Study on the characteristics of multi-infeed HVDC

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Abstract. China has built more than ten HVDC transmission projects in recent years [1]. Now, east China has formed a multi-HVDC feed pattern grid. It is imminent to study the interaction of the multi-HVDC and the characteristics of it. In this paper, an electromechanical-electromagnetic hybrid model is built with electromechanical data of a certain power network. We use electromagnetic models to simulate the HVDC section and electromechanical models simulate the AC power network [2]. In order to study the characteristics of the grid, this paper adds some faults to the line and analysed the fault characteristics. At last give analysis of the fault characteristics.

1 Introduction

In this paper, we have built two typical operation modes a high load mode and a low load mode in certain power network, in which the DC part use detailed electromagnetic transient model, while AC grid is the BPA electromechanical data. The interface is located in low voltage bus of the converter transformer as in figure 1 for example [3]. Some single permanent faults three permanent faults were carried out for the two modes. The interaction between AC and DC and DC-DC was analysed. Then this article analysed the effect of the specific HVDC control on the stability of the operation by count the mount of the commutation failure. Finally, we get some conclusions by compare the statistics of the commutation failure and the failure of the different faults.

2 Detailed Model of Simulation

HVDC transmission systems include detailed converter valve, converter transformer, DC line and AC / DC filter. HVDC control protection system is in accordance with the current which has been put into operation in ±800kV HVDC transmission projects [4]. In addition to DC current, voltage, turn off the arc angle control and low voltage current limit (VDCOL), the main control links in HVDC are added to some auxiliary control which play a key role in AC-DC fault which can improve operating characteristics [5]. Such as increasing the minimum trigger angle limit (RAML) in rectifier station, increasing the off angle limit (GAMMA0) in the inverter station and the commutation failure prevention control (CFPREV).

RAML function: When fault occurs at the AC side the control system will be in the role of the regulator of DC current by changing the trigger angle and it will force the trigger angle reduced to 5 ° quickly at rectifier side (the limited minimum value). When the fault is cleared, the AC voltage will recover as well, if α (the trigger angle) is too small it will lead to DC current recovery too fast which is likely to cause commutation failure. To prevent this happening, the simulation introduce RAML. Typically, it is 30 ° when a voltage drop occurs, after the fault is cleared, the RAML-ORD is reduced to zero at a fixed rate [6].
GAMMA0 function: When the DC voltage of the inverter station is lower than the set value, the inverter control will trigger the DC low voltage control (UD_LOW), which will force the inverter station to set the phase angle to the predictive value. The function is preventing commutation failure by suppressing current rise too fast.

The UHVDC static volt-ampere characteristics are shown in Fig 2[7].

The AC load is composed of constant impedance, constant current or constant power load. The transmission line model adopts Bayesian distribution parameter model.

3 Initialization of Power Flow
When the model is built, the initial operation mode of the UHVDC transmission line may not rated, so it is necessary to adjust the initialization flow of the HVDC to its rated parameters. We can first to adjust γ of the Inverter, then adjust voltage of the rectifier, at last adjust α of the rectifier. The normal value of γ is 17. Because the rectifier side usually take the constant current control, so the line voltage drop is fixed. We can adjust the DC voltage of rectifier to 800kV by changing the transformer taps of the inverter. We can also adjust the rectifier side transformer tap to change the rectifier side firing angle to set level.
From fig 3 we can know that the DC voltage reach to rated value in 3 seconds, while the current reach to the rated value at 15 seconds. So the normal start needs 15 seconds.

4 Interaction between AC and DC systems
To study the dynamic response of ±800kV HVDC in AC / DC system about commutation failure, this article did some simulations. The main contents include: 1) The characteristic of a HVDC commutation failure; 2) Interaction of multi in-feed HVDC; 3) AC / DC interaction;

4.1 Single HVDC test
Simulations at rectifier side: The fault sequence is that the three-phase line-to-ground fault occurs at 17 seconds, it disappeared after 0.1 second. The constant power control is adopted at the rectifier side, and the switching off angle control at the inverter side. The DC voltage and $\gamma$ is shown in below.
From the pictures above we can see the three phase fault occurs at the outlet of the rectifier station, which will lead the decrease of the DC transmission power to 0. When the fault disappears, the DC voltage can recover within one second.

Simulations at Inverter side: The fault sequence is that the three-phase line-to-ground fault occurs at 17 seconds, it disappeared after 0.1 second. The constant power control is adopted at the rectifier side, and the control of fixed turn off angle on inverter side. The voltage and $\gamma$ is shown below.

From the picture above, we can see the three phase fault occurs at the outlet of the inverter station which will lead commutation failure at the inverter, meanwhile cause the power oscillation. When the fault disappears, the DC voltage can recover within one second.

4.2 Simulation of AC/DC power grid

We did a lot of fault experiments in a certain grid which have eight HVDC lines mainly in two modes a high load mode and a low load mode. We find if one HVDC line occur commutation failure it may lead the adjacent DC line to commutation failure. When the HVDC line fault occurs it will lead the bipolar block, which sending out a lot of reactive power injection to AC system caused by the AC filters, meanwhile the converter voltage rise sharply. DC current raise lead the converter transformer leakage reactance to increase, directly lead the time current commutation to increase sharply. So the turn off angle decrease. The commutation margin reduce lead the intermittent commutation failure of the other pole easily. It is recommended that use the measured current to calculate the commutation angle, so that the current raise, the control system can increase the commutation margin as well. Figure 6 show the continuous commutation failure described above.
We did some single phase permanent earth fault tests on 500 kV AC line. In the experiment the UHVDC rectifier adopts constant current control, the inverter side under fixed predict type turn off angle control, and paper 8 proposed using the converter side current to distinguish whether the commutation failure occurred. When the single permanent fault occurs the fault line will be disconnected, at a period of time. The line will reclosed after a fixed time, the relay protection device still detects a fault, after that the line will be disconnected again. General HVDC commutation failure will occur again when the circuit is disconnected again after reclosing, and the disturbance of the system performance is strong than the single-phase instantaneous fault which at the failure time and the recovery is longer. Lower voltage drop is shown in figure 7 below.
We did some three-phase permanent earth fault tests on 500 kV AC line without reclosing. When a three-phase fault occurs at near line on 500 kV AC grid, part of the line will cause 6 HVDC commutation failure simultaneously. During the commutation failure, the DC current rise, DC voltage decline or even reverse, leading DC power instantaneous decreased to 0.
Owing to the absence of reclosing, the three-phase grounding fault does not occur successive commutation failure, so the influence of AC time is shorter than single-phase reclosing fault. While, the AC fault voltage of the three-phase failure is lower than the single-phase, so the impact has a larger range, it prone to cause the multiple HVDC commutation failure at the same time. Comparing the results of the number in two modes, a high load mode and a low load mode in certain power network, we can know the flood low function mode is worse than the others because the worse capability of voltage support. It has more times of commutation failure. The simulation of N-1 fault shows that when the fault occurs in the inverter side of the converter bus it will occur a number of DC simultaneous commutation failure and the system can restore stability. While several N-2 faults can’t recover at the same condition.

Compared with ±600kV HVDC, the ±800kV HVDC projects have almost the same value of reactance, so when the voltage of the inverter side fluctuates, the current changes more quickly, which will make it more likely to occur commutation failure. So it is more important to match the value of low voltage current limiting (VDCOL) to real situations, such as the minimum trigger angle limit (RAML), the turn off angle limit of the inverter (GAMMA0) and the commutation failure prediction (CFPREV).
5 Conclusion
This paper introduced the fine simulation model of a certain AC / DC hybrid power system. Introduced the simulation method. Firstly did a single HVDC test to show that a HVDC line can resume to normal operation after fault. Then studied the interaction between AC and DC systems and some conclusions are obtained at the simulations.

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