

Reactive Power Coordinated Control Strategy of Synchronous Condenser and VSC based on Receiver-end Hybrid System

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Abstract

In the receiving-end hybrid LCC-VSC system, the UHVDC converter station equipped with synchronous condensers and VSC can provide dynamic reactive support to the AC grid, improve system stability, and effectively improve the problem of commutation failure. However, there is a lack of reasonable coordination and cooperation between the two. In response to this problem, considering the existing control strategies and characteristics of the synchronous condensers and the VSC converter station, propose a reactive power coordinated control strategy based on synchronous condenser adjustment and VSC as a supplement. According to the degree of voltage drop, adjusting the reactive power of VSC and synchronous condenser to gives full play to the reactive power compensation function of the synchronous condensers. Finally, simulation in PSCAD verifies the effectiveness of the proposed control strategy.

Keywords

VSC; Synchronous Condenser; Commutation Failure.

1. Introduction

In recent years, the UHVDC transmission method has developed rapidly due to its advantages in long-distance and large-capacity transmission [1-3]. However, as multi-circuit UHVDC transmission projects are completed and put into operation, the problem of "strong direct and weak alternating current" during the transition period of the UHV power grid has become prominent [3-5]. The UHVDC transmission system needs to absorb about 40% to 60% of the reactive power of its transmission power during normal operation [6-7], which is mainly provided by the AC filter configured in the converter station. When the AC or DC system fails, it will cause large fluctuations in the AC bus voltage. If the local dynamic reactive power compensation capability of the power grid is insufficient, the risk of voltage instability will be greatly increased, and the safe and stable operation of the entire AC and DC system will be endangered [8]. The excitation system of the synchronous condenser(SC) can change the nature and size of reactive power by automatically adjusting the excitation current, and flexibly and quickly provide dynamic reactive power support to the grid system. At the same time, as a rotating device, the synchronous condensers can not only provide short-circuit capacity for the system, but also have the advantages of strong overload capacity and better transient performance compared with dynamic reactive power compensation devices based on power electronic technology such as SVC and STATCOM [9], it has unique advantages in reducing the transient overvoltage of the DC sending end, suppressing the commutation failure of the DC receiving end [10], and improving the stability of the system.

At present, domestic and foreign research mainly studies the coordination strategy of LCC and reactive power compensation device. Literature [11] proposes the coordination strategy of adjusting synchronous condensers and LCC-HVDC when the system fails. Compared with the traditional technology, it is found that this kind of coordination strategy can control the voltage

fluctuation within a reasonable range, and can also significantly improve the accuracy of the system in terms of voltage control, and inhibit the commutation failure. Literature [12] proposed an additional reactive power control in transient mode to optimize the transient characteristics of the original receiving end power grid. For weak systems, literature [13] proposed a new type of additional damping coordinated control for the LCC-HVDC system with STATCOM. This control can significantly improve its stability margin and avoid the occurrence of excessively high LCC lock loop gains and small system interference. Instability situation. Literature [14] adjusted the AC voltage reference value of the synchronous condensers, and added additional DC and cut-off angle control in the LCC-HVDC. The proposed control method effectively enhanced the reactive power output level when the system failed, and improved the commutation failure. Literature [15] studied the reactive power coordinated control strategy of the synchronous condensers in the LCC-HVDC system.

In the receiving end hybrid LCC-VSC system, VSC can also provide reactive power to a certain extent and support the AC bus voltage. However, due to the lack of reasonable coordination between VSC and the reactive power control method of the synchronous condensers, this article is based on a new type of receiver. The topology of LCC-VSC with end-parallel hybrid connection, analyzes the reactive power control mode of the synchronous condensers, combines the dynamic reactive power compensation capability of VSC, and proposes a coordinated control method of synchronous condensers and VSC reactive power to suppress continuous commutation failure, and simulates in PSCAD, verifying the effectiveness of the proposed control strategy.

2. Model of LCC-VSC HVDC with synchronous condenser

2.1. System main circuit

2.1.1. Sub-section Headings

The receiving end hybrid LCC-VSC system is a new type of hybrid DC transmission system. The sending end adopts a double 12-pulsation LCC topology structure and is generally located in a clean energy development zone. The receiving end is composed of a high-end converter station and a low-end converter station in series. The high-end converter station adopts the conventional LCC structure, and the low end adopts the VSC structure. Because the LCC receiving end has a large transmission capacity demand, the sending end and the LCC receiving end need to be connected 500kV and above power grids, while the receiving end VSC transmission capacity is relatively low, which can be connected to weak AC power grids or passive power grids. Therefore, this new type of DC transmission system combines the advantages of LCC-HVDC and VSC-HVDC, which can not only realize large-capacity transmission, but also improve system stability problems caused by commutation failure. The main circuit of the hierarchical access UHV DC transmission system with synchronous condenser is shown in Figure 1. Figure 1 is a typical DC system receiving end hybrid LCC-VSC structure, the rectifier side adopts $\pm 800\text{kV}$ conventional DC converter. The three flexible DC converter stations connected in parallel at the low end of the inverter side are connected in series with the high-end conventional DC converter station through the DC line, and the voltage between poles is $\pm 400\text{ kV}$. The new power transmission structure provides a more flexible and fast power transmission method.

The rectifier side adopts dual 12-pulse converters. U_{s1} represents the grid side bus voltage of the rectifier side, U_{s2} represents the grid side bus voltage of the inverter side high valve group, U_{s21} , U_{s22} , U_{s23} respectively represent the grid side bus voltage of the inverter side low valve group, and the rectifier side is pulsed by LCC double 12 Inverter composition, LCC12 pulse converter constitutes the inverter side high valve group, and VSC constitutes the low valve group. Among them, U_{d1} is the DC voltage of the rectifier station, U_{d2} is the DC voltage of the

inverter station, and U_1 is the effective value of the no-load line voltage on the valve side of the converter transformer. The DC power is represented by P_{d1} , the reactive power absorbed by the converter is Q_{c1} , the DC current is I_d , the commutation reactance of each phase is X_{r1} , the commutation overlap angle is μ_1 , the trigger delay angle is α , and $\cos\varphi_1$ is the power factor.

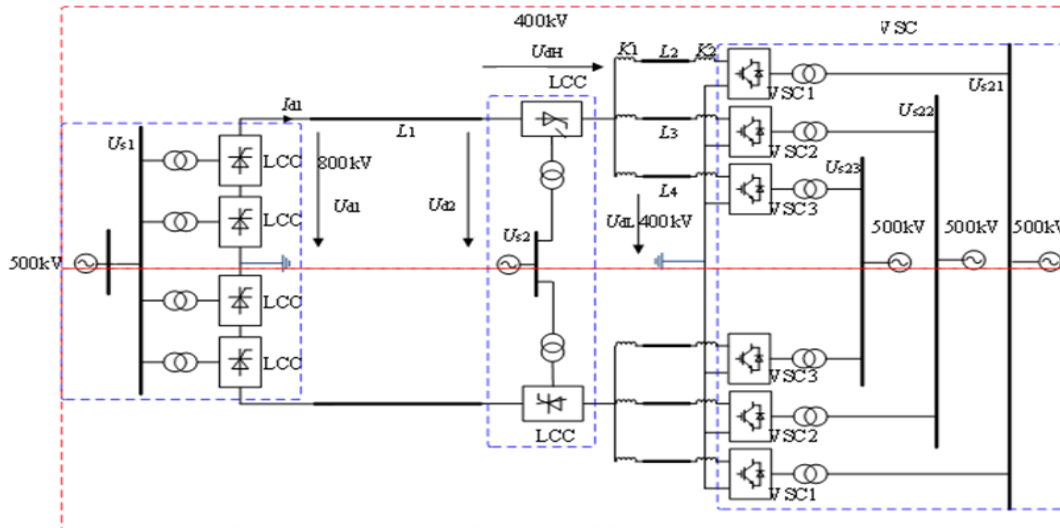


Figure 1. Topology structure of receiving-end hybrid LCC-VSC DC transmission system

Table 1. Parameters of LCC-VSC

System parameters	Value
LCC converter transformation ratio	525kV/210kV
DC voltage rating	500kv
VSC converter transformation ratio	525kV/260kV
Line length	1045km

Table 2. Parameters of SC

System parameters	Value
Rated Capacity	300Mvar
Rated line voltage	20kv
Rated current	8.66kA

2.2. System control strategy

LCC-HVDC adopts control system similar to CIGRE standard test model. Under normal operation, the rectifier side control is equipped with constant current control with minimum trigger angle limit, and the inverter side control is equipped with constant turn off angle control, low voltage current limiting link control ,current error controller (CEC),constant current control.

VSC and STATCOM have the same control structure, and both can control active and reactive power separately. The outer loop control link of VSC and STATCOM is mainly divided into constant reactive power and constant DC voltage control. The reactive power is 0Mvar when the AC bus of the converter station is in normal operation. After the difference between the actual reactive power measurement value Q and the reactive power reference value Q_{ref} , the PI module determines the STATCOM reactive current reference value I_{qref} . I_{qref} adjusts the reactive power required by the system through the current inner loop control to achieve the purpose of stabilizing the system. The working structure of the control system is shown in Figure 2.

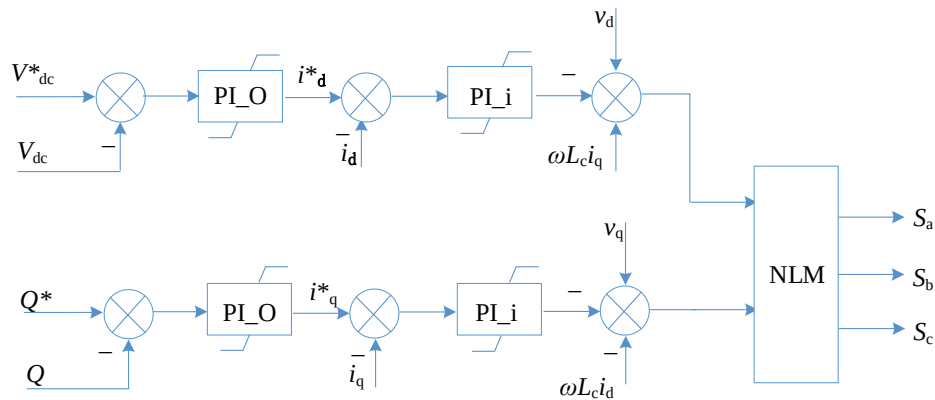


Figure 2. VSC control principle

2.3. Control strategy of synchronous condenser

The synchronous adjustment condenser contains an automatic excitation device, which is a synchronous motor that runs based on a special working state. It works in two modes of over-excitation and under-excitation. The former has relatively outstanding reactive power output characteristics and can be issued when the system reports an error. Reactive power is sent to the system to realize the protection of the bus voltage amplitude and prevent the failure of the converter station in disguise.

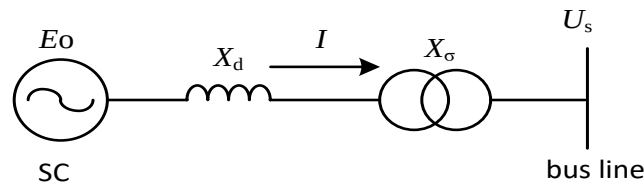


Figure 3. Schematic diagram of synchronous condenser

Synchronously condenser to inject reactive current I into the connected AC system as:

$$I = \frac{E_0 - U_s}{j(X_d + X_\sigma)} \quad (1)$$

E_0 is the excitation electromotive force of the SC, U_s is the bus voltage where the SC is connected to the system, X_d is the synchronization reactance of the SC itself, and X_σ is the leakage reactance of the transformer of the tuning condenser connected to the system. Adjusting the reactive power of the SC is achieved by adjusting the excitation current. In the over-excitation state, $E_0 > U_s$, I lags behind E_0 , the SC is adjusted to work in the late phase operation mode, and it sends out inductive reactive power to the AC system. In the event of a failure, the operating curve of the SC can be divided into sub-transient, transient and steady-state processes, and use the process characteristics to generate reactive power to support the system voltage, which can effectively resist commutation failure.

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3. Synchronous condenser and VSC coordinate and cooperate to resist commutation failure strategy

3.1. Commutation failure

AC faults are divided into symmetrical and asymmetrical types. Although the symmetrical fault reduces the voltage amplitude, it does not cause phase angle distortion. Assuming that the turn-off angle does not change during the commutation process, the overlap area increases in proportion to the DC current, so the turn-off angle decreases after a fault. Asymmetrical faults are the most common type of faults in power systems, which can cause distortion of the rectified voltage. This type of fault not only reduces the commutation voltage amplitude, but also causes the phase angle to shift. The calculation formula of the cut-off angle can be expressed as:

$$\gamma = \arccos\left(\frac{\sqrt{2}kI_d X_c}{U_L} + \cos\beta\right) - \varphi \quad (2)$$

Where: γ is the shut-off angle of the inverter side; U_L is the AC voltage of the inverter side commutation bus; I_d is the inverter side DC current; k is the conversion ratio of the converter transformer; X_c is the equivalent commutation reactance; β is the inverse Variable side leading antennae. φ is the offset value of the phase angle of the voltage waveform.

Providing reactive power compensation equipment at the inverter station can effectively improve voltage stability. Combined with the MMC structure of the receiving end hybrid system, MMC can independently and flexibly adjust reactive power, so reactive power compensation can be used to alleviate LCC commutation failure. Adding a reactive power compensation device is equivalent to increasing the effective short-circuit ratio of the receiving end AC system, the equivalent reactance of the system is reduced, the commutation reactance of the DC system is reduced, the commutation process time is shortened, and the turn-off margin is increased to avoid In order to prevent the occurrence of commutation failure, the commonly used reactive power compensation devices include SC as and static var compensators (SVC) and static synchronous compensators (STATCOM).

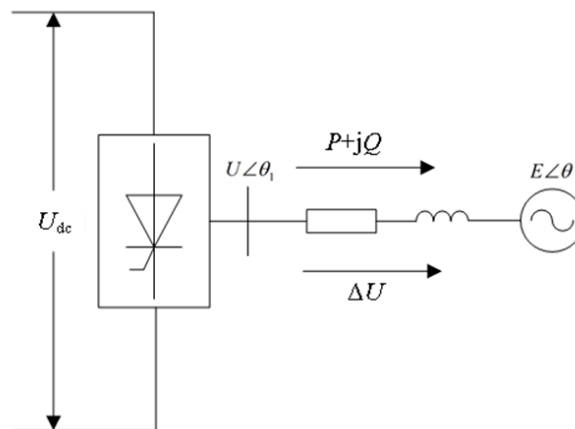


Figure 4. LCC converter station structure diagram

According to the related knowledge of voltage drop in the power system, the longitudinal component of the voltage drop from the voltage at the bus bar to the inverter side power supply voltage in the above figure is:

If there is no reactive power compensation device, the reactive power required by the inverter-side converter is provided by the power supply. The above formula Q is a negative value. If reactive power compensation can be performed at the bus bar, the value ΔU can be increased to increase the commutation The voltage at the bus bar improves the stability of the inverter.

3.2. Reactive power coordination control strategy

Compared with other reactive power compensation equipment, the new generation of synchronous condenser has the characteristics of fast response, low loss, strong overload capacity, and strong non-function. The new generation of SC can be used to improve system operating characteristics.

The synchronous condenser participates in the operation adjustment of the AC steady-state voltage of the DC converter station. With the goal of maintaining the stability of the busbar voltage of the converter station, the regulator operates at a steady-state reactive power output operating point, and the voltage meets the operating requirements of the grid voltage safety zone.

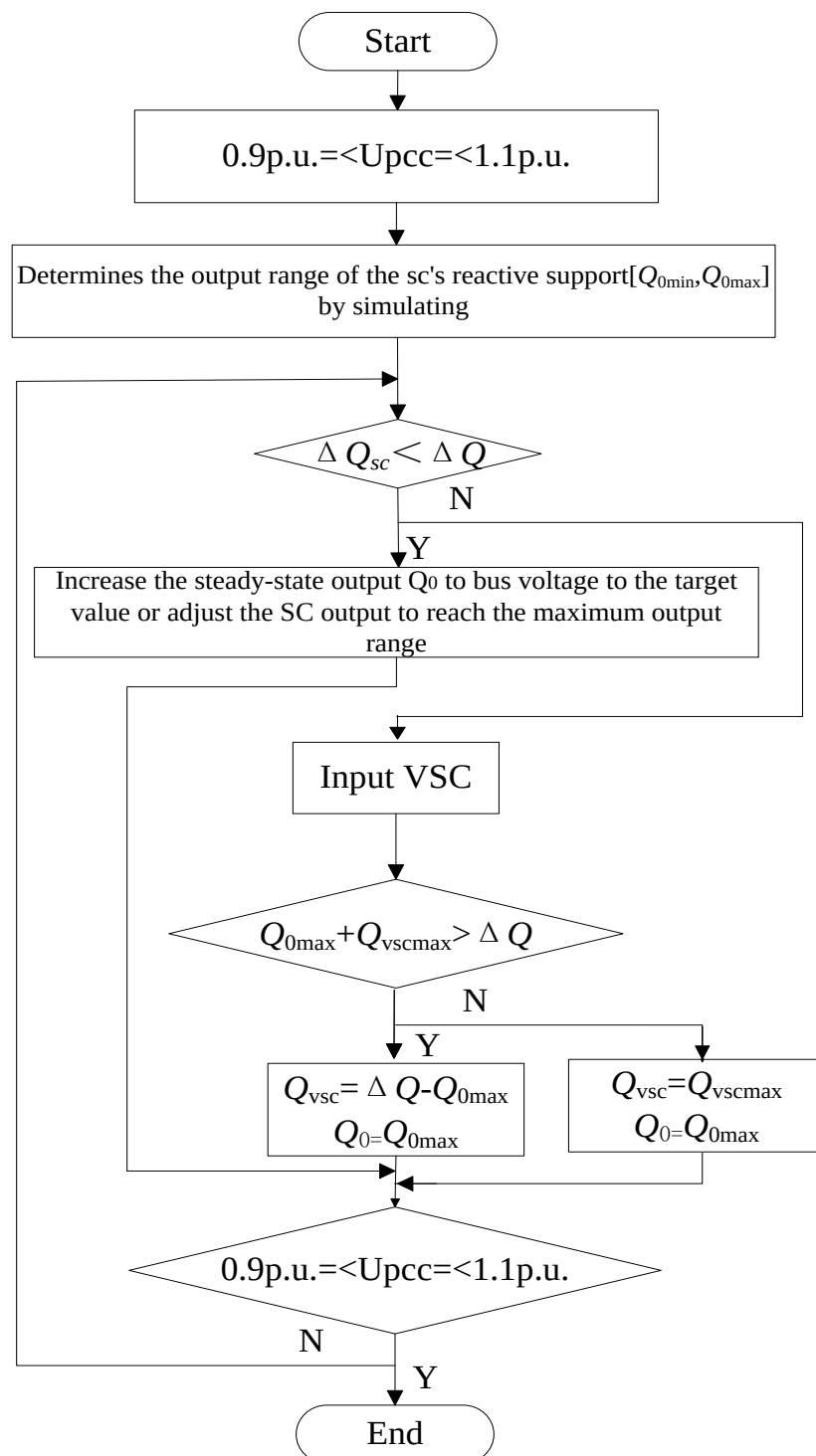


Figure 5. Synchronous condenser and VSC coordinated control block diagram

Therefore, when studying the coordination strategy of the new generation of synchronous regulators and VSC when the system commutation fails in the receiving end hybrid DC transmission grid, the reactive power compensation function of the new generation of synchronous regulators should be fully utilized, and the new generation of synchronous regulators should be used as The main compensation method, VSC is used as auxiliary compensation. The specific steps are shown in Figure 5:

Step 1: Calculate the reactive power output range of the SC. In order to ensure that the converter bus recovers to between $[0.9\text{pu}, 1.1\text{pu}]$ after a converter bus failure, the maximum output capacity of the converter is determined by simulation.

Step 2: Monitor the actual voltage U_{pcc} of the converter bus and make the difference with the target value U_0 , calculate the reactive power, adjust the SC first, increase the steady state output of the SC, and control the converter bus voltage to the target value or adjust the steady state of the SC. The output reaches the upper limit $Q_{\max}$ of the output range to eliminate this deviation. The system can eliminate the voltage deviation ΔU between the target control voltage of the converter station and the actual bus voltage by adjusting the SC.

Step 3: When $\Delta U < 0$, judge whether the compensation amount ΔQ_{sc} of the synchronous adjustment SC meets the reactive power required to raise the bus voltage to the target control voltage.

If $\Delta Q < Q_{\max}$, the steady-state reactive power setting value of the regulator is set to $Q = \Delta Q$ to ensure that the bus voltage of the converter station is within a safe range.

If $\Delta Q > Q_{\max}$, set the SC $Q_0 = Q_{\max}$, and at the same time change the VSC constant reactive power setting value, increase the residual reactive power deviation value to the VSC reactive power outer loop, and increase the VSC reactive power output. Among them, the VSC reactive power outer loop setting value is $Q_{vsc_ref} = \Delta Q - Q_{\max}$.

Step 4: Determine whether the actual voltage U_{pcc} satisfies $0.9\text{p.u.} \leq U_{pcc} \leq 1.1\text{p.u.}$, otherwise step 1 will be repeated, and if the conditions are met, it will end.

4. Simulation analysis

In order to verify the effectiveness of the proposed new-generation SC and VSC coordinated control strategy, this paper designs two schemes for comparison.

Scheme I: Only VSC strategy, VSC is constant reactive power control.

Scheme II: A new generation of SC and VSC coordinated cooperation strategy.

A three-phase ground fault is set at the AC bus on the inverter side, and the size L is set to simulate different fault conditions. The simulation analysis of the changes of each electrical quantity under different fault conditions in Scheme I and Scheme II and comparisons are made.

Condition 1: At $t = 0.8\text{s}$, a three-phase grounding short-circuit fault is set at the receiving end AC bus, and the grounding inductance is set to 0.3H , indicating that the fault point is closer to the receiving end AC bus, and the degree of the fault is more serious. The duration of the fault is 0.1s . The simulation results are shown in Figure 6.

Figure 6 shows that when the original control strategy of Scheme I is adopted after the fault, the AC voltage drops to 450kV . VSC calculates the reactive power that needs to be compensated based on the AC voltage drop and sends it to the reactive power link of the outer loop. Gradually increase, but the reactive power support capacity of VSC is limited, the highest is 400Mvar . When the scheme II coordinated control strategy is adopted, the new-generation synchronous condenser has priority action. Because the new-generation synchronous condenser has a fast reactive power response and strong reactive power output capability, as shown in Figure 6, the new-generation synchronous condenser paring Figure 6(c), it can be seen that with the investment of a new generation of synchronous condenser, the significant increase in reactive

power during failure inhibits continuous commutation failure, and only one commutation failure occurs when the system fails. When only VSC is used, due to insufficient reactive power support capability, the system will fail to commutation twice when the voltage drop is severe. Therefore, the use of a new type of phase modulation as the main compensation equipment and the VSC as the auxiliary compensation equipment can quickly increase the reactive power output to make it stronger for the AC voltage and reduce the probability of commutation failure to a certain extent. Ensure the stability of the AC voltage at the receiving end.

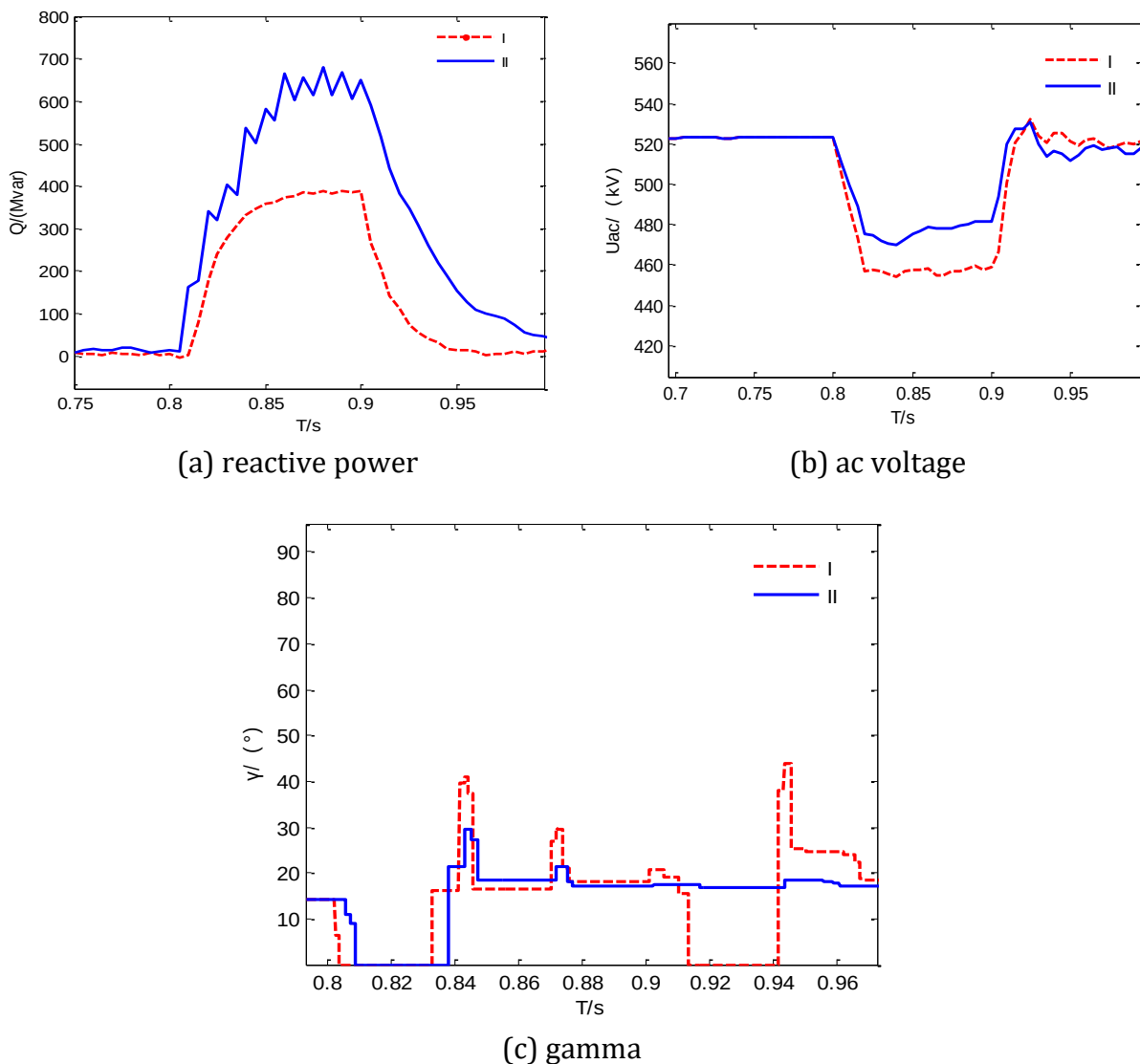


Figure 6. Curve comparison chart for working condition 1

Condition 2: At $t=0.8s$, a single-phase grounding short-circuit fault is set at the receiving end AC bus, and the grounding inductance is set to $0.5H$, indicating that the fault point is closer to the receiving end AC bus and the degree of the fault is relatively light. The fault duration is $0.1s$, and the simulation results are shown in Figure 7.

It can be seen from Figure 7 that when the AC voltage drops slightly, when the original control strategy is adopted, the reactive power generated by the VSC gradually increases to $220Mvar$, and the voltage drops to $475kV$. When adopting the improvement plan II, the new generation of synchronous condenser will be started first and emit reactive power, the maximum is $300Mvar$, and the minimum voltage drops to $480kV$. Comparing Figure 7(c), it can be seen that with the investment of a new generation of synchronous adjustment condenser, the increase in

reactive power during faults inhibits commutation failures. When the system fails, the turn-off angle is at least 10° , which is higher than the critical shutdown Broken angle. When only VSC is used, due to insufficient reactive power support capability, when the voltage drops, the turn-off angle of LCC drops to 0° , and the system fails a commutation. Therefore, when adopting the improved control of Scheme II, the reactive power emitted by the reactive equipment is larger, and the AC voltage is supported stronger, ensuring the stability of the AC voltage at the receiving end, and reducing the risk of commutation failure. The more serious the fault, the coordinated control The effect of the strategy is more obvious.

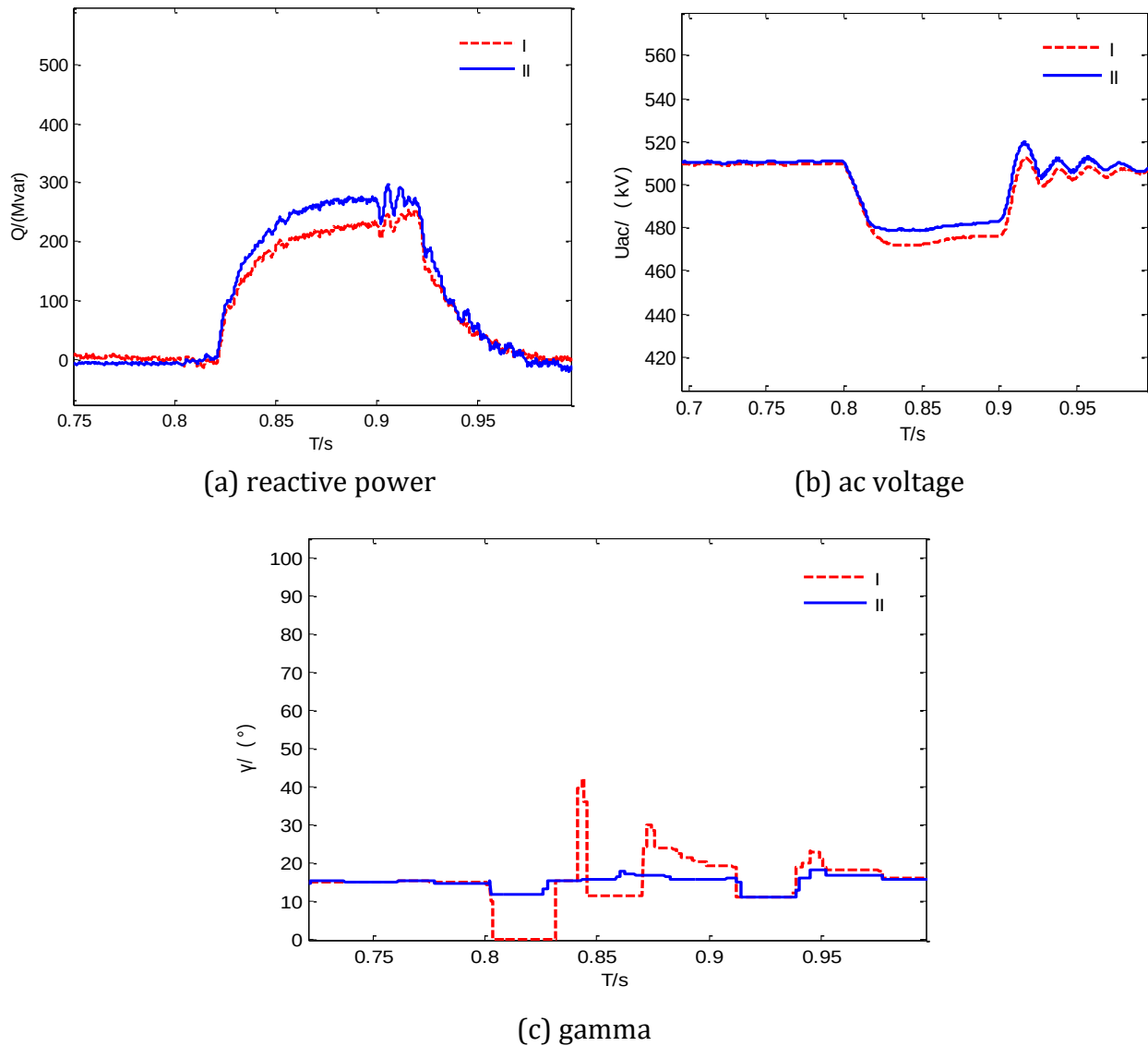


Figure 7. Curve comparison chart for working condition 2

5. Conclusion

In this paper, the reactive power output characteristics of VSC and a new generation of control condenser are studied, and the suppression effect of VSC and sc connected to the inverter power grid is simulated and analyzed. The control strategy of VSC and synchronous condenser proposed, and the simulation results can be compared: the input of STATCOM or synchronous condenser can play the role of voltage support at the commutation bus, but the response time and reactive output characteristics of the two are different. Regarding the problem of

insufficient power generated by the VSC under severe faults and the cost of reactive power compensation equipment during faults, a coordination strategy between VSC and a new generation of synchronous condenser is proposed, and the strategy's ability to suppress commutation failures is verified.

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