The Journal of Engineering

The 14th IET International Conference on AC and DC Power Transmission (ACDC 2018)

IET Journals
The Institution of Engineering and Technology

An optimal reactive power control scheme for rectifying station considering the coordination control of low-voltage reactor and AC system

eISSN 2051-3305
Received on 28th August 2018
Accepted on 19th September 2018
E-First on 10th January 2019
doi: 10.1049/joe.2018.8701
www.ietdl.org

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Abstract: When rectifier station of line-commutated converter based high-voltage direct transmission current has power fluctuations running at large load, reactive power compensator controlled in groups at rectifying station are switched frequently. That problem potentially has impact on service life of corresponding circuit breaker and threatens the safe operation of the DC system. In this study, in view of the characteristic of close connection between rectifier station and AC system, combined with the existing reactive power control scheme, in order to reduce the number of switching times of reactive power compensator, an optimal reactive power control scheme is proposed when rectifier station running at large load. When the converter station absorbs reactive power, the presented strategy takes converter bus voltage as the main control quantity with the starting point of taking full account of the reactive power support capacity of available generators near the station. When the converter station produces excess reactive power, the strategy takes the reactive power exchange of AC and DC system as the main control quantity, with the starting point of taking full account of reactive power absorption capacity of low-voltage reactor. The simulation results in power system analysis and synthesis program show the effectiveness of the proposed method.

1 Introduction

In line-commutated converter based high-voltage direct current (LCC-HVDC) transmission system, the converter is the non-linear load of AC system because of the constant change of topology structure. The result is that the converter consumes much reactive power, whether it is rectifying or inverting [1]. Therefore, for the AC system, the HVDC system is a reactive load. Based on the principle of reactive power compensation with ‘local balance’, the reactive power consumption of the converter is balanced to ensure the stability of the AC voltage by the AC equipment in the converter station [2]. In order to meet the requirements of harmonic elimination and economic operation of converter stations, reactive-load compensation equipment, which is mainly composed of passive AC filter and shunt capacitor, is an important part of HVDC system. The reactive-load compensation equipment controlled in groups is directly connected to the commutation bus through the corresponding circuit breaker. It is mainly used to provide reactive power compensation for DC system, which directly affects the DC transmission power and the stability of AC voltage [3]. When the reactive power consumption varies with the DC transmission power, the DC control system will adjust reactive power supply of reactive-load compensation equipment to achieve reactive power balance of AC and DC system. The reactive compensation provided by the reactive-load compensation equipment in the converter station varies with the number of connecting the reactive power compensation equipment. Connecting or disconnecting the reactive power compensators in the converter station is completed by the corresponding circuit breaker, so that if the reactive power compensators are frequently switched, it will reduce the service life of the circuit breakers and the failure of reactive power compensators. The above problems lead to the failure of reactive power compensation equipment group, abnormal input, and other failures, which affect the voltage stability of converter bus, and even threaten the safe operation of DC system. Therefore, the optimisation study of reactive power control strategy, which is aimed at reducing the switching times of reactive-load compensation equipment, is important for ensuring the normal operation of DC system.

When the HVDC system runs at high power, the optimisation strategy of reactive power control is not much involved in the classic publications. Through the analysis of the reactive power scheme of Guangzhou HVDC converter station in [4], the control parameter mismatch is the main cause of the frequent switching of AC filter station, and the paper proposes a strategy with increasing the allowable range of reactive power control, but the paper did not give the power control logic in detail. According to the characteristics of more alternator in the vicinity of the rectifier station, [5] outlines the importance of reactive power compensation in AC system to reduce the switching frequency of AC filter and realise the reactive power balance of AC and DC system. However, similar to [4], the specific implementation method is not mentioned. The reactive power control scheme in [6] uses DC voltage as input reference value and reactive power exchange as feedback control. However, the disadvantage of this method is that the existing reactive power control strategy needs great changes. Compared with the above researches, the domestic and foreign scholars have done a lot of research on the reactive power optimisation strategy of DC system in low power operation. For example, the low load power reactive power optimisation (LLRPO) function has been developed [7]. The LLRPO control strategy is divided into two kinds [2]. One is DC voltage direct control scheme, which directly increases the trigger angle of converter according to the calculation of pre working condition, in order to make the reactive power consumption of converter increase and reduce the excess reactive power generated by DC system. The other is a control scheme based on the control criterion of the reactive power exchange. The strategy can be adapted to different reactive power control requirements, but the operation is more complex.

This paper will review the existing reactive power control strategy. Aiming at the characteristics of more alternator in the vicinity of the rectifier station, this paper will explore the causes of AC filter or shunt capacitor caused by frequent switching, improve the reactive power control criterion combined with AC voltage control criterion, for the sake of making the reactive power compensation of AC system can be fully utilised. Meanwhile,

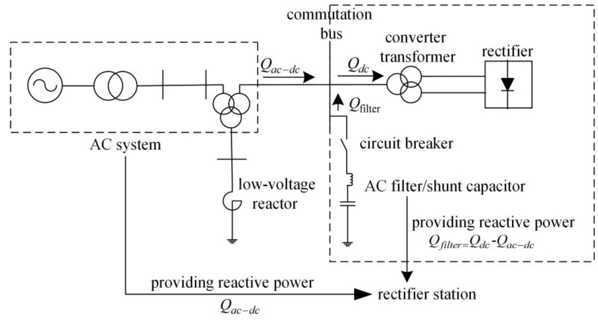

Fig. 1 *Reactive power compensation in rectifying station*

unified reactive power control criterion will be adopted to realise unified control for low-voltage reactor, AC filter and shunt capacitor, and the effectiveness of the strategy will be verified by simulation.

2 Optimal reactive power control scheme

2.1 Reactive power compensation mode of rectifying station

Fig. 1 is a diagram of the reactive power compensation mode of the rectifier station. Q_{DC} is the reactive power consumption in the station, Q_{AC-DC} is the reactive power compensation capability of the AC system, and Q_{filter} is the reactive power compensation capability of the reactive power compensator, whose main type is AC filter and shunt capacitor. The condition of reactive power balance between AC system and DC system is $Q_{filter} = Q_{DC} - Q_{AC-DC}$. Fig. 1 shows that when the DC system runs steadily, the AC system and the reactive compensation equipment in the rectifying station provide reactive power to the converter station together.

When the HVDC system runs at high power, the converter station produces a lot of reactive power consumption. Therefore, the converter station needs to absorb reactive power from the reactive power compensators. For a rectifier station, when the HVDC system runs at high power, the available generator units near the converter station in the AC system has a certain reactive power compensation capability [8]. Making full use of the reactive power compensation capacity of the AC system has two advantages. On the one hand, it can reduce reactive power compensation equipment installed in converter station and reduce the cost of converter station. On the other hand, when reactive power consumption changes frequently, using reactive power compensation capability of AC system can reduce frequent switching of reactive power compensation devices in stations. The reactive power of the generators in the AC system is controlled by the automatic voltage control (AVC) system. Therefore, the failure to make full use of the reactive power regulation of the AVC system is one of the reasons for the frequent switching of the reactive power compensators in the station.

When the HVDC system operates at low power, the reactive power provided by AC filters are larger than the reactive power consumption in the station due to the limitation of filter performance. Therefore, the converter station will inject excess reactive power into the AC system and affect the stability of the AC voltage. For the rectifying station, the generators in AC system have a certain capacity of reactive power absorption. However, the performance of the AC system is limited [9]. As shown in Fig. 1, the shunt reactor connected to the low-voltage side of the main transformer of the converter station also has the ability to participate in the reactive power control. When the excess reactive power is generated at the converter station, if the low-voltage reactor cannot take priority in absorbing reactive power, the AC filter will be frequently removed to achieve the purpose of reducing excess reactive power.

In summary, as for the rectifying station, when high-voltage DC system, make full use of the reactive power compensation capacity of AC system, and when low power high-voltage DC system, the priority of reactive absorption capacity of low-voltage reactor use, which are the effective ways to reduce AC filters and shunt capacitors frequent switching times.

Reactive power control in HVDC control system of the converter station is a link to control reactive power of converter station. It is mainly used to adjust the input number of the reactive power compensator in the station or to change the tap changer of the converter transformer, in order to control the reactive power exchange or commutated bus voltage in the specified range [10, 11]. The purpose of adjusting the switch of the converter transformer is to adjust the reactive power consumption in the station. Only after the trigger angle of the converter exceeds a certain range, the adjustment function of the tap changer of the converter transformer is started. Therefore, when the DC system is running steadily, the trigger angle of the converter is less volatile, and the adjustment function of changing the converter transformer tap cannot be used. The result is that when the HVDC system is running steadily, the DC control system realises the reactive power balance between AC system and DC system by controlling the number of connecting reactive power compensators.

The reactive power control function to control the number of input groups of AC filters or shunt capacitors is realised by a number of submodules according to a certain priority and criteria. The subfunctions of reactive power control include the following five items according to the priority from the high to the low [12].

2.1.1 Absolute minimum filter control function: When DC is unlocked, the number of filter banks must be guaranteed. This group of filters avoids long term operation in abnormal state and being damaged due to overload.

2.1.2 Maximum or minimum limit of AC voltage function: This function is used to monitor and limit the voltage of the steady state AC bus. When the voltage of the commutation bus is higher than the set value, the control function will emit an instruction to remove the reactive compensation device or limit the input of the reactive power compensators. When the voltage of the commutation bus is lower than the set value, the control function will send out the instruction of the reactive power compensators or the excision of the reactive power compensator.

2.1.3 Maximum limit function for reactive power exchange: By limiting the maximum reactive power of the converter station to the AC system, the maximum number of input to the AC filter can be controlled, and the maximum number of the AC filters can be controlled, so that the commutation bus voltage is too high.

2.1.4 Minimum filter control function: The function of the converter is satisfied by limiting the number of input groups of AC filters. If the minimum number of AC filters is not satisfied, an alarm signal will be sent.

2.1.5 Reactive power control function: The function of this function determines the number of connecting the reactive power compensators based on the reactive power exchange of the AC and DC system, and does not restrict the fluctuation of the voltage of the commutation bus. When the reactive power compensator receives the connecting command, it should meet the criterion in (1).

$$Q_{exc} < Q_{ref} - Q_{band} \tag{1}$$

where Q_{exc} is reactive power exchange between AC and DC system; Q_{ref} is reactive power reference value; Q_{band} is the dead value for reactive power; Q_{DC} is the reactive power consumed by converter station.

$$Q_{exc} = Q_{filt} - Q_{DC} \tag{2}$$

When the reactive power compensator receives the disconnecting command, it should meet the criterion in (3).

$$Q_{exc} > Q_{ref} + Q_{band} \quad (3)$$

AC voltage control function and reactive power control function belong to the same grade and cannot be used at the same time. When the reactive power compensator receives the connecting command, it should meet the criterion in (4).

$$U_{bus} < U_{ref} - U_{band} \quad (4)$$

When the reactive power compensator receives the disconnecting command, it should meet the criterion in (5).

$$U_{bus} > U_{ref} + U_{band} \quad (5)$$

where U_{bus} is the actual voltage of the commutation bus; U_{ref} is the reference voltage for the commutation bus; U_{band} is the voltage dead zone value.

According to the fifth stage reactive power control function, the existing reactive power control schemes are divided into reactive power control scheme and AC voltage control scheme. In order to meet the requirements of harmonic elimination in converter stations, the connecting order of reactive power compensation equipment groups is that AC filters are connected firstly, and then shunt capacitors are connected. Therefore, when the HVDC system runs high power, the DC control system mainly realises the reactive power balance between AC and DC system by the switching shunt capacitor. The breakthrough point of reactive power optimisation in HVDC high power operation is to optimise the fifth level reactive power control function without considering the filter performance requirements of converter station. When the DC system runs low power, the converter station is easy to produce excess reactive power flow to AC system. The DC control system uses switching AC filters to realise the reactive power balance between AC and DC system. Thus, the breakthrough point of reactive power optimisation strategy for HVDC low power operation is to make full use of reactive power absorbing devices based on meeting the minimum filter bank restrictions.

The low-voltage reactor is a kind of AC equipment with reactive power absorption capacity. Under the existing reactive power control methods, AC filters and shunt capacitors are considered to participate in the reactive power control of the converter station firstly. The low-voltage reactor is only invested in a specific DC transmission power range. The criterion for the switching control of the low-voltage reactor without phase selection is different from the switching control criterion of the AC filter and the shunt capacitor. The current control strategy of low-voltage reactor causes the AC filter circuit breaker that needs phase selection to switch frequently, which seriously affects the service life of reactive power compensators. Therefore, studying the unified control method of the low-voltage reactor, the AC filter, and the shunt capacitor is an effective way to reduce the switching frequency of the AC filter and the shunt capacitor.

2.2 Study on the mechanism of frequent switching of reactive power compensators

Based on the principle of reactive power compensation with 'local balance' and, and considering the influence of operation conditions on the AC voltage control scheme, most of the current domestic rectifying stations use reactive power exchange as the control criterion for controlling the reactive compensation equipment at present [12, 13]. Under the current reactive power control strategy, when the DC transmission power is adjusted frequently due to the randomness of the load, the reactive power consumption (Q_{DC}) in the station is frequently changed. If the reactive power compensation of the AC system (Q_{AC-DC}) is small, the reactive power exchange of AC and DC systems (Q_{exc}) is easily met (1) and (3), so that of circuit breakers for reactive power compensators are reclosed frequently. Moreover, according to (2), the actual reactive power compensation provided by the AC filter or the shunt capacitor to the converter station is corrected by the commutation bus voltage. Under the condition of constant power transmission of the DC system, if the AC voltage will fluctuate frequently in a small range, (1) and (3) will be alternating satisfied, and it will also lead to frequent switching of circuit breakers of reactive power compensation groups.

Therefore, improving the existing reactive power control logic, reducing the influence of DC transmission power or AC voltage on the switching control of reactive power compensators is the key to reduce the number of connecting or disconnecting reactive power compensators, which mainly include AC filters and shunt capacitors.

2.3 Reactive power control strategy considering AC system

In order to reduce the influence of AC voltage fluctuation on switching control of reactive power compensators, a reactive power control strategy based on AC voltage control criterion is first proposed. The reactive power control strategy fully considers the compensation capacity of the AC system, and adopts the control mode of the coordinated control of reactive power and AC voltage. According to (4) and (5), as long as the commutation bus voltage does not exceed the allowable range of voltage control, DC control system will not issue input or cut-off command. The specific control principle is as follows.

when the reactive power compensator receives the connecting command, it should meet the criterion in (6) or in (7).

$$Q_{AC-DC} > Q_{G\max} \quad (6)$$

$$Q_{AC-DC} < Q_{G\max}, \quad U_{bus} < U_{ref} - U_{band}, \quad t > t_{ref} \quad (7)$$

where, Q_{AC-DC} is reactive power compensation of AC system; $Q_{G\max}$ is maximum reactive power compensation capacity of AC system; t_{ref} is the control time reference value. This value is related to the timing of the reactive power output of the generator by the AVC system.

When the reactive power compensator receives the disconnecting command, it should meet the criterion in (8).

$$Q_{AC-DC} < Q_{G\max}, \quad U_{bus} > U_{ref} + U_{band}, \quad t > t_{ref} \quad (8)$$

According to the above principle, the flow chart of the reactive power control scheme is shown in Fig. 2.

The reactive power control strategy considering the reactive power compensation capacity of the AC system has many advantages compared with the current reactive power control strategy. Firstly, the reactive power control strategy aims at the characteristics of the rectifier alternator near the AC generator, and makes the reactive power compensation capability of the AC system vary with the reactive power consumption in the substation. The change of Q_{AC-DC} makes the reactive power exchange between AC system and DC system no longer as a smaller constant value, so that it reduces the influence of DC transmission power fluctuation or AC voltage fluctuation on reactive power compensation equipment switching. Then, compared with the current AC voltage control scheme, the AC voltage and AC system are coordinated to control reactive power compensators. The control mode solves the problem that the AC voltage control scheme is more affected by the operation conditions of the system, and ensures the reactive power balance of AC system and DC system. Furthermore, when the rectifying station needs to absorb the reactive power, the delay control link can give priority to the regulation of the reactive power of generators by the AVC subsystem. The scheme makes full use of the reactive power compensation ability of the AC system by using dynamic reactive power control and delay control.

However, the aforementioned reactive power control strategy does not consider the reactive power absorption capacity of the low-voltage reactor. The switching control of the low-voltage reactor is still determined by the certain number of reactive power compensation groups. When the number of connecting reactive power compensators which determines connecting a group of the low-voltage reactor is not equal to the current number of

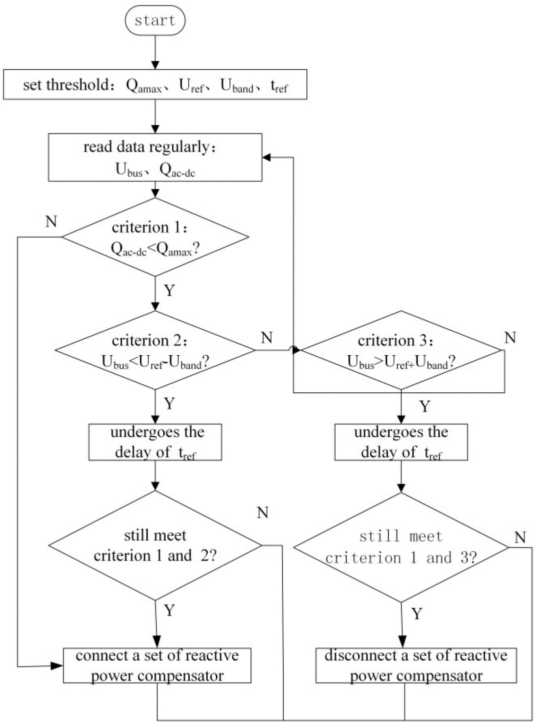

Fig. 2 *Flow chart of control strategy considering AC system*

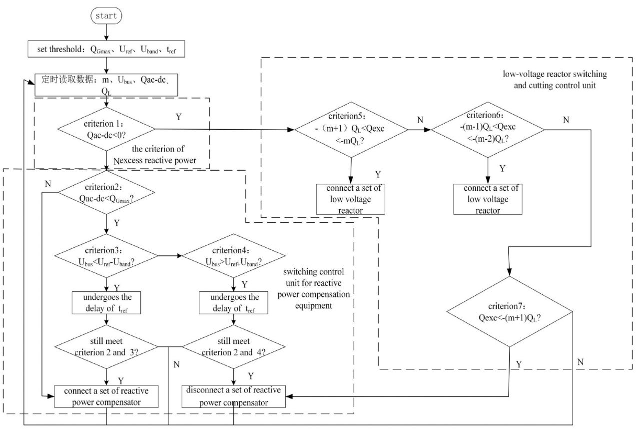

Fig. 3 *Flow chart of control strategy considering AC system and low-voltage reactor*

connecting inputs of reactive power compensators, the low-voltage reactor will not work. Therefore, when the DC transmission power is low, the converter station injects excess reactive power into the AC system. If only the reactive power compensation ability of the AC system is considered, the DC control system will give priority to the removal of AC filters, which makes the AC filters frequently be disconnected.

2.4 Reactive power control strategy considering AC system and low-voltage reactor

The realisation of unified control of low-voltage reactors, AC filters and shunt capacitors is a basic way to improve the reactive power control strategy considering reactive power compensation capability of AC system. Therefore, the paper proposes an optimal reactive power control scheme for rectifier station considering the coordination control of low-voltage reactor and AC system.

The strategy determines the input number of the low-voltage reactor based on the exchange value of the AC and DC system. The reactive power control strategy is based on the control strategy of the reactive power compensation capacity of the AC system. When the converter station runs at high power, the low-voltage reactor can also take part in the reactive power control of the converter station according to the corresponding reactive power criterion. If the converter station injects an excess reactive power into the AC system, the DC control system will give priority to the control of the low-voltage reactor. When all available low resistance is unable to achieve reactive power balance, it will be switched to switching control unit of the AC filter. The specific control principle is as follows.

When the reactive power compensator receives the connecting command, it should meet the criterion in (9) or in (10).

$$Q_{AC-DC} > Q_{G\max} \tag{9}$$

$$0 < Q_{AC-DC} < Q_{G\max}, \quad U_{bus} < U_{ref} - U_{band}, \quad t > t_{ref} \tag{10}$$

When the reactive power compensator receives the disconnecting command, it should meet the criterion in (11) or in (12).

$$0 < Q_{AC-DC} < Q_{G\max}, \quad U_{bus} > U_{ref} + U_{band}, \quad t > t_{ref} \tag{11}$$

$$Q_{AC-DC} < 0, \quad Q_{AC-DC} < -(m+1) \times Q_L \tag{12}$$

where, Q_L is actual reactive power absorption of a group of low-voltage reactor; m is the input number of current low-voltage reactor.

When the low-voltage reactor receives the connecting command, it should meet the criterion in (13).

$$Q_{AC-DC} < 0, \quad -(m+1) \times Q_L < Q_{AC-DC} < -m \times Q_L \tag{13}$$

When the low-voltage reactor receives the disconnecting command, it should meet the criterion in (14) or in (15).

$$Q_{AC-DC} < 0, \quad -(m-1) \times Q_L < Q_{AC-DC} < -(m-2) \times Q_L \tag{14}$$

$$Q_{AC-DC} > 0, \quad m = 1 \tag{15}$$

According to the above principle, the flow chart of the reactive power control scheme is shown in Fig. 3.

Compared with the reactive power optimisation strategy which only considers the reactive power compensation capacity of the AC system, this strategy takes full consideration of the reactive power absorption capacity of the low-voltage reactor. Therefore, when the converter station injected the excess reactive power into the AC system, the low-voltage reactor preferentially takes part in reactive power control of the converter station, instead of reducing the excess reactive power through disconnecting the group of the AC filter.

In theory, the reactive power optimisation strategy reduces the frequent switching of the AC filter when the DC system runs at low power. Compared with the original reactive power control strategy, the reactive power control strategy adopts a unified reactive power control criterion to control the AC filter, shunt capacitor, and low-voltage reactor uniformly. As shown in Fig. 3, the reactive power compensation of the AC system (Q_{AC-DC}) represents the reactive power exchange of the AC and DC system (Q_{exc}). Judging whether or not Q_{AC-DC} is positive is the judgment of the working state of the rectifying station. When HVDC system runs at high power, Q_{AC-DC} is not <0, which represents the converter station need to absorb the reactive power from the outside world. The strategy takes advantage of the reactive power compensation ability of the AC system in order to reduce the switching times of reactive power compensators. When the HVDC system operates at low power, Q_{AC-DC} is smaller than zero, which represents the converter station injects excess reactive power into the AC system. The strategy preferentially utilises the reactive power absorption capability of the low-voltage reactor, which can effectively reduce the disconnecting times of reactive power compensators.

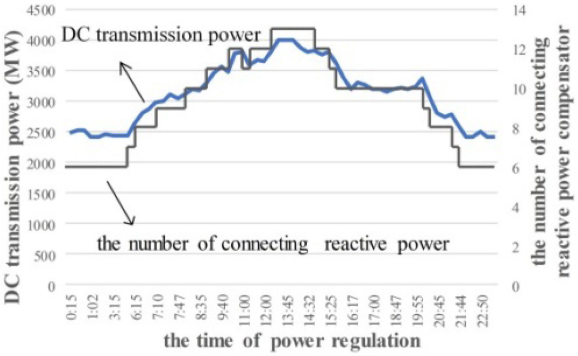

Fig. 4 *Switching times of reactive power compensators under the original control strategy*

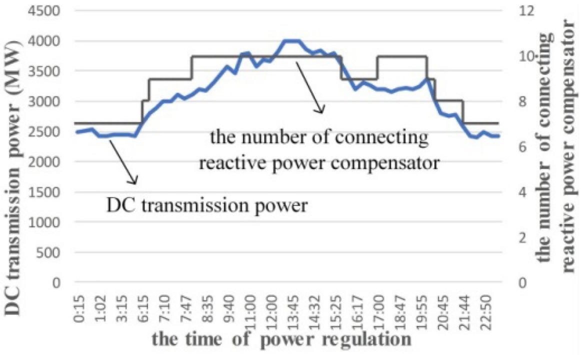

Fig. 5 *Switching times of reactive power compensators under the strategy considering AC system*

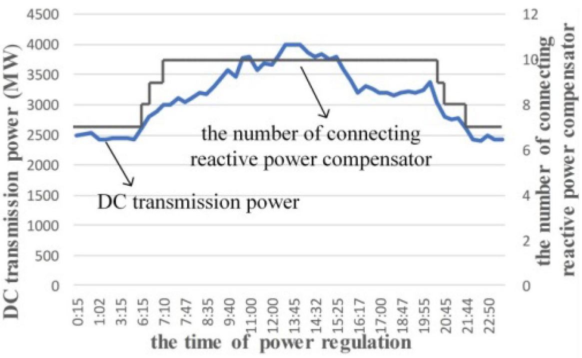

Fig. 6 *Switching times of reactive power compensators under the strategy considering AC system and low-voltage reactor*

3 Results of the simulation

A converter station with the voltage class of 330 kV is taken as an example to verify the feasibility of the optimal reactive power control scheme for rectifier station considering the coordination control of low-voltage reactor and AC system. The equipment involved in reactive power control includes seven groups of AC filters, seven groups of shunt capacitors, and two groups of low-voltage reactors. The reactive power control scheme is adopted in the converter station, and the reactive power control criterion is the reactive power exchange of the AC and DC system. Under the current reactive power control strategy, the reactive power compensation capacity of the AC system is always 180 Mvar, and the allowable range of reactive power exchange of AC and DC systems is [68, 292 Mvar]. The rated DC transmission power of the DC system is up to 4000 MW. Under the scheme considering the coordination control of low-voltage reactor and AC system, the value of $U_{\rm ref}$ is 345 kV, which takes the system voltage. The value of $U_{\rm band}$ is 5 kV, which takes 0.015 times the system voltage. The value of $Q_{G\max}$ is 800 Mvar which is calculated according to the actual situation. The value of s is ∼15 min.

Table 1 Switching number of AC filters and shunt capacitors under two kinds of reactive power control optimisation strategies

P, MW	The switching number of AC filters and shunt capacitors	
	The strategy only considering AC system	The strategy considering AC system and low-voltage reactor
$3200 \le P \le 4000$	10	10
$3000 \le P < 3200$	9	10

where *P* is DC transmission power.

The power flow calculation model of the converter station and its adjustable generator is established by using power system analysis and synthesis program (PSASP). According to the DC transmission power adjustment curve of the station, respectively, under the current reactive power control strategy, the reactive power strategy considering the AC system, the reactive power strategy considering the AC system and low-voltage reactor, the switching times of AC filters and shunt capacitors are calculated. The calculation conditions are as follows: the converter station is a rectifier station, and the DC works are forward, bipolar, and full pressure. The results are shown in Figs. 4–6.

The lowest transmission power of the converter station is 2417 MW, the highest transmission power is 4000 MW, and the power is adjusted 95 times. As shown in Fig. 4, under the original reactive power control strategy, the switching times of the AC filter and the shunt capacitor in the station is 16 times. As shown in Fig. 5, under the reactive power control strategy considering the reactive power compensation capacity of the AC system, the switching times of the reactive power compensators is to eight times. Compared with the original strategy, the number of switching is reduced by eight times. According to Figs. 4 and 5, the control scheme considering the reactive power compensation capacity of the AC system, can effectively reduce the maximum number of reactive power compensation equipment. When the DC transmission power is rated as the rated transmission power, under the strategy considering the reactive power compensation capacity of the AC system, the number of connecting reactive power compensators is to 10 groups, and 3 units are reduced compared with the original strategy. When the DC transmission power is the lowest, the reactive power compensation device takes into account the reactive power control strategy of the AC system, and the number of connecting reactive power compensators is to seven groups, and the number of connecting groups increased by 1 unit compared to the original strategy. Therefore, taking full consideration of the reactive power compensation capacity of the AC system can effectively reduce the switching times of AC filters and shunt capacitors.

Fig. 6 shows the switching times of reactive power compensators under the coordinated control strategy of the AC system and the low-voltage reactor. As shown in Fig. 6, under the reactive power control strategy considering the reactive power compensation capacity of the AC system and the reactive power absorption capacity of low-voltage reactor, the switching times of the reactive power compensators is to six times. Compared with the original strategy, the number of switching is reduced by 10 times. Compared with the strategy only considering the AC system, the number of switching is reduced by two times. Under the reactive power control strategy considering the AC system and the low-voltage reactor, when the DC transmission power is >3000 MW, the input number of reactive power compensation equipment is to 10 groups. However, under the control strategy only considering the AC system, the switching times of reactive power compensators is to two times, as shown in Table 1.

To sum up, the control strategy considering the coordinated control of AC system and low-voltage reactor can effectively reduce the switching times of reactive power compensators in the rectifying station, which mainly include AC filters and shunt capacitors.

4 Conclusion

Under the current reactive power control scheme, once the AC system provides the power of reactive power, the AVC system will no longer participate in the regulation of the voltage of the commutation bus. At the same time, because the reactive power absorption capability of the low-voltage reactor is not fully utilised, when the converter station produces excess reactive power, the DC control system realises reactive power balance of AC and DC system by switching AC filters or shunt capacitors. The above methods lead to frequent switching of reactive power compensators. In view of the characteristics of the AC generator sets near the rectifying station, a reactive power optimisation strategy is proposed, which considers the coordinated control of the AC system and the low-voltage reactor. Under the control of this strategy, when the converter needs to absorb the reactive power, the DC control system gives priority to the reactive power compensation capability of the AC system. When the converter station produces excess reactive power, the DC control system gives priority to the reactive power absorption capacity of the low-voltage reactor. Finally, this paper validates the effectiveness of the strategy by using PSASP. The simulation results show that the switching times of reactive power compensators in the rectifying station can be reduced from 16 to 6 times under the optimised strategy. The strategy can reduce the switching times of the reactive power compensators, in order to increase the service life of corresponding circuit breaker and ensure the safe operation of the DC system.

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