IOP Conf. Series: Materials Science and Engineering **199** (2017) 012149 doi:10.1088/1757-899X/199/1/012149

Research of Modulation of Bilateral Frequency Difference Based on Load Mode

Shenghong Lin[1], Chizu Mao[1,a], Jianquan Zhu[1] and Junyu Lu[1]

[1]School of Electric Power, South China University of Technology, Guangzhou, China

[a] Corresponding author : 249559676@qq.com

Abstract: Owning to high reliability, simple operation and easy acquirement of signals, modulation of bilateral frequency difference (MBFD) in HVDC is worthy for application in practical engineering. With the example of an AC/DC hybrid network and the software PSD-BPA, this paper analyses the effect of MBFD to DC block. The modulators parameters are setting by means of simulation. Two types of loads modes are considered to research the impact of them on simulation. The results indicate that in cooperation with operation modes adjusting at AC system, MBFD will effectively release the impact from DC block and shortage of reactive power caused by rapid variation of DC power owning to modulation. To achieve the best effect, only modulators of some HVDC systems instead of all of them are opened.

1. INTRODUCTION

If the severe fault happens to HVDC system, it may lock itself and block transmission power. Such common incidents in AC/DC hybrid system are called as DC block, which cause huge impact to the AC part due to mass power flow transfer. DC modulation is that additional controller is added to existent HVDC controlling system, to access signals inflecting faults and consequently adjust DC power. It is quickly response and effectively copes with the DC block, to improve stability of AC system and avoid or reduce economic damage owning to generators and loads shedding.

Paper [1] tries to recognize the system transfer function and set the parameters of modulators. Paper [2] implies that DC modulation gets better effect than power increasing/decreasing. Papers [3]-[5] indicate that modulators with frequency as input signals do well in enhancing system damping and stability in the area interconnected power grid. Many methods for modulation stating in academic paper consider only one HVDC system participating in power support. In actually network, there are more than one which will open the function to get the better effect. This paper analyses MBFD under the situation of DC bipolar block in a DC/AC system in China including the parameters setting, the coordination among various HVDC system and the cooperation measures in AC system.

2. STUDY OF MBFD

MBFD is that the controllers access the frequency signals from both sides of DC line, which inflect fault situation, as input signals, and modulation power is generated as output signals and added to DC transmission power, so as to deal with large disturbance. There are so many advantages in MBFD [5]. Firstly, frequency inflects the operation condition of the entire network, so as to monitor and control the system conveniently. Then, if sampling signals are frequency of both commutation buses, they are acquired easily and not easy to be lost. The last but not lease, it meets the demand of easy operation and high reliability in engineering. Thus, it is worthy for application in practical engineering.

IOP Conf. Series: Materials Science and Engineering **199** (2017) 012149 doi:10.1088/1757-899X/199/1/012149

The practical example is a huge network in China, where power is transfer from the west to the developed eastern district by 7 HVDC systems along with AC channels. It is worth noting that most of them are connected with commutation buses with 550kV buses except T-G DC with 220kV, and DC of N-C I and N-C II share the same commutation buses. Load in this chapter is 50% I-M (Impedance-motor) mode, within which motor applies the common parameters recommended by China EPRI. Such load mode is in common use in power system analysis.

2.1 The Transfer Function

The most important content of modulation research is to design the controller, which includes transfer function designing, parameters setting and input signals determining. This paper selects DC-8 type modulator, whose transfer function is shown in Fig. 1.

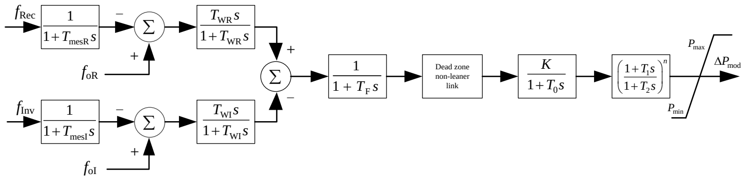


Figure 1. Transfer function of DC-8 type modulation

The input signals are from both commutation buses generally. They are firstly input through measure and respectively subtracted from the reference value (50Hz generally) in their own sides; then they are subtracted and frequency difference is got; and it goes through filter, dead zone link, gain, lead-lag stage; finally, the signal is output by limiting and added to the DC power signal.

2.2 Parameters Setting

A bipolar block fault is set in P-Q DC which transmits power by 5000MW, and other DC systems open their modulators. Such fault may give rise to mass transfer of power flow, angle instability and voltage collapse in receiving network [6]. This section researches the appropriate parameters values in each link at this fault situation. But some time constants are directly set to be empirical values. For instant, T_{mea} of measure is 0.1s; T_W of differential is 10s; T_F of filter and T_0 of gain is 0.1s. Empirical values are substitute into the remaining parameters at first, and they will be regulated one by one.

2.2.1 Dead zone non-linear link. Normally, frequency difference between both sides is less than ±0.02Hz [7]. In order to avoid frequent action of the function, a dead zone with ±0.05Hz is determined.

2.2.2 Lead-lag stage. It is designed to compensate legging phase caused by front inertia links. The maximum advance phase φ_m and the corresponding frequency f_m is show below [8] (it is assumed that there is only one link):

$$\begin{cases} \omega_m = 2\pi f_m \\ \varphi_m = \arctan(\omega_m \cdot T_{mea}) + \arctan(\omega_m \cdot T_0) + \arctan(\omega_m \cdot T_F) \end{cases} \tag{1}$$

The other parameters are calculated by the following formulas:

$$\begin{cases} \omega_m = \dfrac{1}{\sqrt{T_1 \cdot T_2}} \\ T_2 = \alpha \cdot T_1 \\ \alpha = \dfrac{1 - \sin\varphi_m}{1 + \sin\varphi_m} \end{cases} \tag{2}$$

The link is supposed to meet the demand of inhibiting low frequency oscillation, which is with frequency of 0.25~2.0Hz. Particularly, inter-area mode, with the frequency ranging between 0.2~0.7Hz and weak damping, is more dangerous. According to formula (1)(2), value of f_m determines the value of the remaining parameters, and it is set according to the actual oscillation frequencies. If a disturbance happens, the actual compensated angle of a link is

$$\varphi_{act} = \arctan(2\pi f_{act} \cdot T_1) - \arctan(2\pi f_{act} \cdot T_2) \tag{3}$$

By means of Prony analysis, it is found that the frequency difference curves have the similar oscillate mode with angle curves, which is the same as paper [1]. In consideration of compensation effect, f_m is defined as 0.5Hz. According to formula (1) (2), φ_m = 52.32°, and if there are two links, T_1 = 0.5110 and T_2 = 0.1983.

2.2.3 Gain and Limiting. Gain coefficient *K* is one of the most important parameters. Small value results in poor effect, but large value is difficult to be realized. Additionally, the effect is limited by limiting link. HVDC systems have the overload ability of 1.5 times of rated capacity within 3s so limiting is set to be ±50%. The empirical value of *K* is 50000. Various values are substitute into the parameter in order to get the best value. Other parameters use the value determined at above. Modulation effect with difference value of *K* is exhibited in Fig. 2, in which the vertical axis means the power angle of TOG plants referred to KM plants. It shows the better effect to 5000 in comparison with the value under that. But the result is not improved dramatically as *K* increase if it is over 5000. So, it can draw a conclusion that 5000 is a relatively suitable value.

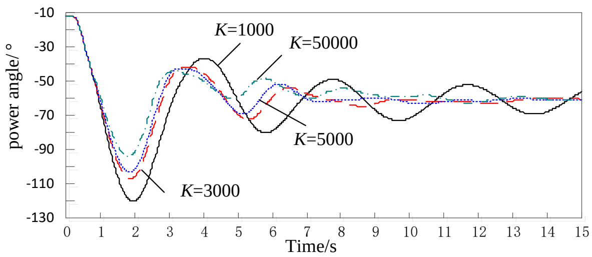


Figure 2. Modulation effect with difference value of *K*

2.3. Popularity

The controllers with above parameters are proper in the scene of bipolar block of P-Q DC. It is tried to be applied to other six HVDC lines. All DC systems enable the function except the fault one. Simulations indicate that the impact caused by them is released and the system is stable finally. Thus, as long as the modulators with parameters set in this chapter are installed to all HVDC systems, MBFD effectively cope with bipolar block from any HVDC system. Perhaps these parameters are not the best, but as long as they are effective, they are proper for the network.

3. IMPACTS OF LOADS MODES ON MBFD AND SOLUTIONS

3.1 The simulation in Load mode of 'SLM'

Load mode is the key factor to voltage stability and plays an important part in simulation. Actually, many power sectors use recommended modes instead of those with measures parameters, so the simulation results do not always accurate. Thus, it is necessary to study the influence of different load modes. In principle, simulation results are supposed to be as conservative as possible. Then relevant precautionary measures are proposed in advance to protect the network from severe impact.

China EPRI proposes Synthesis Load Mode (SLM), which takes distribution network into account and is conservative in voltage stability. Its structures and natures are stated in papers [9], [10]. Parameters of SLM are shown in Tab. 1.

Table 1. Parameters of SLM

R_S	X_S	X_m	R_R	X_R	A	B	$P_M\%$
0.03	0.114	3.2	0.0114	0.114	0.85	0	40
s_0	T_j	R_D	X_D	$P_Z\%$	$P_I\%$	$P_P\%$	
0.0116	2.36	0.025	0.05	30	45	25	

For convenience, the system with I-M mode in last chapter is called as system 1. System 2 is defined here: SLM is used in receiving end and the near area, while the remaining areas are still with I-M mode. Impact of bipolar lock and the modulation effect at the system 2 is analysed. The experiments imply that the modulators can cope with bipolar lock from DC of T-G, G-Z, X-A, N-C I or N-C II. However, difference conditions occur to DC of Y-G or P-Q. This chapter tries to stabilize the system by means of other measures along with modulation.

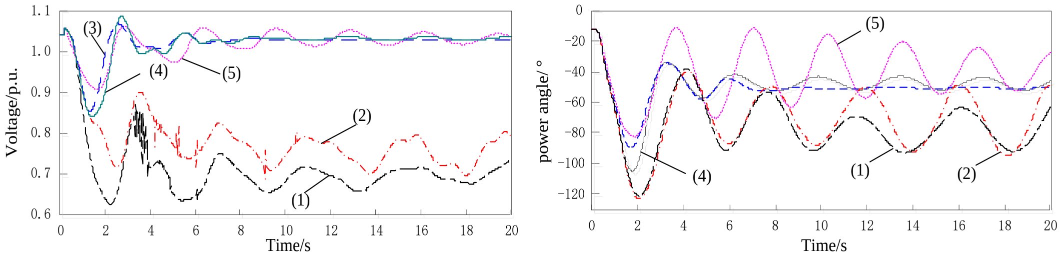
3.2 The Solutions

Firstly, the compensation capacitor bank at both-side commutation buses should be retained after DC block happens. In general, capacitors are cut in 0.1s after the DC line is blocked. However, it is another disturbance. On the other hand, reactive power contained in capacitor is about half of the transmission power of the DC line, so retaining the capacitor will avoid another disturbance and keep extremely precious reactive power to avoid further deterioration of voltage condition [11]. There is no evident overvoltage in the network. At most the inverter bus is with the voltage of 540kV and rectifier with 550kV. Even if buses voltage is over allowed upper limit, the capacitors will be cut step by step after the system is stable. But the practice only is not enough for P-Q DC block, at which the measures discussed below are aimed.

Secondly, some of the modulators must be closed. Paper [12] indicates that it is not necessary to open all modulators. To achieve the best result, only some of them participate in modulation. Because rapid changing in DC power result in voltage fluctuation. The following experiments try to close the function of some DC lines. The results reveal that on the view of voltage stability and modulation effect, closing controllers of N-C II DC (or N-C I DC), G-Z DC and T-G DC reaches the best effect. Voltage collapse does not happen in 500kV nodes including commutation buses (except T-G DC), but their voltage curves are still with oscillation, and some motors lost stability. Besides, voltage of commutation bus in T-G DC, which is 220kV level, is less than 0.7 (p.u.).

Thirdly, generators tripping or power fast decrease (generator fast shut) may be the common practices with satisfactory effect. The common measure is to cut generators in NDZ plant by 3900MW, which is near 80% of transmission power of P-Q DC. But it does not need to cut so much anymore. Compare with tripping, power fast decrease is only to decrease generated output instead of making generators be divorced from the gird, so it brings comparatively less impact on the plant.

The results of simulation are showed as follow. At first, four measures should be defined: a. Retaining capacitor; b. locking modulators of DC of N-C II, G-Z and T-G; c. tripping two generator unit in NDZ plant by power of 1100MW; d. decreasing power of 2 generators by 1540MW in 1.5s (generator fast shut). Then 5 situations are defined and Fig. 3 show the effect of them.: (1) applying measure a; (2) applying measure a, b; (3) applying measure a, b, c; (4) applying measure a, b, d; (5) common generator tripping.



(a) Voltage curve of inverter bus of T-G DC (b) Angle curve of TOG plants referred to K-M plants

Figure 3. Effect with difference strategies

Situation (3) receives the best result. Generator fast shut is more economic than tripping, but Situation (4) indicates that the system response more slowly. Curve (5) is still with oscillation after 10s, because the practice is for system 1 and not appropriate to system 2. In conclusion, with the parameters set in system 1, locking modulation function of DC of N-C II, G-Z and T-G along with retaining capacitors and generator tripping by 1100MW is the most appropriate strategy to cope with bipolar block from P-Q DC.

3.3 Similar Measures for Block of Other Six HVDC System

According to this general, the similar measures are promoted to other HVDC lines. The results are shown in Tab. 2. In Tab. 2(a), the sign '√√' means the modulator is essential or contribute considerably, and the sign '√' means it have comparatively little contribution. Because DC of N-C I and N-C II share the same commutation buses, they have the same contribution for the network.

Table 2. Popularity of the measure

(a) Contribution of the modulators

Modulation / Block	T-G	G-Z	X-A	Y-G	P-Q	N-C I	N-C II
Power/MW	1800	3000	3000	5000	5000	3200	3200
T-G	-		√	√√	√√	√√	
G-Z		-	√√	√√	√	√√	
X-A		√	-	√√		√√	
Y-G			√	-	√√	√	
P-Q			√√	√√	-	√√	
N-C I				√√	√√	-	√
N-C II				√√	√√	√	-

(b) Operation mode adjusting in AC system

Blocked DC	Specific measures
Y-G	Retaining capacitor in commutation on both sides
P-Q	Retaining capacitor, generator tripping by 1100MW locking modulators of DC of N-C II, G-Z and T-G
Others	No need

There is something inferred from the Tab 2. (1) DC of YG, P-Q, N-C I are the main strength for modulation function; (2) DC of N-C I and N-C II is complementary, and it is no need for both of them to participate in modulation; (3) Without operation mode adjusting in AC system, modulation only is not enough to cope with bipolar locking from DC of Y-G and P-Q; (4) The function are not necessary to applied in T-G DC, and DC of G-Z and N-C II (or N-C I DC) do not need it absolutely.

If the modulators are removed from DC of G-Z and N-C II, and lock the modulators which have the sign '√' in the Tab. 2(b), the effect is still satisfactory. At most, after 10s, peak-to-peak value of power angle is increased to a value of about 3° from previous 1°. Therefore, in consideration of the cost, it is reasonable that modulators are not added to DC of G-Z and N-C II.

4. CONCLUSIONS

This Paper tries to setting the parameters of DC-8 type modulator by simulation to deal with bipolar block at any HVDC systems in various load modes. It can draw following conclusions.

(1) For the actual interconnected network, the parameters are set by means of simulation. MBFD with proper parameters are effectively release the impact from DC block on AC system.

(2) Load mode plays an important role in modulation research. SLM is more conservative than I-M mode in voltage stability. For system with SLM, in cooperation with operation mode adjusting, the

controllers with parameters setting previously for CLM is also able to release the impact from bipolar DC block of any HCDC system and shortage of reactive power.

(3) Rapid variation of multiple DC power may give rise to voltage instability, so some of them should be locked when DC block happens to another DC line. In the other hand, the modulators in some HVDC which make less contribution are no need to be installed. It will save investment.

ACKNOWLEDGMENT
This paper is sponsored by National Science Foundation of China National Natural Science Foundation of China under Grant 51307064.

References

[1] S. J. Wang and J. Yang, Study on DC Modulation of Bilateral Frequency Difference Based on Transfer Function Identification, *Shanxi Electric Power*, vol. **42**, pp. 4-8 (2014).
[2] L. Zhu, X. R. Wang, and Q. Q. Lu, Research of emergency DC power support strategies for large-scale power grid based on PSD-BPA, *Power System Protection and Control*, vol. **41**, pp. 139-144 (2013).
[3] D. Yan, P. Jiang, and J.K. Liu, "Research on the Multi Signal Comprehensive DC Modulation of UHVDC in Improving System Transient Stability," *Jiangsu Electrical Engineering*, pp. 9-12 (2012).
[4] H. X. Chen and J. Mo, Study of DC bilateral frequency power modulation to improve UHVDC transient stability, *Electric Power*, pp. 34-38 (2009).
[5] Y. Jing, C. Hong, and J. P. Yang, Suppression of Inter Area Power Oscillation in Southern China Power Grid by HVDC Modulation, *Power System Technology*, vol. **29**, pp. 53-56 (2005).
[6] Y. Gao, M. X. Han, and X. Y. Chen, Research on Characteristics of Commutation Failure in DC Power Modulation of Multi-infeed HVDC System, *Journal of North China Electric Power University*, vol. **41**, pp. 36-40,46 (2014).
[7] Q. Tian, Studies on the abnormality of bilateral frequency difference modulation in Tian-Guang HVDC, *Power System Protection and Control*, pp. 94-98, (2011).
[8] M. Driels, *Linear Control Systems Engineering*, vol. I. Beijing: Tsinghua University Press, pp. 396-410 (2000).
[9] Q. Chen, J.B. Sun, and M. Cai, Parameters Determination of Synthesis Load Model Considering Distribution Network Connection, *Proceedings of the CSEE*, pp. 45-50, (2008).
[10] J. X. Hou, Y. Tand, and H. B. Zhang, "A Synthesis Load Model with Distribution Network," *Power System Technology*, vol. **31** (2007).
[11] M. H. Z. L. Wenfeng Zhang, *Variation analysis of fault feature in receiving network of AC/DC hybrid system*, vol. I. Beijing: China Electric Power Press, 2015.
[12] H. F. Xie, Y. Zhang, and L. X. Lin, Emergency DC Power Support Control Based on Time-Optimal Control and Auto-Disturbance Rejection Control, *Transactions of China Electrotechnical Society*, vol. **25**, pp. 145-153,173 (2010).