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Energy Procedia 12 (2011) 443 – 449

Energy Procedia

ICSGCE 2011: 27–30 September 2011, Chengdu, China

Research of Coordinated Control Strategy for Multi-UHVDC in AC/DC Hybrid Power Grid

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Abstract

The control strategy and modulation scheme of DC system have great effect on transient stability and dynamical stability in AC/DC hybrid power grid. In order to decrease the effect of UHVDC blocks and AC lines faults, a coordinated control strategy of emergency power modulation and small signal modulation is put forward by making use of the fast controllability and the overload capability of HVDC system. Simulation results show that the coordinated control strategy may decrease power loss and improve the dynamical stability of the AC/DC hybrid system.

Keywords: AC/DC hybrid system, emergency power modulation, small signal modulation Introduction

1. Introduction

The distribution of the resources for electricity generation and the electricity demands ask for high-power supply of wide range. China Southern Power Grid is developing the long-distance and huge capacity power system with AC and DC transmission lines in parallel and a power grid with three UHVDC and two UHV AC will be formed in Sichuan of China till the year of 2015, as shown in Fig.1. The transmission capacity of bipolar UHVDC is more than 6000 MW and large power flow will be delivered to Eastern China. If UHVDC system faults with unipolar or bipolar blocking, more than 3000MW power flow will transport to AC system, which will cause the AC tie-line power flow damp slowly, even impact the transient stability.

The control and modulation scheme of DC system have great effect on transient stability and dynamical stability in AC/DC hybrid power grid[1]. According to the project plan, JinSha River and JP

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doi:10.1016/j.egypro.2011.10.059

UHVDC will have 2h long-term over-load(1.1 times) capability and 3s transient over-load(1.4 times) capability. Meanwhile, the FL and SL UHVDC converter stations of sending end are connected directly, and the electrical distance is very close, which means the two UHVDC systems can support each other. Though the YL UHVDC converter station is far away from FL UHVDC and SL UHVDC converter stations, the power will mainly transport to 500kV HG substation and 1000kV LS substation, and transported outside by 500kV HG-BQ parallel transmission lines and 1000kV LS-CQ parallel transmission lines. The sending system of Sichuan UHVDC is as Fig.1.

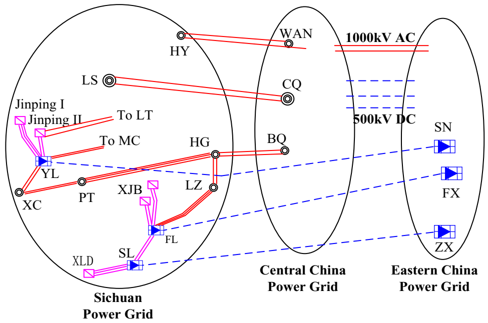

Fig. 1. The sending system of Sichuan AC/DC system

This paper is based on the planning power network frame to study the coordinated control strategy for Multi-UHVDC system in Sichuan AC/DC hybrid system. Emergency power modulation is put forward to decrease power loss. And small signal modulation is studied to improve the dynamical stability of the AC/DC hybrid system when fault occurs in the main AC transmission lines.

2. Study of Modulation Scheme of DC System

2.1. Modulation with bilateral frequency difference

In modulation scheme by bilateral frequency difference, frequency difference between rectifier bus and inverter bus is taken as the input signal. Take XJB UHVDC as example, the frequency difference of FL converter station 500kV bus and FX converter station 500kV bus is taken as the input signal. This frequency difference then successively passes derivative control unit, filter, notch-filter, guide tache unit, the amplifier and limiter. The output P_{mod} is superimposed upon the original power signal as the additional control signal to control the UHVDC output power, which will then improve the stability of the AC/DC hybrid system. The control scheme is as Fig.2 [2].

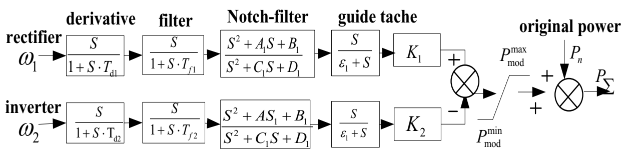

Fig. 2. Control scheme of bilateral frequency difference modulation

where T_{d} is the derivative time constant; T_{f} is the filter time constant; ε is the compensating factor; A, B, C, D are parameters of notch-filter; K is the transmission gain. Subscripts 1 and 2 stand for rectifier and inverter separately. These parameters cannot be got by analytic method because of the nonlinearity, and should be studied and calculated according to a specific system by dynamic simulation program.

This paper take XJB UHVDC as example, and these parameters which do better to system stability are as follows in Table 1. Parameters for rectifier and inverter are the same.

Table1. Bilateral frequency difference modulation controller parameters/MW

T_d	T_f	ε	A	B	C	D	K	P_{mod}^{min}	P_{mod}^{max}
10	0.15	1	1	1	1	1	9999	320	-320

The UHV AC systems will realize national network interconnection until 2015, and the capacity at that time is very huge, which means the bilateral frequency difference is small. Taking XJB UHVDC bolck as example, the bilateral frequency difference is less than 0.01Hz, and the additional current is less than 38A, which is only 1% of the rating current. This small value cannot accomplish emergency power modulation efficiently. Power modulation by bilateral frequency difference is poor efficient in observability.

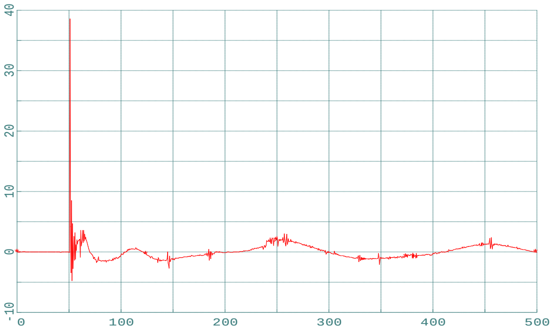

Fig. 3. XLD UHVDC power output of bilateral frequency difference modulation

2.2. Modulation with power of AC line

As seen above, observability of the bilateral frequency difference modulation is low efficient for the small bilateral frequency difference under DC block when the national network interconnection is realized. In AC/DC hybrid system, the DC power will mainly transport to AC transmission lines when DC block occurs, which may cause power flow to fluctuate in AC transmission lines. Based on this, the observability will be satisfied if the analogue information as reactive power, current of AC transmission lines is taken as the additional control input signal. The AC tie-line of 500kV HG-BQ lines is the main channel of transport outside for Sichuan power grid, so DC block in FL, SL or YL UHVDC will cause acute fluctuation in HG-BQ lines. The analogue information of HG-BQ lines can be taken as the DC additional control input signal.

The control scheme of modulation with power of AC line is as Fig. 4 [4]. Where the derivative control unit has a fast responsibility, and the filter and the guide tache can provide phase compensation. So this modulation not only responses the DC power output quickly to improve the system transient stability, but also can damp oscillation to improve the dynamical stability. Meanwhile, to fully make use of the UHVDC 2h long-term over-load(1.1 times) capability, the DC power is given as 1.1 P_n when the first power-angle is stable ($t \geq t_0$) to decrease the power surge to AC transmission lines. Time t_0 is relative to system oscillation period.

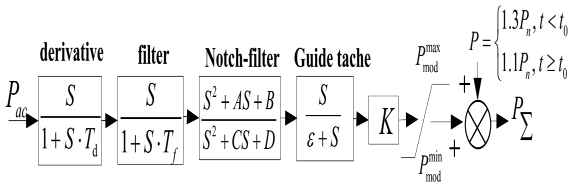

Fig. 4. The control scheme of modulation by power of AC inverter

3. Simulation Results

3.1. Emergency power modulation

The impact of DC unipolar or bipolar block to AC transmission lines is huge. Without DC modulation, the power of AC transmission lines decreases slowly. Without stability control equipment, the power-angle will be out of step under DC bipolar block.

The primary goal of DC modulation is to improve the transient stability as DC block. The modulation schemes and parameters of Sichuan UHVDC is the same, which is shown in Table 3. According to the simulation results, the oscillation frequency between Sichuan power grid and Central China power grid is about 0.33Hz(T=3s) when there is DC block or AC line fault. Given the stability of the first power-angle, take the maximum modulation amplitude as 40% I_n and t_0 less than 1.5s.

Table 3. Parameters of emergency power modulation

T_d	T_f	ε	A	B	C	D	K	I_{mod}^{min}/I_n	I_{mod}^{min}/I_n
1.0	2.0	0.01	1	1	1	1	800	-10%	40%

When XJB UHVDC has unipolar block, 3200MW will be tripped from XJB plant to maintain system stability without emergency power modulation. While only 800MW will be tripped from XJB plant with emergency power modulation under bipolar block, and the JP UHVDC and XLD UHVDC will increase by 1800MW and 190MW separately in 1.0s~2.0s. The maximum modulation amplitude is less than 1.4 times of the rating current, and duration time is about 1s, which is shown as Fig.5 and Fig.6. The results of emergency power modulation under XJB UHVDC, JP UHVDC, XLD UHVDC and LS-CQ AC lines N-2 faults are separately shown in Table 4

Table 4. Effect of emergency power modulation (unit: MW)

Fault	*Without modulation*	*With modulation*	*reduced trip power*
XJB bipolar	3200	800	2400
JP bipolar	3600	1800	1800
XLD bipolar	3900	2300	1600
LC N-2	3000	600	2400

It should be noted that, DC modulation can improve the transient stability, and long-term over-load (1.1pu) capability can also decrease the power of AC transmission lines transported. While the redistribution power is more than 6000MW after DC block, the power flow of tie-line will increase by more than 4000MW and bus voltage drop is almost 0.1p.u. After DC block, which will cause HG-BQ lines to be out of thermal stability limitation

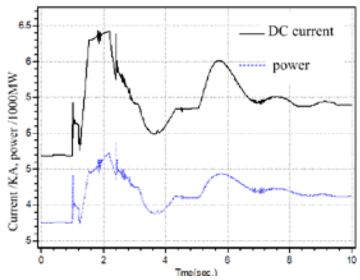

Fig. 5. The current and power output with XLD modulation under XJB bipolar blocks

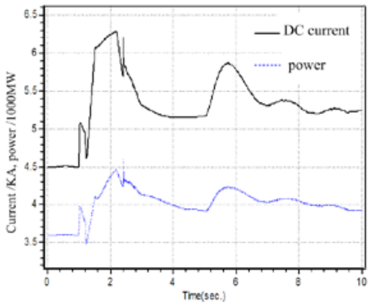

Fig. 6. The current and power output with JP modulation under XJB bipolar block

3.2. Small signal modulation

AC signals are introduced in DC modulation. The damping ratio of local power oscillation and inter-area power oscillation will be maximized by optimizing and coordinating the parameters of DC modulation, which will improve the stability of AC/DC hybrid system. The DC system need not to bear high current or power in damping system low frequency oscillation, and the modulation amplitude is much smaller than emergency power modulation. In addition, long-term over-load (1.1 times) of DC system does not need to be considered.

3.2.1. Coordinated modulation by Multi-UHVDC

The optimized parameters of XJB UHVDC, XLD UHVDC, and JP UHVDC POD (power oscillation damping) controller are as Table 5. The modulation amplitude of output current is ±5% of the rating current.

Table 5. Parameters of POD controller

T_d	T_f	ε	A	B	C	D	K	I_{mod}^{min} / I_n	I_{mod}^{min} / I_n
5	0.15	0.01	1	1	1	1	800	-5%	5%

When a three phase permanent fault occurs in LS-CQ UHV transmission line, the system power-angles with DC additional control and without additional control are shown as Fig.7. The current dynamical change of XJB UHVDC and XLD UHVDC under faults is shown as Fig.8. The output current will be about 0.05% higher than rating current in time of 1.02~1.80s after fault cleared, while the output current will be about 0.05% lower than rating current in time of 2.2~3s with DC modulation. Power oscillation can be damped quickly, and the second power-angle will be stable as shown in Fig.8.

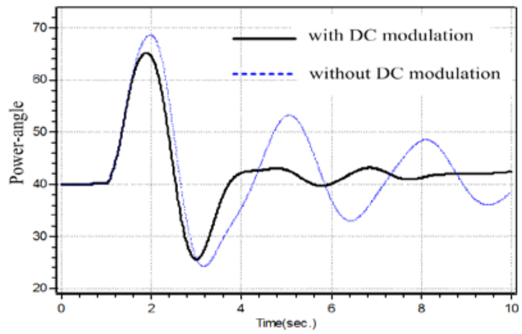

Fig. 7. Power-angle of SC-HB with DC modulation and without DC modulation

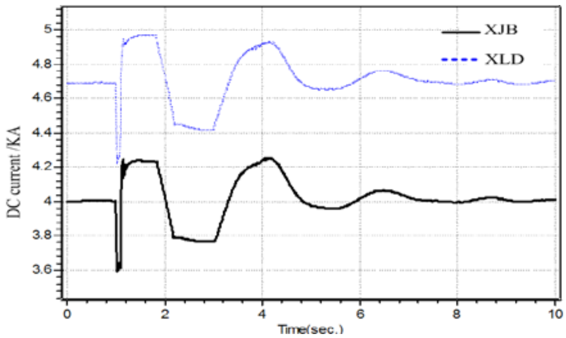

Fig. 8. Current of XJB UHVDC and XLD UHVDC with DC modulation

3.2.2. Modulation by single UHVDC

Generally speaking, the modulation amplitude is small when it is used for damping system low frequency oscillation, so if the other DC UHVDC systems are down, modulation by single-UHVDC can be considered. Compared to the coordinated modulation by Multi-UHVDC, the single-UHVDC modulation amplitude can be increased to 10%. Still consider a three phase permanent fault occurs in LS-CQ UHV transmission line, the system power-angles without DC additional control, with coordinated modulation by Multi-UHVDC and with single-UHVDC modulation are shown as Fig.9. It can be seen that, when amplitude of XLD single-UHVDC modulation is increased by ±10%, the effect is almost the same with coordinated modulation by Multi-UHVDC with ±5% amplitude.

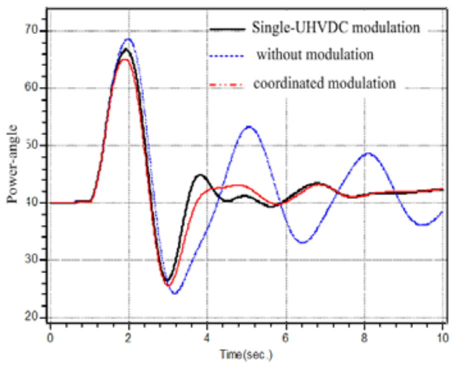

Fig. 9. Comparison of coordinated modulation by Multi-UHVDC, single UHVDC modulation and effect without modulation

4. Conclusion

Converter stations of UHVDC sending end in Sichuan are connected directly, which means the electrical distance is very close. Also the planned UHVDC systems will have transient over-load capability and steady-state over-load capability, which opens the way for coordinated control strategy for Sichuan multi-UHVDC system. Emergency power modulation by multi-UHVDC system can improve the transient stability and the tripped power under DC bipolar blocks will be decreased by 1600~2400MW. Modulation by power oscillation damping will greatly improve the dynamical stability, and the low frequency oscillation under faults will also be improved.

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