Study on Dynamic Response of a New Type Ultra High Voltage AC-DC Hybrid Power Grid

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Abstract. The new high-capacity condenser can better meet the dynamic reactive power demand brought by the large-scale development of UHVDC System, and its electrical parameters are bound to be different from the traditional condenser. In this paper, the influence of electrical parameters on the transient process and sub transient process of the condenser is analyzed, and the key parameters of the dynamic optimization of the new high-capacity condenser are extracted. Then, based on epri-36 bus system and PSASP simulation platform, the DC sending and receiving system with the new high-capacity condenser is simulated and analyzed. The simulation results show that the condenser is in UHV AC / DC system. The hybrid system plays a positive role in fault response.

Keywords: condenser; electrical parameter; transient process; ultra-high voltage.

1. Introduction

China's primary energy and load are inversely distributed, and energy delivery and load demand are extremely unbalanced. Therefore, the State Grid vigorously develops large capacity, long-distance UHVDC transmission technology [2]. According to the design principle of UHVDC, the DC system does not provide reactive power to the system while delivering active power on a large scale. Therefore, in the dynamic process of system failure, the UHVDC transmission system needs to absorb a large amount of reactive power from the near area power grid to meet the reactive power consumption of converter station, resulting in the decline of dynamic reactive power reserve capacity of receiving end system with large-scale DC feed in, and the voltage stability is becoming more and more prominent. In addition, the sending end of UHVDC transmission system is mostly built in remote areas with large-scale new energy construction such as wind power, photovoltaic power, etc. At the same time, the DC fault of the sending end system will cause the transient voltage rise of the sending end bus, and in serious cases, it will lead to the large-scale disconnection of new energy [3-6].

With the rapid development of UHV technology, voltage stability has become one of the main problems of power grid security. Aiming at the problems of dynamic reactive power capability at the sending and receiving terminals of HVDC system and the insufficient bus voltage support of converter station, a large number of dynamic reactive power compensation devices must be equipped for large-
scale transmission of DC transmission. As a synchronous rotating equipment, compared with SVC, STATCOM and other flexible dynamic reactive power compensation devices, the condenser has strong high-voltage and low-voltage ride through ability and large short-circuit overload capacity, and can effectively provide short-circuit capacity for the system. Its operation characteristics are not affected by system voltage, and has strong instantaneous reactive power support capability in case of fault. It has unique advantages in restraining overvoltage of converter station bus, restraining commutation failure of DC system, and improving system stability by using forced excitation [7-9].

Considering that in the transitional period of power grid construction, the interaction between UHV AC and DC is more obvious. Facing the problems of transient overvoltage and short-circuit capacity support of sending end system, dynamic fast reactive power regulation and overload capacity of receiving end system, the electrical parameters of new-type condenser and traditional condenser must be quite different. Firstly, this paper analyzes the dynamic characteristics of the condenser and optimizes the key parameters. Through the platform simulation, it demonstrates the effect of the condenser and the necessity and effectiveness of configuring a large capacity new type of condenser, so as to prepare for the following study.

2. Optimization of Electrical Parameters of a New Type of Large Capacity Condenser

2.1. Assumptions and main influencing factors of dynamic characteristics of a new high-capacity condenser [1].

In the current power grid structure, the dynamic reactive power demand under fault condition is the main problem of system stability. In the study of generalization, the dynamic characteristics of the condenser are measured by the reactive power injected into the high voltage bus by the condenser. The time of sub transient process is very short, the influence of excitation system is ignored in the analysis process, and the influence of damping winding and stator winding is ignored in the transient characteristic analysis.

The reactive power output of the condenser can be expressed by equation (1).

\[ Q = U_q i_d - U_d i_q \]  

Among them,  \( U_d, U_q, i_d, i_q \) represent the voltage and current of the d-axis and q-axis of the motor respectively. The power angle  \( \delta \) of the condenser can be approximated to 0, which can be expressed as follows:

\[ U_d = U \sin \delta \approx 0 \]  
\[ U_q = U \cos \delta \approx U \]

It can be concluded as:

\[ Q \approx U_q i_d \approx Ui_d \]  

When the system fails, the change of reactive power can be expressed as:

\[ \Delta Q = Q - Q_0 = U_i d - U_q i_{d0} \approx (U_0 + \Delta U)(i_{d0} + \Delta i_d) - U_0 i_{d0} \]

\[ = U \Delta i_d + \Delta Ui_{d0} \]

Among them, the voltage after fault and voltage variation mainly depend on the system capacity, grid structure and fault type. The initial value of d-axis current  \( i_{d0} \) is related to the initial working condition of the pre fault condenser. Therefore, the dynamic parameters optimization of the condenser is mainly related to the  \( \Delta i_d \) parameters optimization.
2.2. Sub Transient Reactive Power Characteristics and Key Parameters of Large Capacity New Condenser

Taking the equivalent impedance from the generator terminal as a part of the condenser stator leakage reactance, the expression of the secondary transient current increment of the condenser without considering the excitation system can be expressed as follows:

\[
\Delta i_d = \left[ -\frac{\Delta U_q}{x_d + x_k} - \frac{\Delta U_q}{x_d + x_k} \right] \frac{i_d}{T_{ds}} - \left( \frac{\Delta U_q}{x_d + x_k} - \frac{\Delta U_q}{x_d + x_k} \right) e^{\frac{t}{T_{us}}} - \left( \frac{\Delta U_q}{x_d + x_k} - \frac{\Delta U_q}{x_d + x_k} \right)
\]

\[
-\left( \frac{\Delta U_q}{x_d + x_k} \cos t + \frac{\Delta U_q}{x_d + x_k} \sin t \right) e^{\frac{t}{T_{us}}}
\]

Where, \( \Delta U_q \) is the change of q-axis component of \( U \); \( x_d, x'_d, x''_d \) are the d-axis steady-state reactance, transient reactance and sub transient reactance respectively; \( x_k \) represents the short-circuit reactance of the step-up transformer of the condenser; \( T_{ds} \) and \( T''_{ds} \) are the transient short-circuit time constant and sub transient short-circuit time constant of d-axis respectively, \( T_{us} \) reflecting the transient time constant of stator winding.

The instantaneous expression value of reactive power is:

\[
\Delta Q = -U \Delta U / (x'_d + x_k) + \Delta U i_{d0}
\]

When the voltage drops, \( \Delta U \) is negative and \( \Delta Q \) is positive, which is consistent with the reactive power demand of the system. According to formula (7), the smaller \( x'_d \) is, the stronger the instantaneous reactive power support capacity is. The smaller the initial current \( i_{d0} \) is, the more favorable it is for the condenser to send reactive power to the system.

2.3. Transient Reactive Power Characteristics and Key Parameters of Large Capacity New Condenser

In the process of transient analysis, the influence of damping winding and stator transient winding is ignored. The d-axis equation of the condenser can be expressed as follows:

\[
U_q + x_d i_d = E'_q - x'_d i_d
\]

Write it in the form of increment and calculate the \( \Delta i_d \):

\[
\Delta i_d = (\Delta E'_q - \Delta U) / (x_d + x'_d)
\]

The third order transient equation of synchronous motor controlled by excitation system is as follows:

\[
T_{d0} \frac{dE'_q}{dt} = E'_m - E'_q - (x_d - x'_d) i_d
\]

From reference [1] we know that under small disturbance, the smaller \( x'_d \) is, the better the reactive power support is in the early stage of fault; the larger \( x_d \) is, the better the reactive power support is in the later stage of fault; Transient during forced excitation, the smaller \( T_{d0} \) is, the faster the transient reactive power response is.
3. Simulation and Analysis of Dynamic Operation Characteristics of UHV AC/DC System with the Participation of Large Capacity New Condense

3.1. Simulation platform and model

The simulation platform is power system analysis software PSASP. Take the EPRI-36 system shown in Fig. 1 as an example, the system has three regions. The sending and receiving terminals of DC line are bus33 and bus34 respectively, which operate in bipolar mode. In order to meet the needs of simulation, a condenser is added to the DC sending and receiving terminal node on the basis of the original system. The illustration system takes adding a condenser in the receiving system.

3.2. Dynamic operation characteristics of condenser in UHV AC/DC hybrid system under bus overvoltage

1. Overvoltage of sending-end system caused by DC line open circuit

When the system is in normal operation, when \( t = 1 \)s, the double pole open circuit fault occurs on the DC transmission line, and the fault is removed after 0.1s. The diagram of bus voltage \( U_{bus33} \) at sending end and reactive power output of condenser without condenser, ordinary condenser and new type condenser is as follows:
2. Overvoltage caused by open circuit of AC network bus in receiving-end

When the system is in normal operation, \( t=1 \)s, the bus29 in the receiving-end of the DC transmission line is open circuited, and the fault is removed after 0.1s. The diagram of the bus voltage \( U_{\text{bus33}} \) and the reactive power output of the sending end bus with no condenser, ordinary condenser and new type condenser is as follows:

![Fig. 4 Bus voltage of bus34 in condition 2](image)

**Fig. 4** Bus voltage of bus34 in condition 2

**Fig. 5** Reactive power output of condenser II in condition 2

Based on the above two conditions, the following conclusions are drawn.

1. Under the two working conditions, the overvoltage caused by fault can be effectively suppressed by adding the condenser compared with that without the condenser. Compared with the ordinary condenser, the suppression effect of the new type of condenser is more obvious.

2. When the fault occurs, the new type of condenser is better than the ordinary one. After the fault is over, the voltage at the DC sending and receiving terminals can reach a stable state faster.

3. In the case of DC bus over-voltage, the reactive power absorbed by the new condenser from the power grid is significantly more than that of the ordinary condenser, which is more conducive to the stability of the system after fault.

3.3. Dynamic operation characteristics of condenser in UHV AC / DC hybrid system when bus voltage drops

The voltage drop of receiving terminal bus is 50%. The system operates normally. When \( t=1 \)s, three short-circuit faults occur on bus29 in the receiving-end of DC system. By changing the access resistance, the voltage of the receiving bus drops to 50%. The voltage of the receiving bus, reactive power output of the new type of condenser are shown in the figure.

Based on the above two situations, the conclusion is drawn:

1. Compared with the non-condenser, the new condenser has more obvious supporting effect on the receiving bus voltage under fault condition, and the supporting effect of the new type of condenser is more obvious than that of the ordinary one.

2. Compared with the common condenser, the new type of condenser has better mitigation effect and recovery ability after the fault disappears.

3. In the process of fault occurrence, the reactive power output of the new condenser is obviously better than that of the ordinary condenser, and its response ability to the fault is also better than that of the ordinary condenser, so it has a better support function for the receiving terminal bus voltage.
4. Summary
Through the analysis of the dynamic characteristics of the condenser, the improvement of the relevant electrical parameters is given, and the advantages of adding the condenser to the system and the effect of the new large capacity condenser on the fault ability are analyzed by simulation. The results show that the new high-capacity condenser designed in this paper is better than the traditional condenser in UHV AC/DC hybrid system, which verifies the feasibility of this paper.

References
[1] Z. Q. LI, W. Y. JIANG, Y. B. WANG, et al. Key Technical Parameters and Optimal Design of New Types of Large Capacity Synchronous Condenser. Large Electric Machine and Hydraulic Turbine. (2017) No. 04, p. 15-22.
[2] Z. L. GUO, L. L. HAO, Z. G. Chen, et al. Analysis on Excitation Loss Characteristics of Synchronous Condenser and Its Influence on Direct Current System. Automation of Electric Power Systems. Vol. 43 (2019) No.20, p. 130-139.
[3] H. RAO, D. H. ZHANG, X. B. ZHAO, et al. Practice and Analyses of UHVDC Power Transmission. High Voltage Engineering. Vol. 48 (2015) No.08, p. 2481-2488.
[4] H. CAI, D. X. LIU, C. R. LIU, et al. Dynamic Voltage Stability Analysis on UHVDC Accessing to Jiangxi Power Grid. Modern Electric Power. Vol. 28 (2011) No.06, p. 17-22.
[5] X. J. FENG. AC / DC influence analysis of long distance large capacity HVDC transmission in practical large-scale system. Science and Technology Innovation Herald. (2012) No.33, p. 89-91.
[6] T. CUI, Y. W. SHEN, B. ZHANG, et al. Influences of 300MVar synchronous condensers on the stabilities of Hunan power grid. Hunan Electric Power. Vol. 36 (2016) No. 03, p. 1-4+8.
[7] Y. P. ZHENG. Secondary equipment and technology of Intelligent Substation. China Electric Power Press, 2014, p. 4-5.
[8] H. L. ZHANG, F. S. LIU, W. LI. Site Selection for Dynamic Reactive Power Compensation and Improvement of Recovery from Commutation Failures in Multi-infeed HVDC System. Automation of Electric Power Systems. Vol. 40 (2016) No. 05, p. 133-138.
[9] J. W. ZHAO, Z. YAN, H. D. SUN, et al. Voltage Collapse Risk Assessment of AC-DC Power System. Water Resources and Power. Vol. 29 (2011) No. 10, p. 193-196+115.