluctuations in the reactive power and bus voltage of the condenser.

Table 2. Switching Function Test

TEST CONTENT	TEST RESULT
AVC turn on	
AVC turn off	
AVC local manual ↔ local automatic	
Local Manual ↔Remote control	

If no new command has been received for 15 minutes for 3 consecutive cycles, the main station is considered withdrawn, and the AVC sub-station automatically switches from the remote mode to the local automatic mode, keeping the command unchanged.

After resuming normal reception of the master station's reactive power adjustment command, the AVC sub-station automatically switches from the local automatic mode to the remote mode.

6.6 Protection function test

- Upper and lower limit protection function test, over-limit command will not be executed;
- Test of communication failure from AVC master station equipment;
- Power-off/reset/communication interruption test of the host computer of the AVC substation;
- Blocking test of the control of the master station while the voltage measurement of the high-voltage side is faulty;
- Blocking test of the control of the sub-station while the voltage measurement of the auxiliary power side is faulty.

6.7 AVC system reactive power command response test

AVC system adopts the substation-wide control mode and closed-loop (remote) control mode. The AVC master station system delivers the voltage/reactive power target value to the AVC substation system of the condensers. The test personal records the change curves of the electrical quantities such as the reactive power, output voltage, output current, excitation voltage and excitation current of the converter station, and checks whether the operating indicators of the AVC system meet the requirements and how it affects other electrical equipment in the plant.

7 Conclusion

Generally, UHV-DC converter stations are equipped with 2*300MVA condensers as dynamic reactive power support equipment. This paper presents the control strategy and deployment of the condenser. Taking DC station as an example, it introduces the test methods and contents of the on-site control modes of the AVC system in the converter station with the large-scale condensers. The test of the AVC system of the condensers can ensure the high-quality, high-efficiency and safety operation of the UHV-DC grid.

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