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Influences of ±800 kV Yunnan-Guangdong HVDC System on Security and Stability of China Southern Power Grid

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ABSTRACT

The interaction mechanism between AC and DC systems in a hybrid AC-DC transmission grid is discussed with PSS/E software. Analysis shows that receiving-end AC faults may cause much more damage on the HVDC system operation than the sending-end AC faults in a multi-infeed HVDC system, and the damage severity depends on the power recovering rate of the HVDC systems. For HVDC systems with slow power recovering rate, the receiving-end AC faults may probably be a critical factor to constrain power transfer limits. Larger capacity of HVDC system means not only higher power transfer-limit of the parallel connected AC-DC transmission grid, but also more expensive stabilizing cost.

Keywords: HVDC; Security; Stability; AC/DC; Power System; Interaction

1. Introduction

Yunnan-Guangdong HVDC (YG HVDC) with 5GW capacity is the first ±800kV ultra HVDC system in the world. Its capacity is equal to about two thirds of total Yunnan export power in 2010, or one third of total Yunnan grid load in 2010, or one quarter of CSG west to east tie-line scheduled capacity in 2010. Thus it has important influences on the stability of China Southern Power Grid (CSG). This paper focuses on the mutual influences of YG HVDC and the AC systems based on 2010 CSG operation mode [1-8].

Mutual influences of HVDC and AC systems include the following two aspects:

(1) AC system faults effects on HVDC power transfer capability and thus degrades system stability.

(2) Huge power redispatches from HVDC system to AC transmission network caused by HVDC system faults and degrade system stability further.

Therefore, the kernel of this kind of study is to probe mutual effect of HVDC and AC system in a hybrid HVDC and AC parallel connected system. In this paper, related techniques in PSS/E is introduced in section 2, and then both the two mentioned stability characteristics of CSG is investigated by PSS/E software in detail in section 3 and 4. Finally the paper concludes in section 5.

2. Simulation Model

The Siemens PTI PSS/E software package is widely recognized as one of the best commercial programs available for power systems analysis. The most prominent characteristics of CSG power system is that five HVDCs including YG HVDC parallel connected with several AC transmission lines indeed into Guangdong power system, which is shown in **Figure 1**. Therefore, the HVDC model is the most important part to simulate dynamics of CSG accurately.

Both response model and detailed model of HVDC are built in PSS/E software. The response models of HVDC such as CDC6T suppose that HVDC has fast response, and thus its dominant transient dynamics in DC circuit and DC control system could be neglected. In addition, steady equation of converter is used for response model of HVDC to calculate real and reactive power injecting into AC system. The PSS/E detailed models of HVDC such as CASEA1 and CDCRL consider transient dynamics of DC circuit and DC valve control system; it is

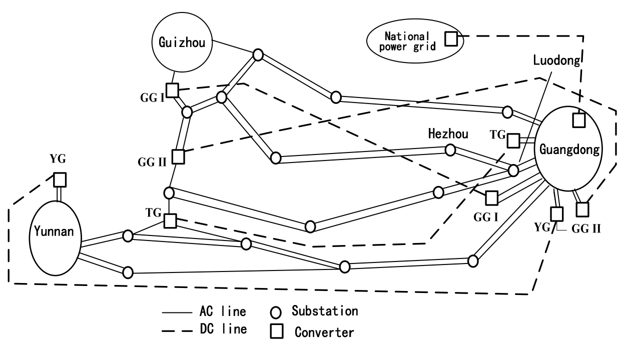

Figure 1. CSG grid structure framework in 2010.

solved with much smaller integration steps compared to AC system. Since the response model of HVDC in PSS/E is simple and flexible and can simulate various dynamics of HVDC conveniently and simply, it is easy to implement sensitivity analysis about the effect of DC system dynamic characteristics on stability and security of AC system. Therefore, CDC6T response model of HVDC in PSS/E is used in this paper, which is shown in Figure 2[13]. HVDC control structure consists of substation control, polar control and valve control with different function respectively. Substation control can realize reactive power control and DC control; valve control can produce trigger pulse control; and polar control is just in between the previous two controls and it is the key control part to produce DC system voltage and current order and can transfer it into trigger angle order to valve control. The polar control rectifier side has fixed DC current control, fixed DC voltage control and minimum trigger angle control, the inverter side has fixed DC voltage control, fixed DC current control, fixed extinction angle control and current difference control. Under normal operation, the rectifier side employs fixed current control; the inverter side utilizes fixed DC voltage control. In transient process, various control variables are compared in DC rectifier side, and control switch is based on minimum priority rules; various control variables are compared in the inverter side, and control switch is based on maximum priority rules.

Restoring rate of HVDC power has great impacts on multi-infeed HVDC system. The following parameters can be set to simulate various restoring rate of HVDC in PSS/E software, all of them can be found in **Figure 2**.

Tvdc and Tidc: Measurement time constant of voltage and current;

Vramp and Cramp: Ramping rate after communication failure of voltage and current.

According to response curves of HVDC simulated by BPA software and actual curves simulated by RTDS for dynamic performance test of Guizhou-Guangdong II HVDC, Tvdc and Tidc are set as 0.02 second, and Vramp and Cramp are set as 8 p.u./s for all HVDC in CSG, which is abbreviated as paramater A.

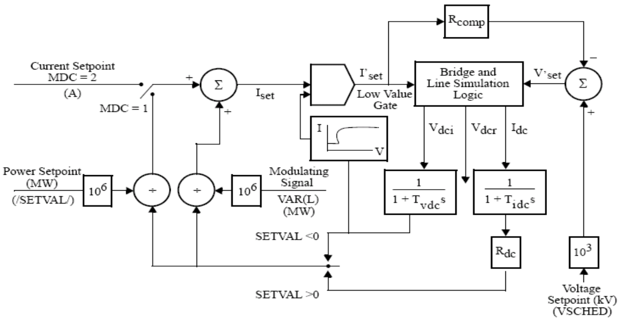

Figure 2. Diagram of DC model CDC6T.

BPA software is widely employed by CSG planning and operation engineers to simulate dynamics in the system, and BPA format data for 2010 planning CSG power system are built. All the devices of CSG power system are converted from BPA model into PSS/E model according to the same mathematics model. Computation result shows that power flow obtained with PSS/E agrees with the counterpart from BPA, and the difference of real power through each branch is no more than 1 MW and the difference of voltage at each bus is no more than 1 kV. Moreover, transient stability results from PSS/E are also consistent with BPA.

3. Influences of YG HVDC Faults on AC System

Fault on each HVDC pole may redispatch the power from DC transmission lines to AC transmission lines in hybrid AC-DC transmission systems, while larger capacity of HVDC means more power flow is redispatched to AC transmission system from the blocked pole of HVDC, and then more reactive power will be required to support the requirement. Under such case, an AC transmission system may lose stability if dynamic VAR compensation is not enough to support voltage magnitude around its nominal rating. Effects of YG HVDC block patterns on system stability are analyzed as following [9-14].

3.1. Influences of YG HVDC Mono-polar Block on System Stability

In hybrid AC-DC transmission systems, HVDCs with small capacity have little effects on system stability if mono-polar block happens. With HVDC capacity increasing, mono-polar block has much more impacts on system stability and will develop into a critical fault that restricts the power transfer limit. However, HVDC mono-polar block becoming as a critical fault does not mean that power transfer limit will decrease with HVDC capacity increasing, the larger capacity of HVDC may also bring higher power transfer limit. Computation result in CSG 2010 power system shows that Yunnan power transfer limits are 8100 MW, 9550 MW and 10700 MW when YG HVDC transmits 2500 MW,3750 MW and 5000 MW respectively, which shows that larger capacity of YG HVDC means more power transfer limit of Yunnan power grid.

The above results can be explained as follows. In a hybrid AC-DC system, AC transmission system must reserve some power transfer capability to carry on the power flow redispatched from blocked pole of YG HVDC. However, the required reserved power transfer capability of AC transmission system will always be less than the capacity of blocked pole of YG HVDC, so total transfer capability of the hybrid AC-DC transmission system is still increased when the capacity of both pole of YG HVDC increased.

3.2. Influences of YG HVDC Bipolar Block on System Stability

In peak load period during 2010 summer season, any bipolar block except YG HVDC will not destabilize the CSG system and repeated restart attempts are allowed to reduce their forced outage times remarkably. Bipolar block of YG HVDC will destabilize CSG system and some generators are required to be tripped to keep system stable. The amount of tripping generators after YG HVDC bipolar block will increase noticeably with export power of Yunnan AC system increasing.

When Yunnan exporting 7800 MW scheduled power, 2125 MW hydro units in Yunnan power system will be tripped in 200 milliseconds after an YG HVDC bipolar block happens. If one restart attempt is considered after the last blocked pole, 430 MW additional hydro units in Yunnan power system need to be tripped. If two restart attempts are considered after last blocked pole, 4225 MW hydro units need to be tripped and western Yunnan regional power grid is disconnected with the main Yunnan power grid after restart attempt fails.

Table 1. Effect on Yunnan output power limit by different operation pattern of YG HVDC.

Operation Pattern	Constrained Fault	Yunnan Output Limit（MW）
YG HVDC operation with bi-polar transfer 5000MW	YG HVDC mono-polar block	10700
YG HVDC operation with bi-polar transfer 3750MW	YG HVDC mono-polar block	9550
YG HVDC operation with mono-polar transfer 2500MW	YG HVDC mono-polar block	8100

Table 2. Stability analysis of YG HVDC blocks and restart pattern if Yunnan transfer 7800 MW out in 2010.

Order	Fault Pattern	Stability and corresponding action
1	YG HVDC bi-polar lock	System stable after generation shedding 2125MW
2	YG HVDC mono-polar block, another polar DC line fault restart success	Stable
3	YG HVDC mono-polar block, another polar DC line fault restart failure	System stable after generation shedding 2555MW
4	YG HVDC mono-polar block, another polar DC line fault second-restart success	Stable
5	YG HVDC mono-polar block, another polar DC line fault second-restart failure	Generation shedding 4225MW, and split Yunnan northwestern area grid to stabilize the whole system

Table 3. Stability analysis of YG HVDC blocks and restart pattern when Yunnan output 10700MW.

Order	Fault Pattern	Generation shedding(MW)
1	HVDC bi-polar block	System stable after generation shedding 6525MW
2	HVDC mono-polar block, the other polar DC line fault restart failure	System unstable after splitting northwestern area of Yunnan and generation shedding 6525MW

When power export of Yunnan power grid reaches the power transfer limit 10700 MW, 6525 MW hydro units in Yunnan power system will be tripped in 200 milliseconds after YG HVDC bipolar block happens. If one restart attempt is considered after last blocked pole, CSG system can not keep stability even if 6525 MW hydro units are tripped and the western Yunnan regional power grid is disconnected with the main Yunnan power grid.

Therefore, only one restart attempts are suggested for YG HVDC line fault for sake of simplying strategy for stability control system. Otherwise, stabilizing cost is expensive and more strong dependency of CSG system on stability control system may be induced.

4. Influences of AC System Faults on Hvdc Systems

HVDC sending end and receiving end faults can have different effect on HVDC system. HVAC fault near HVDC rectifier side result in low converter bus voltage and HVDC VDCL start and lower down HVDC power; HVDC fault near HVDC inverter side can result in commutation failure and reduce the HVDC power to zero. AC system faults in CSG 500kV grid are scanned. The results show that AC system faults in Yunnan and Guizhou power grid may cause one or two HVDCs decreasing active power and do not influence other HVDCs whose converter are far away from the fault point. However, AC faults in 500 kV power grid of Guangdong Chu Chiang Delta may cause five HVDC to be commutation failure due to five HVDCs feed into Guangdong Chu Chiang Delta area and the electrical distance is too close among each converter station. The system may lose stability if multiple HVDCs can not restore power quickly after commutation failure.

It is predicted that restoring rate of converter bus voltage and HVDC power after a short circuit fault will become slower if proportion of motor load in Guangdong Chu Chiang Delta power grid increases . In order to individually analyze the influences of slow restoring rate of HVDC on system stability, Tvdc and Tidc are set as 0.05 second, and Vramp and Cramp are set as 4 p.u./s, which is abbreviated as parameter B while ZIP load model still kept unchanged.

Comparing with simulation results for parameter A, simulation results for parameter B shows that AC system faults in 500 kV power grid of Guangdong Chu Chiang Delta have more severe influence on system stability and restoring rate of HVDCs will become slower. 200 milliseconds are required for HVDC to restore eighty percent of rated power, which are 100 milliseconds more than that of parameter A. (Shown in **Figure 3**). In addition, power transfer limit of Yunnan power grid decrease about 1306 MW than that of parameter A, AC fault occuring in Wuzhou-Luodong 500kV transmission line turns into the critical fault restricting power transfer limit, instead of mono-polar block of YG HVDC for parameter A.

Analysis above shows that restoring rate of HVDCs determines power transfer limits and critical fault. Substantially, no matter the critical fault is mono-polar block of YG HVDC or AC system fault of Guangdong system, the stability mechanism is the same, that is, partial or full power of HVDC redispatches to AC transmission system when HVDC operation is disturbed or destroyed. YG HVDC mono-polar block will permanently redispatch full power of one pole of YG HVDC and its influences on system stability depend on the capacity of YG HVDC and the strength of the AC transmission system. Whereas influences on system stability of AC faults of Guangdong system depend on the number of disturbed HVDC and strength of AC transmission system as well as restoring rate of disturbed HVDCs. Therefore the fault restricting

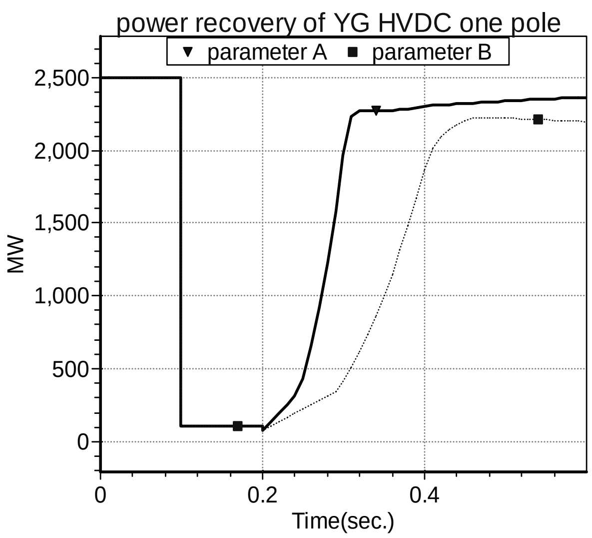

Figure 3. YG HVDC mono-polar power restoration comparison curve under parameters A and B.

power transfer limit may be AC system faults on Guangdong system when the restoring rate of HVDC becomes slow.

If Guizhou-Guangdong AC transmission lines are strengthened and all CSG HVDC is modeled by parameter B, power transfer limit exporting from Yunnan power grid can be restricted again by mono-polar block of YG HVDC. It is explained that power angle between Guizhou and Guangdong does not enlarge because the strengthened Guizhou-Guangdong AC transmission lines can carried on more power diverted from Guizhou-Guangdong HVDC during the period of commutation failure. AC system faults in Guandong power grid do not restrict the power transfer limit of Yunnan power grid because their influence on system stability is reduced with the strengthening of AC transmission lines.

5. Conclusions

The conclusions can be drawn after calculation and analysis from PSS/E:

(1) Although large capacity of YG HVDC increases power transfer limit of CSG remarkably, it could also bring CSG tremendous security risks. If YG HVDC restart is not considered after HVDC line fault, the security and stability control policy tripping generation or shedding load could be reduced, but HVDC availability could decreased. If DC restart is considered after YG HVDC fault, the stabilizing cost is expensive and the policy is also much more complicated.

(2) In CSG system, the AC system faults in receiving end system (Guangdong) can have much more severe damage on stability of the system than those in sending end system and may redispatchav power transfer of all HVDCs of CSG. Power transfer limit of CSG may be restricted by AC system faults in receiving system when the restoring rate of HVDCs is slow.

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