Improvement of Rotor Angle Stability and Dynamic Performance of AC/DC Interconnected Transmission System

Ramesh Gantha[1], Rasool Ahemmed[2]
[1]eee Kl University, India
[2]*AsstProfessor, EEE KL University, INDIA*

Abstract— **this paper illustrates a study on improvement of rotor angle and dynamic performance of AC/DC interconnected system. High voltage direct current transmission is an economic way for long distance power delivery and/or interconnection of asynchronous system with different frequencies. With the development of modern power system, HVDC system plays much more important role in power grids due to their huge capacity and capability of long distance transmission. An AC/DC parallel transmission system and a three-in feed HVDC system are modeled using PSCAD/EMTDC. Simulations corresponding to different situations are performed. From the simulation results, HVDC Light is proven to be able to improve the rotor angle stability and dynamic performance of AC/DC interconnected transmission system, and support the AC voltage during the system fault to enlarge the margin of the voltage stability which is the basic difference from conventional HVDC. HVDC Light can also prevent commutation failure in multi-in feed HVDC system and help the recovery of HVDC system too.**

Key words —HVDC Light; AC/DC transmission system; Power stability; commutation failure

I.INTRODUCTION

Towards 2015, there will be 7 HVDC transmission systems constructed in China South Power Grids (the CSGs). Conventional HVDC transmission system is based on line commutated thyristor rectifier. With the advent of high voltage and high power gate turnoff (GTO), insulated gate controlled transistor (IGBT), and more recently insulated gate controlled thyristors (IGCT); high power solid-state switches have symmetrical turn-on and turn-off capabilities. They have given the birth to a new generation of HVDC stations. HVDC light also called as Voltage-source-converter (VSC) HVDC.

Unlike conventional HVDC scheme that employs line-commutated current source converters with thyristors, HVDC Light is a new technology utilizing forced-commutated voltage source converters. HVDC light can be applied to the voltage support in the receiver systems, interconnection between asynchronous power systems.

So far, there are 12 HVDC Light projects for different purposes already in operations worldwide.

HVDC systems are responding and can be controlled within tens of milli-seconds. HVDC systems can also improve the stability, especially transient stability of power system..

By pulse wide modulation (PWM) control, HVDC Light realizes independent control of active and reactive power control, and does not need reactive compensation in both rectifier and inverter side. It can also be used with static synchronous series compensation (SSSC) characteristics to damp the power system oscillations. HVDC Light applies self-commutated solid-state device, so there are no commutation failure issue.

For AC/DC interconnected transmission systems, the introduction of HVDC Light can enhance the voltage support and improve the system stability. The following sectors will discuss the effect of HVDC Light for improvement of the AC/DC interconnected systems.Two simulation models have been set up with HVDC Light built in; one is an AC/DC parallel transmission lines system, and the other is a multi-infeed HVDC systems.

II. PRINCIPLE OF HVDC LIGHT

HVDC Light is composed of transformer, filters, converters and DC capacitors, as shown in figure 1. Transformer is used to step down the AC voltage to satisfy the demand of self-commutated solid-state devices, such as series and parallel of GTOs, IGBTs or IGCTs. High frequency components caused by the switches of valves are isolated from power system by filters. The key parts of HVDC Light are converters, which can realize the conversion from AC to DC bi-directly. DC capacitors are used as the DC voltage source in HVDC Light, which need being charged and recharged.

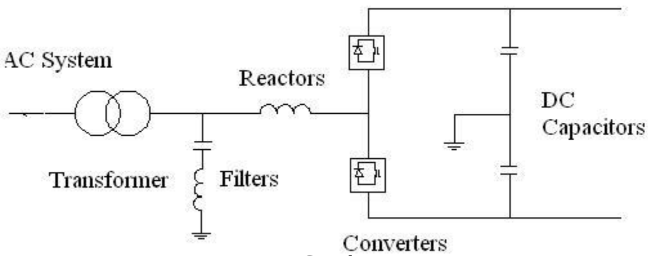


Fig.1 HVDC Light converter

The equivalent circuit of converter is shown in figure 2. By PWM control, the converter outputs fundamental frequency voltage with different magnitude and phase angle through the high pass filters. As a consequence, the converter is considered as a voltage source from AC side. The magnitude and phase angle decide the reactive power and active power exchange between AC and DC system respectively. The power transmitted by HVDC Light is given as:

$$S_b = P + jQ = \sqrt{3}U_F I_R^* = \frac{\sqrt{3}U_F (U_C - U_F)}{Z_R} \quad (1)$$

where S_b is the apparent power of HVDC Light; P is the active power and Q is reactive power. U_F is the voltage of AC system; U_C is the output voltage of converter; Z_R is the equivalent impendence of the converter system including the transformer and reactors.

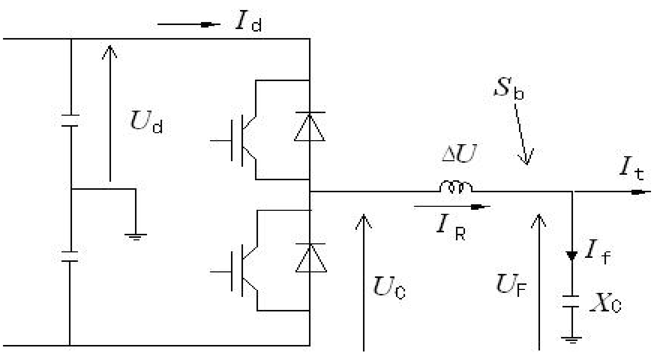


Fig.2 Equivalent circuit diagram of the HVDC Light converter

Active power and reactive power are given respectively as:

$$P = \frac{U_F U_C \sin\delta}{\omega L} \quad (2)$$

$$Q = \frac{U_F (U_F - U_C \cos\delta)}{\omega L} \quad (3)$$

Worked as inverter. The converter will generate reactive power, if $U_F > U_C \cos\delta$, and will absorb reactive power on the contrary.

III. HVDC LIGHT CONTROL SYSTEM

Rectifier of HVDC Light applies the active and reactive power control, while inverter applies the DC and AC voltage control. In the sender system, active power is controlled by the phase angle of converter output voltage, and the reactive power is controlled by the magnitude of converter voltage. In that sense, the active and reactive power can be controlled independently. In receiver system, DC voltage is controlled by the phase angle of converter output voltage, while the AC voltage is controlled by the magnitude of converter voltage. The following two sectors introduce the controller of rectifier and inverter respectively.

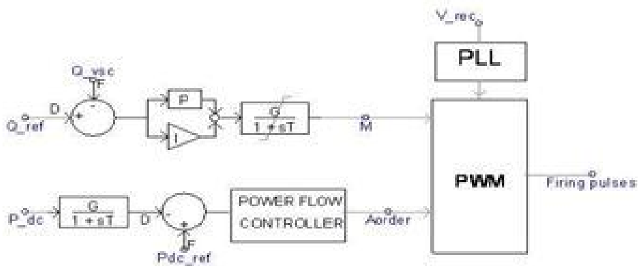
A. Rectifier controller

The rectifier controller is shown in figure3. The controller Consists of four parts: power flow control loop, reactive power control loop, phases locked loop (PLL), and PWM pulse firing. After a time delay, the P_dc is compared with the desired DC power Pdc_ref, and the comparator outputs the error signals to the power flow controller. The reactive power controller is a PI controller. The measured reactive power and the desired reactive power Qref are the input of the controller. The outputs of active and reactive power control loop are the inputs of PWM pulse generator. PLL provides the synchronous signal of pulse generator. PWM pulse generator sends the pulse signals to drive the valves in the converter. By the rectifier controller, the rectifier can produce the active and reactive power as the designations.

The control loop, there are other AC voltage control loop and DC voltage control loop. PI controllers are used for both AC voltage control loop and DC control loop. The inverter controller is shown in figure 4. The inverter controller can control the AC and DC voltage of the receiver system in HVDC Light.

The rectifier controller is shown in below figure 3.

Fig.3



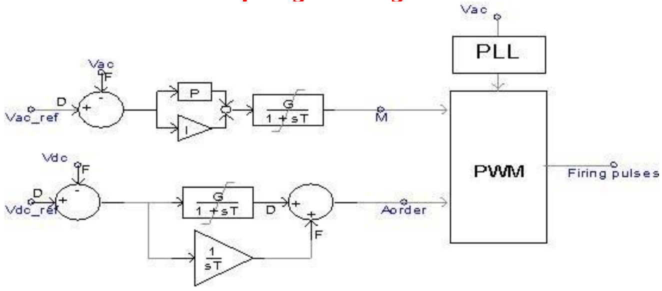


Fig.4 the inverter control system

IV. SIMULATION RESULTS

A. HVDC Light in AC/DC hybrid transmission systems

HVAC/DC hybrid transmission systems are very common nowadays. If AC transmission lines are paralleled with HVDC Light, there will be more advantages. For the simulation purpose, a model of HVDC Light paralleled with two AC lines connecting two areas are built using the PSCAD/EMTDC software [14]. The model is shown in figure 5. In zone 1, the power source is a 360MW generator, which is equipped with exciter controller and power system stabilizer (PSS). The nominal capacity of HVDC light is 120MW. The solid-state devices are IGBTs. The controller of HVDC Light is as the one given in section III. The rectifier uses constant active and reactive power control, while the inverter uses constant DC voltage and AC voltage control. The AC line's nominal voltage is 230kV and their lengths are both 200km. In zone 2, there is a voltage source with a 26.45Ω impendence. It can be considered as an infinite bus. A permanent three-phase short circuit fault site is set on the middle of line 1, and the inception time is 4s. The duration of fault is 0.1s (5cycles) and the circuit breaker will trip the line at 4.1s.

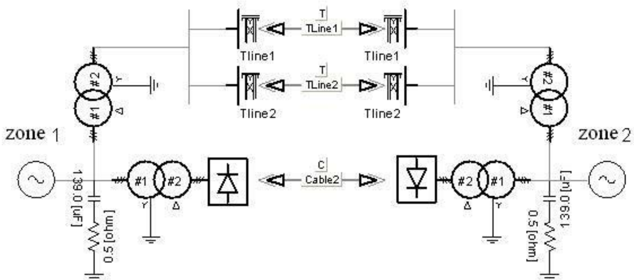
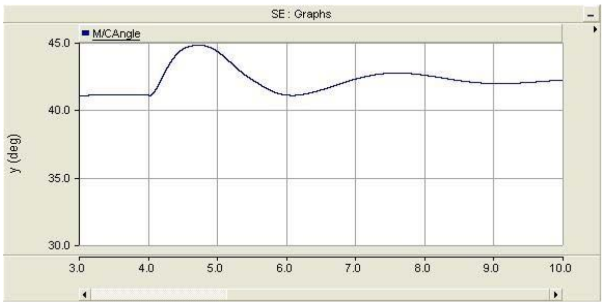


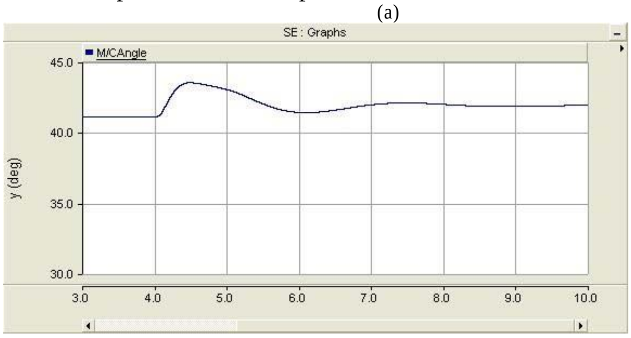
Fig. 5 Model of HVDC Light with two AC lines

Figure 6 presents the shape of power angle of the generator with HVDC Light and without HVDC Light. With HVDC Light, its ability of regulating of the DC power can help damp the oscillation when system has fault. The magnitude of oscillation decrease from 45 degree to 43 degree, and the stabilization time decrease from 4s to 2.5s.

If the power demand of receiver system increases, the system will lose its stability without HVDC Light, just like figure 7(a). If HVDC Light is put into operation, the system can be kept stable, and the performance can be satisfied.

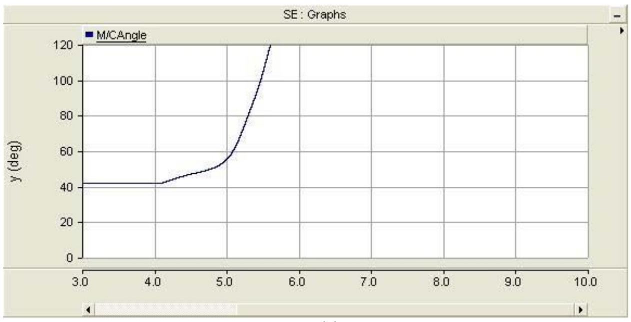


(a)

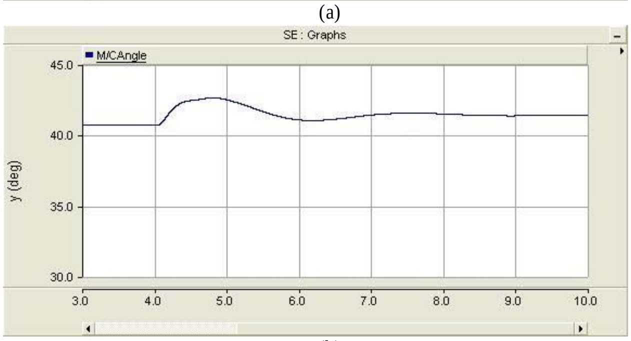


(b)

Fig.6 the shape of power angle when system is stable (a) without HVDC Light (b) with HVDC Light



(a)



(b)

Fig.7 the shape of power angle when system is unstable (a) without HVDC Light (b) With HVDC Light constant AC voltage control in inverter, it can produce reactive power and help the recovery of the AC voltage. Considering the control mode is constant active and reactive power control on rectifier side, the AC voltage recovery in rectifier side is more slowly than on inverter side. Compared to AC voltage without HVDC Light in figure 9(a), the HVDC Light is with high ability for voltage support.

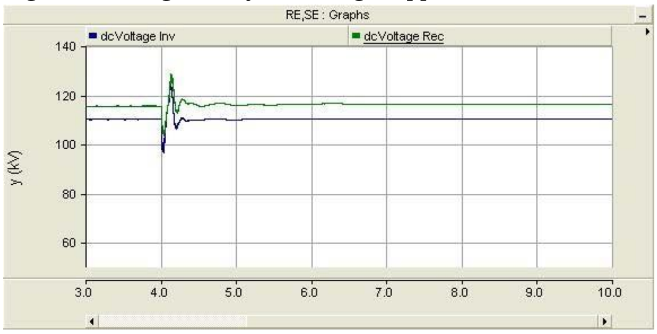
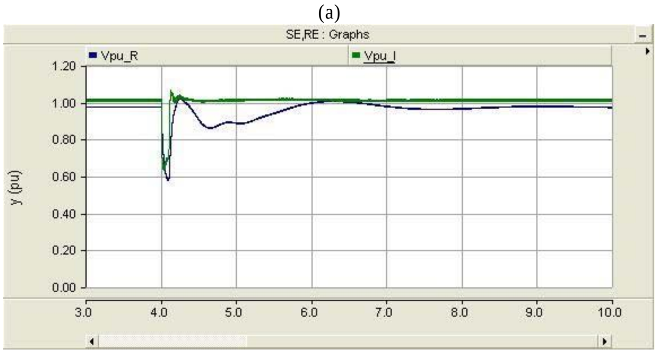


Fig. 8 the shape of DC voltage of HVDC light

(a)



(b)

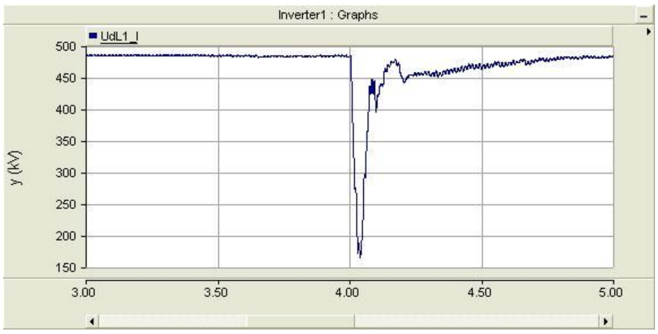
Fig. 9 the shape of AC voltage RMS (a) without HVDC Light (b) with HVDC Light

B. HVDC Light in Multi-infeed HVDC systems

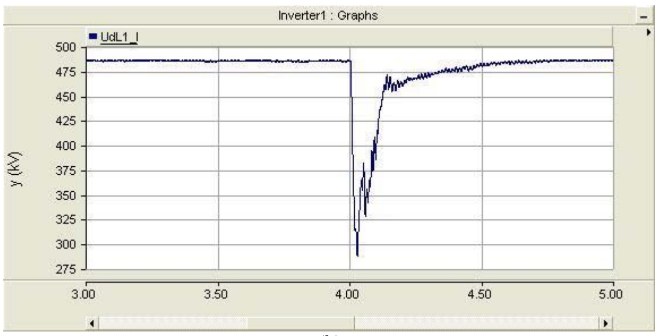
In order to research the interaction between HVDC Light and HVDC in multi-infeed HVDC transmission system, a simulation model of multi-infeed HVDC system with two conventional HVDC systems and one HVDC Light system is built in PSCAD/EMTDC.

HVDC I and HVDC II in figure 10 are conventional HVDC lines, which use CIGRE Benchmark model [15]. HVDC Light is the same as in the first simulation. It is put at the similar place as conventional HVDC in multi-infeed system. The voltage support ability is the concern here. A single phase to ground fault is set at the AC bus of HVDC I inverter. The fault inception time is 4s and the duration is 0.1s (5 cycles). Figure 11 and figure 12 present the shape of DC voltage of HVDC I and HVDC II respectively when HVDC Light is and is not equipped. Without HVDC Light, HVDC I and II will have commutation failures occurred.

The DC voltage in HVDC I inverter side decreases to about 150kV and The DC voltage in HVDC II inverter side decreases to about zero. With HVDC Light, the HVDC I still has commutation failure, but the DC voltage only decreases to about 300kV. HVDC II does not have commutation failure, and the DC voltage only decreases to about 0.8pu. The reason is that the AC voltage can be supported by HVDC Light as shown in figure 13. The constant AC voltage control makes the inverter produce the reactive power to sustain the AC voltage in inverter side. The AC voltage can be kept higher than 0.9 pu which will prevent the commutation failure of HVDC II.

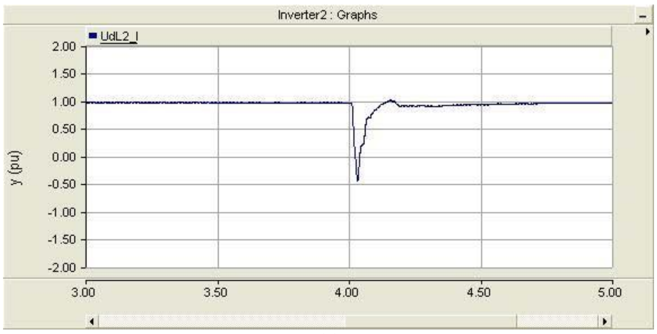


(a)

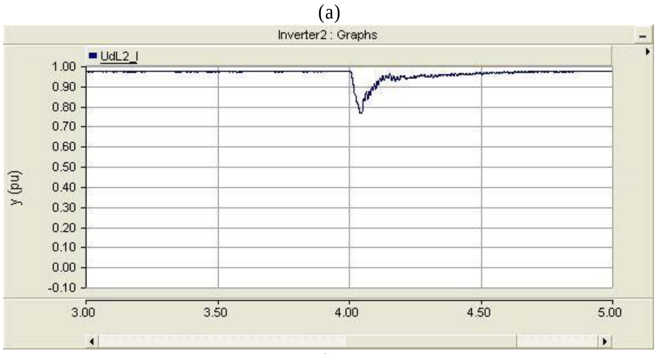


(b)

Fig. 11 the shape of DC voltage in HVDC I inverter side (a) without HVDC Light (b) with HVDC Light

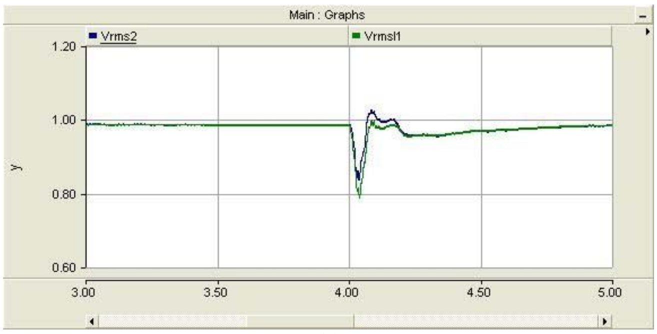


(a)

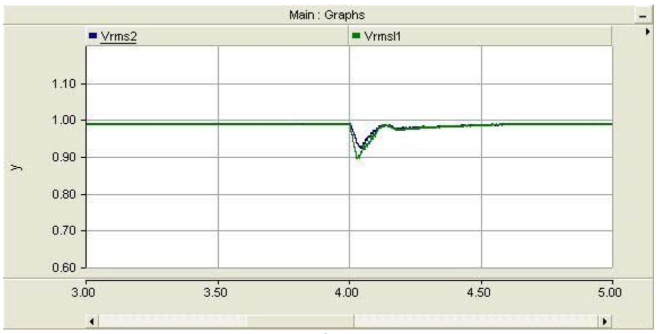


(b)

Fig. 12 the shape of DC voltage in HVDC II inverter side (a) without HVDC Light (b) with HVDC Light



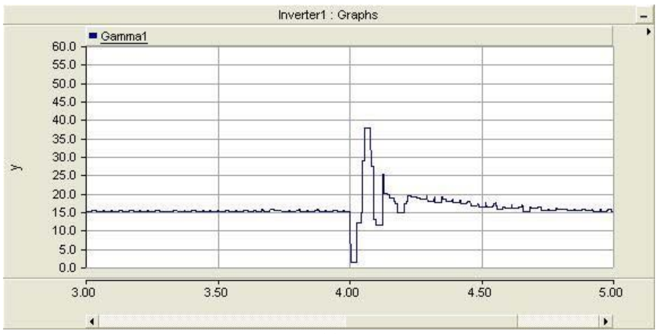
(a)



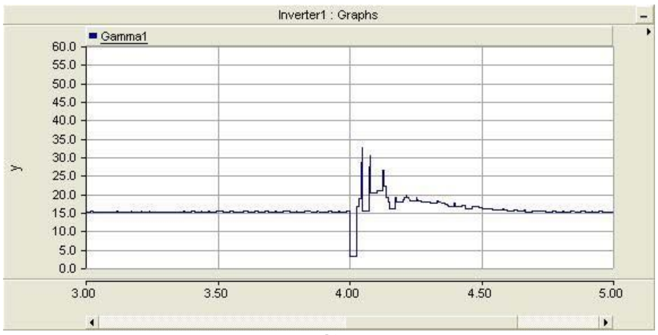
(b)

Fig. 13 the shape of AC voltage RMS in HVDC inverter side (a) without HVDC Light (b) with HVDC Light

Another aspect can be taken into account is the ignition angles γ of HVDC inverters. Figure 14 and figure 15 depict the ignition angles of inverters in HVDC I and HVDC II. If $\gamma < 8^\circ$, HVDC is supposed to have commutation failure. In figure 14, HVDC I cannot be prevented commutation failure, but the duration of commutation failure is shorten and it is easier to recover the HVDC system. The commutation failure is not presented in HVDC II and the γ is larger than 8˚ when HVDC Light is put into operation.

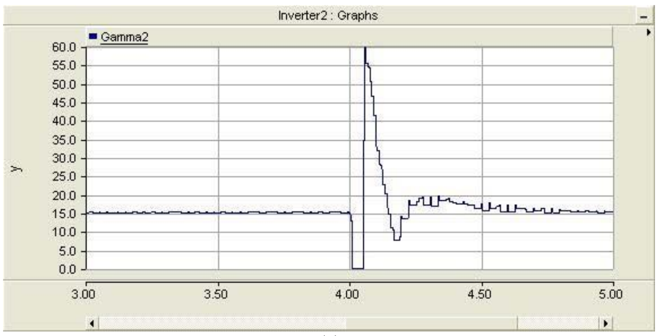


(a)

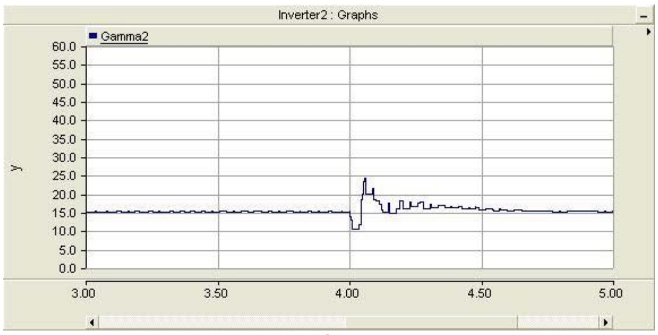


(b)

Fig. 14 the shape of ignition angle in HVDC I inverter side (a) without HVDC Light (b) with HVDC Light



(a)



(b)

Fig. 15 the shape of ignition angle in HVDC II inverter side (a) without HVDC Light (b) with HVDC Light

According to the analysis above, HVDC Light has the capability of controlling active and reactive power respectively. It can support the AC voltage and DC voltage during the faults in power systems. In multi-infeed HVDC system, HVDC Light can help the recovery of HVDC system and prevent commutation failure in it.

V. CONCLUSION

HVDC Light is a novel power electronic device, which utilizes the technology of VSC converter. By PWM control model, it can control the output of active power and reactive power independently. It is the major difference from line-commutated HVDC transmission system. In AC/DC interconnected transmission system, the rotor angle stability of power systems can be improved by the control of active power. The AC voltage in inverter side can be supported by the control of reactive power. In multi-infeed HVDC transmission system, system faults can cause commutation failure in several HVDC systems. With the capability of voltage support from HVDC Light, the AC voltage can be supported to prevent the commutation failure in some HVDC systems. As a conclusion, HVDC Light is a novel approach to improve the performance and stability of power system. It has bright future to be applied in power systems in many fields.

ACKNOWLEDGMENT

This work was supported by National Nature Science Fund of China (50337010) and National S&T Support Program for the 11th Five-Year Plan Period of China (2006BAA02A17)

REFERENCES

[1] B. R. Andersen, L. Xu, P. J. Horton, P. Cartwright. Topologies for HVDC VSC Transmission. IEEE Power Engineering Journal, June, 2006: 142-150.

[2] Mao Xiao-ming; Zhang Yao; Guan Lin; Wu Xiao-chen. Coordinated control of interarea oscillation in the China Southern power grid [J]. IEEE Trans. on Power Systems, 2006, 21(2):845-852.

[3] P. Kundur. Power System Stability and Control. McGraw-Hill, Companies, Inc, New York, 1994.

[4] Z. Zhao, M.R. Iravani. Application of GTO Voltage Source Inverter in a Hybrid HVDC Link. IEEE Trans. On Power Delivery, 1994, 9(1): 369-377.

[5] D. N. Kosterev. Modeling Synchronous Voltage Source Converters in Transmission System Planning Studies. IEEE Trans. on Power Delivery,1997, 12(2): 947-952.,

[6] Z. Huang, B. T. Ooi, L.-A Dessaint, F. D. Galiana. Exploiting Support of Voltage-Source HVDC. IEE Proc. Gener. Transm. Distrib.2003, 150(2): 252-256.

[7] B.-M. Han, S.-T. Baek, B.-Y. Bae, J.-Y. Choi. Back-to-back HVDC system using a 36-step voltage source converter. IEE Proc.-Gener. Transm. Distrib., 2006, 153(6): 677-673.