Multi-DC commutation safety and system stability coordination control evaluation method

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Abstract. Due to the influence of multiple DC commutation failure after AC failure and stable interaction of system frequency, voltage and power Angle, the operation control of power grid is greatly difficult. The control scenario of multi-feed DC commutation failure or system instability is constructed, the comprehensive control performance cost ratio index of emergency control measures to the safety of multi-turn DC commutation and system stability is proposed, and the search method of coordinated control strategy based on global optimal is developed to avoid the risk of chain failure caused by negative control effects. The evaluation of control search path and control target after joint optimization is realized, which is conducive to the construction of system-level defense method and improves the adaptability of strategy.

1 Introduction

With the construction of UHV DC projects, East China and Guangdong have formed the multi-feed DC system with the largest capacity and the most complex network in the world, and the problem caused by commutation failure is becoming more and more serious. Currently, the UHVDC commutation failure acceleration protection strategy has been developed to limit the number of commutation failures, actively block DC and trigger the safety control cutting machine. On the other hand, the active and reactive response caused by the action of the power electronic equipment of the receiving end system induces the instability of the system voltage, power Angle and frequency, which causes a huge short-time power impact on the system with the time scale of seconds. In other words, for AC systems with multiple DC feeds, equipment safety and system stability problems coexist.

Some paper proposed energy storage fast reactive power regulation, adjust the sub-transient support of the camera, and large-capacity dynamic reactive power support to control the commutation failure[1-3]. Other papers obtained optimize the emergency control under transient power Angle instability by using generator controllable factor sequencing[4-6]. These papers only optimize the control measures for a single stability problem. However, for different power grids, DC commutation failure is intertwined with system stability problems such as power Angle, voltage and frequency. From the perspective of control, measures to solve DC continuous commutation failure are not necessarily beneficial to solve system stability problems, and the control of a single problem may aggravate the evolution of another problem, leading to the risk of cascading failures.

Some papers have studied the architecture design of the existing stability control system[7-10]. The existing stability control system is often designed for a single stability problem. In order to facilitate reliable execution, there is less interaction between the control system and the control system. The control of DC commutation failure and the control of system stability are bound to interact the two sets of stability control systems. From the perspective of control effect and economic benefits, the transformation of stability control is meaningful only when the cost of coordinated control is greater than that of the superimposed average control of traditional single set of stability control.

In this paper, a heuristic iterative search algorithm for emergency control strategy with dynamic modification of comprehensive sensitivity index is designed to dynamically calculate the sensitivity index of candidate measures for multiple types of problems, which improves the adaptability of emergency control algorithm to deal with complex interaction between DC and system. According to different instability conditions, compared with the traditional single measure superposition, the intuitive description of the reduction effect of coordinated control cost is conducive to control decision-making, device implementation level planning and design, and reduce the risk of system blackout.

2 The scenario of DC commutation security and system stability coordination control

According to the standard model, the operation mode is adjusted, and the control scenario set of synchronous power grid instability or multi-feed DC commutation failure is constructed through comprehensive fault scanning.

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2.1 Mode adjustment strategy

(1) Operation mode of DC system: Consider multi-feed DC different transmission power, DC control protection mode, etc., expressed by A, A=1,2... .t represents different transmission power and control schemes, and the unbalanced power is borne by all power sources in the system;

(2) DC near-area boot mode: Adjust the boot combination of DC near-area synchronous unit, represented by B, B=1,2... k represents different boot modes, and the unbalanced power is borne by new energy sources in the near area;

(3) System load level: Adjust the local or overall system load level, expressed by C, C=1,2... .m respectively represents different load levels, and the unbalanced power is borne by local or all power sources of the system;

(4) Section power: Adjust the internal power supply out of section, cross section power, expressed by D, D=1,2... n respectively represents different power levels, and the unbalanced power is borne by the power supply on both sides of the section.

2.1.1 Fault adjustment strategy

(1) Fault type: consider single-phase short-circuit three-phase jump off fault, single-phase short-circuit single-phase reclosing failure fault, line/main transformer three-phase short-circuit three-phase jump off fault, line/main transformer three-phase short-circuit reclosing fault, three-phase short-circuit single-phase switch rejection fault, expressed by E, E=1,2... p represents different fault types.
(2) Fault duration: According to the guidelines for different levels of line main protection action cutting fault time Settings, failure protection action time is 0.25s, reclosing time is 1s or 1.3s.
According to the above four mode factors and two fault factors, through arrangement and combination, a synchronous power grid instability (system power Angle/voltage/frequency stability margin is less than zero) or commutation failure (commutation safety margin is less than zero) scenario is formed, as a scenario that needs comprehensive coordinated control, expressed by S, S=1,2... q represents different control scenarios. Synchronous power grid instability includes at least one form of instability, such as power Angle, voltage and frequency.

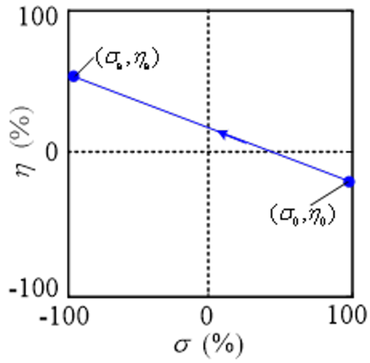
3 Control strategy for DC commutation safety and system stability

3.1 Traditional control strategy

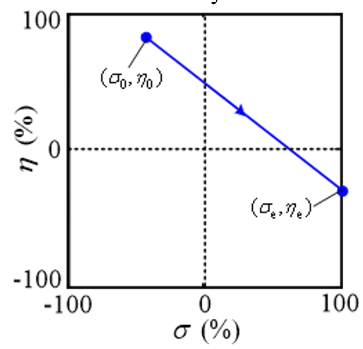
The emergency control measures after the traditional DC single commutation failure are mainly to prevent the converter valve from being damaged due to multiple continuous commutation failures. The emergency control measures are mainly to control reactive power in an emergency manner, such as the reactive power control means that sends commands to the adjusting camera, filter and reactive power compensator through steady control, or the emergency DC power back down. The sensitivity of the measure is characterized by the change in commutation margin $\Delta\sigma_z(j)$ after the application of measure j.

The emergency control measures for the single instability of the traditional system include cutting machine, cutting load, cutting pumping storage, DC/new energy/energy storage modulation, and the sensitivity of the measures is represented by the change of system stability margin $\Delta\eta_{\delta/V/f}(i)$ after the application of measure i.

According to the coordinated control scenario of DC commutation safety and system stability, the control measures of single DC commutation failure or single system instability are searched and sorted based on time domain simulation until the system stability margin and multiple DC commutation indexes are greater than 0. Since a single control does not pay attention to another stabilization effect, the control goal does not necessarily return to the first quadrant, when it returns to the second and third quadrants, that is, the negative effect of control, as shown in the figure1, may cause subsequent chain failures.



(a) System stability control deteriorates DC commutation safety



(b) Dc commutation failure control deteriorates system stability

Control an indication that one problem is effective while exacerbating another

3.2 Coordination control strategy

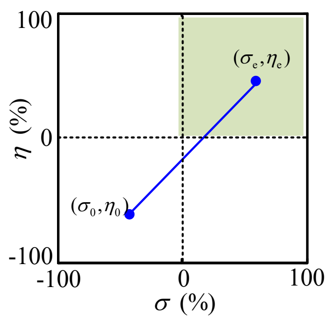
For the scenario requiring coordinated control, the dynamic sensitivity index of a control measure designed for emergency control search is：

$$K(h)=\Delta\eta_{\delta/V/f}(h)+\sum_{z=1}^{N}(\frac{1-\sigma_z}{1-\eta_{\delta/V/f}}\Delta\sigma_z(h)) \quad (1)$$

In formula (1), σ_z and $\eta_{\delta/V/f}$ are divided into commutation safety margin and system safety and stability margin of DC z before the control is applied, and N is the total number of DC feeds into the receiving power grid; $\Delta\sigma_z(h)$ and $\Delta\eta_{\delta/V/f}(h)$ are divided into commutation safety margin changes of DC z and system safety and stability margin changes after control measures h are applied.

In formula (1), $\frac{1-\sigma_z}{1-\eta_{\delta/V/f}}$ is the conversion coefficient between DC commutation margin and system stability margin. If DC commutation margin is smaller, this value is larger. The value interval of commutation margin and system stability margin is [-1, 1]. According to this index, the comprehensive control effect of all measures in the measure library can be sorted. In terms of control effect, measures for the most serious equipment/system stability have the largest conversion factor and are most likely to be prioritized.

In order to avoid the distortion of the stability region under large scale control, when the control measure with the maximum sensitivity is obtained, the time domain simulation check is carried out to obtain the equipment safety margin and system stability margin after the implementation of the measure. Then refresh the conversion coefficient and carry out the next round of iteration. This can ensure the effective stability of the integrated system after each measure is implemented, while avoiding the repetition of control measures. Finally, the search path is optimized until the system stability margin and multiple DC commutation indicators are greater than 0, and the control target is returned to the first quadrant, as shown in Figure 2.



The control is effective for both DC commutation safety and system stability

4 Evaluation of control effect of different control strategies

4.1 Control cost calculation

Active power control measures and control quantities that need to be taken in a certain control scenario are represented by P, P=1,2... r represents the modulation of DC, regulation of new energy power, regulation of hydropower, excision synchronizer, excision of new energy, excision of extraction and storage, etc., the corresponding unit control cost is expressed by λ, λ=1,2... r;The reactive power control measures and control quantities that need to be taken are represented by Q, Q=1,2... w represents switching static reactive power compensation, adjustment camera emergency control, etc., and the corresponding unit control cost is expressed by γ, γ=1,2... w.

The control cost index in a fault scenario is:

$$Y_s=\sum_{i=1}^{r}\lambda_i P_i+\sum_{j=1}^{w}\gamma_j Q_j \quad (2)$$

4.2 Average control cost calculation

The control cost of traditional commutation failure acceleration section protection and synchronous network instability is $\sum_{s=1}^{q}Y_{s0}$ after superposition.

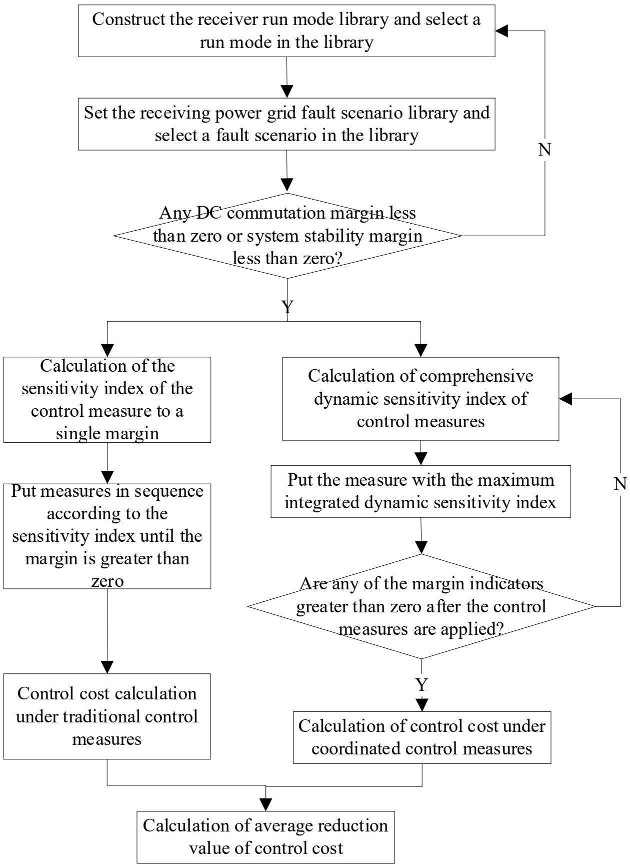
After comprehensive coordination of multi-feed DC commutation security and synchronous power grid security and stability, the control cost is x, and the average reduction value of the control cost is:

$$\Delta Y\%=\frac{\sum_{s=1}^{q}Y_{s1}-\sum_{s=1}^{q}Y_{s0}}{\sum_{s=1}^{q}Y_{s0}} \quad (3)$$

When the value is greater than 10%, the coordination control policy is considered effective and is delivered to the stability control device. Otherwise, the corresponding measures are linearly stacked according to multiple instability scenarios.

4.3 Control method evaluation process

Therefore, the emergency control strategy and evaluation process considering the coordination of multiple DC commutation failure and system stability are as shown in Figure 3:



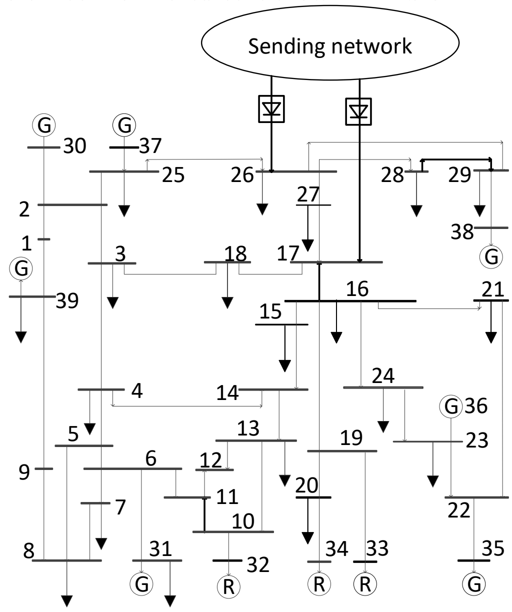
Control method evaluation process

(1) Construct any scenario where the DC commutation safety margin is less than zero or the system stability margin is less than zero by adjusting the operation mode and fault;
(2) Select measures according to the sensitivity of the traditional single measure corresponding to the single problem, until the single problem is solved and the margin is greater than zero; For the chain failure that causes another problem, the cost calculation is carried out after the superposition of traditional control measures.
(3) The control measures calculate the dynamic sensitivity index of multiple types of problems, gradually input measures and refresh the sensitivity index, until any DC commutating safety margin and system stability margin are greater than zero, and calculate the control cost of coordinated control measures;
(4) The average control cost reduction is calculated, which is used as the basis for evaluation of coordinated control scheme and reference for decision-making of stability control transformation.

5 Example verification

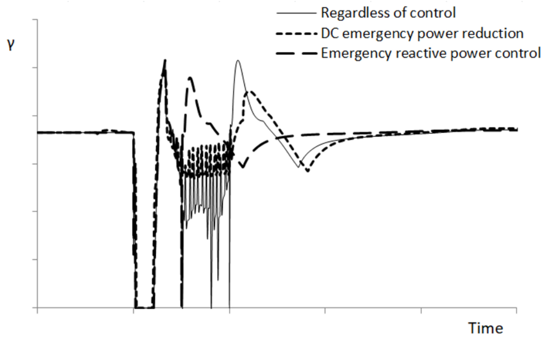
5.1 Validation of coordinated control methods

The short-circuit failure of the receiving end of the DC feed may lead to multiple DC commutation failures or continuous commutation failures. The short-time impact energy may cause the transient power Angle instability or frequency instability of the power grid at the sending end, and the response characteristics of the DC and the new energy at the receiving end are coupled through the system voltage. In serious cases, the low-frequency load shedding action will be triggered, resulting in a large area of power outage.
From the perspective of single control, reactive power control for DC can reduce the risk of subsequent commutation failure of DC, thus reducing the depth of transient frequency drop. The types of measures include reducing DC power back, adjusting camera emergency force, emergency capacitive reactive power, energy storage reactive power support, etc. For the control of the system's transient low frequency, the traditional control resources only support one-way control, which is easy to trigger chain high frequency after short-term transient low frequency. Therefore, it is appropriate to use flexible new energy and energy storage to release energy urgently, or to provide power support by short-term upgrading of the DC that has not entered the commutation failure. Therefore, from the perspective of control effect, there is a contradiction between short-time active support and reactive support, and it is necessary to use the indicators proposed in this paper to conduct sensitivity analysis on the adjustment direction of control measures, and then determine the coordinated control scheme.
Take the receiving system network structure of IEEE 10 machine 39 nodes with two DC feeds as an example, as shown in Fig4,the total load of the system is 1 000 MW, the constant power model is adopted, and the active power frequency response coefficient of the load L=2.0. There are 7 synchro machines with inertial time constant of 4s, 3 wind farm stations with rated capacity of 100 MW, 50 MW and 50 MW39 nodes respectively, DC drop point bus 17 and bus 26 respectively, DC feed power of 200MW. The instantaneous metallic ground fault occurs between BUS16-BUS17, and the fault disappears after 0.2s. The comprehensive sensitivity calculation of different control measures is shown in **Table 1.**

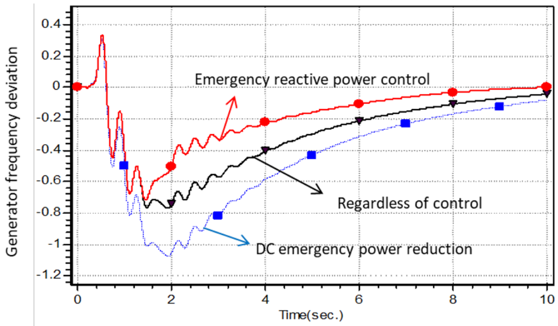


Multi-dc receiving 39-node network
Line parameters and control cost after exiting thermal power unit

control strategy	Measure search	$\Delta\eta$	$\Delta\sigma$	The cost of control (ten thousand yuan)	
Coordination control strategy	1	35%	0	2.5	11.0
	2	42%	0	2.5	
	3	8%	32%	6.0	
Traditional control strategy	1	-7%	22%	3.0	15.0
	2	-9%	15%	2.0	
	3	37%	0	5.0	
	4	52%	0	5.0	



Photovoltaic sunrise force fluctuation curve



Power fluctuation curve of Golmud section

As can be seen from FIG. 5, DC commutation failure is improved after the control measures of DC emergency rapid power drop and emergency reactive power drop are taken. As can be seen from FIG. 6, DC emergency rapid power drop needs to be strictly coordinated in the fallback time, fallback power, and callback after the fallback. Improper coordination will deteriorate the frequency stability characteristics of the system, resulting in negative control effects. It can be seen from the table 1 that through three rounds of coordinated control strategy search, the final frequency of the system recovers to above the threshold of the first round of low-frequency load reduction action [49.4Hz,0.3s], and the control cost is less than that of the traditional single-search commutation failure and single-search system frequency stability control measures.

5.2 Validation of control evaluation methods

Taking the above example as the research object, in addition to the coexistence of frequency stability and commutation failure, power Angle instability and DC commutation failure also exist in the network. By continuously increasing the proportion of new energy and load power, and adjusting the power of different DC gears, there are a total of 8 calculation examples of DC commutation safety or system instability, which can be obtained by searching calculation examples. The control costs under these 8 calculation examples are respectively shown in **Table 2.** Line parameters and control cost after exiting thermal power unit

Sequence number of example	Coordination control strategy (ten thousand yuan)	Traditional control strategy (ten thousand yuan)
1	11	15
2	30	50
3	42	69
4	56	90
5	66	72
6	3	3
7	7	7
8	9	9
Control cost summation	224	315

It can be seen from Table II that by substituting the cost of coordinated control and the cost of traditional single problem and single solution into formula 3, the average control cost is reduced by 40%. At the same time, the control measures for case coordination are the same as the traditional control measures, which indicates that for the system, a single control measure is effective for multiple problems at the same time. Based on the average control cost evaluation, it is necessary to integrate the emergency control for DC commutation failure and the emergency control for system stability in the same control master station. Taking the adjusting camera, reactive power resource and energy storage as the control sub-stations for statistical monitoring can greatly reduce the control amount and improve the control efficiency.

6 Conclusion

This paper presents a control evaluation method for the coordination of multi-DC commutation safety and system stability. Based on different DC operating conditions and AC fault combination of the receiving power grid, the control scenario of multi-fed DC commutation failure or system instability is constructed, and the comprehensive control performance cost ratio index of emergency control measures on multi-DC commutation safety and system stability is proposed. Combined with the cross-coupling relationship between multi-feed DC commutation security and system stability, a coordinated control strategy search method based on global optimal is developed, which can greatly improve the efficiency of control search and reduce the risk of instability of the receiving end network.

Acknowledgement

This work is supported by the National Key Research and Development Program of China (2021YFB2400900)

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