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Dynamic Simulation of a VSC- HVDC Transmission System

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Abstract: The purpose of this study is to understand the control structure of the VSC-HVDC system and establish the controllers of the converter. A mathematical model of the control system based on the relationships between voltage and current is described for the VSC. A control system is developed combining an inner current loop controller and outer dc voltage controller. The vector control strategy is studied and corresponding dynamic performance under step changes and system fault is investigated in PSCAD/EMTDC simulation package. The findings of this study show that the use of VSC technology and Pulse Width Modulation (PWM) has a number of potential advantages such as short circuit current reduction, independent control of the active and reactive power. Therefore this study recommends with advantages of VSC-HVDC is definitely going to be a large part of future transmission and distribution systems.

Keywords: VSC-HVDC, control strategy, pulse width modulation, active power, reactive power

1.0 INTRODUCTION

The voltage source converter based high voltage direct current transmission (VSC-HVDC) is becoming a more competitive technology. Due to the use of electronic switches with fully controllable capabilities, VSC-HVDC system is less influenced by the ac network, offers advantages of independent active and reactive power control and flexible operation. For a proper technical and economical solution, it has broadened the potential range of HVDC transmission to applications for power supply to islands, offshore wind farms, city power supply, and multi-terminal systems. VSC-HVDC transmission can be beneficial to overall system performance including the advanced features of high quality dc link voltage and ac currents with low level harmonics. However, unbalanced grid conditions will result in the oscillation in dc-link voltage and low-order harmonics in ac currents, even the distortion, which will subject the VSC power switches and other facilities to additional voltage and over-current stresses in case of a major grid imbalance.

In the case of VSC-based HVDC transmission systems the transfer of power is controlled in the same way as in the case of a classical HVDC transmission. The inverter side controls the active power, while the rectifier side controls the DC voltage. If the power transmission is considered between two AC grids, the power flow can be bidirectional.

But, if the VSC-based HVDC system is used to deliver power from an offshore wind power plant, the active power flow is unidirectional. One of the advantages of VSC-HVDC using PWM technology is that it makes possible to independently control the active power and the reactive power. Thus, the reactive power may be controlled separately in each converter. The active power flow can be controlled by means of the DC voltage on the DC side or by variation of frequency on the AC side. Moreover, the active power flow can be set manually. In conclusion, when using VSC-based HVDC technology the active and reactive power, as well as the AC and DC voltage and the frequency can be controlled. A typical VSC-HVDC system is shown in Fig. 1.

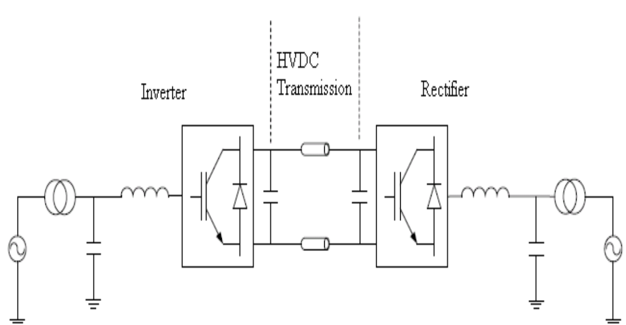

Fig 1 Configuration of a VSC-HVDC System

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2.0 VSC-HVDC TRANSMISSION SYSTEM MODEL

A diagram of VSC-HVDC system is shown in Fig. 2 by using PSCAD/EMTDC simulation software. Two VSC stations are connected through dc cables and to the ac system through the converter transformers or reactors. The dc capacitors provide an energy buffer to keep the power balance and reduce the voltage ripple on dc side. Tuned shunt filters are needed to reduce the high frequency switching harmonics on ac system. The two converters are normally implemented with one converter operating as a dc voltage regulator and the other controlling the active power. Either the ac voltage magnitude or the reactive power at all converters can be regulated to supply the ac system reactive power support.

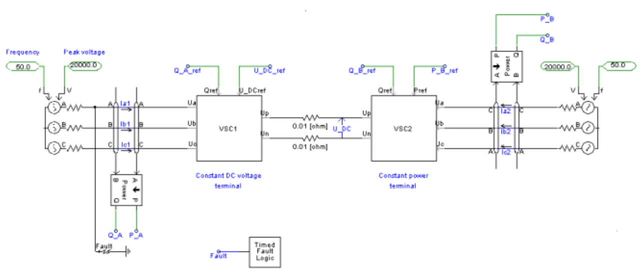


Fig. 2 Diagram of VSC-HVDC system

3.0 CONTROL SYSTEM STRATEGY

The control system of the VSC-based HVDC is realized by using a fast inner current control loop and several outer control loops. The control system of the VSC-HVDC systems has at its base level a fast inner current control loop controlling the AC currents. The AC current references are provided by the outer controllers. The slower outer controllers include the DC voltage controller, the AC voltage controller, the active power controller, the reactive power controller and the frequency controller. Thus, the reference of the active current can be obtained from the DC voltage controller, from the active power controller or from the frequency controller. On the other hand, the reference of the reactive current can be derived from the reactive power controller or from the AC voltage controller. The overall control structure of the VSC-based HVDC transmission system considered in this study is shown in Fig. 3.

The grid synchronization is a very important and necessary feature of grid side converter control. The synchronization algorithm is able to detect the phase angle of grid voltage in order to synchronize the delivered power. Moreover, the phase angle plays an important role in control by using Park's transformation. There are several methods capable to detect the phase angle such as the zero crossing detection, the filtering of grid voltages and the phase locked loop (PLL) technique. In this study, the PLL algorithm is implemented in order to synchronize the delivered power. The PLL is a phase tracking algorithm, which is able to provide an output synchronized with its reference input in both frequency and phase. The purposed of this method is to synchronize the inverter output current with the grid voltage, in order to obtain a unity power factor.

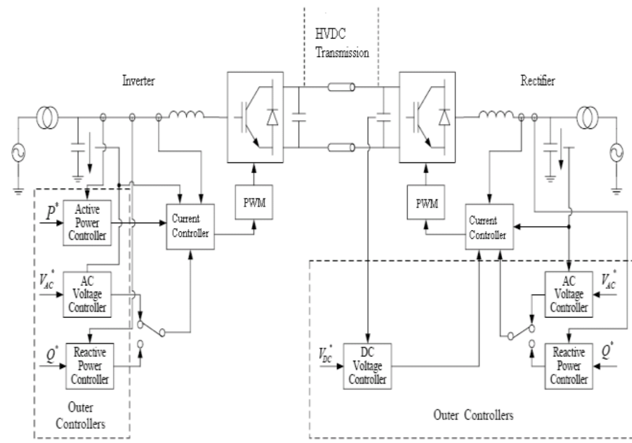


Fig 3 Overall control system of the VSC-based HVDC

4.0 SIMULATION RESULTS

The performance of the proposed inverter control strategy is evaluated by simulation using the PSCAD/EMTDC simulation software. Simulations were carried out to investigate the effectiveness of the VSC-HVDC control scheme in managing power. Simulation results are presented for the performance of the transients in DC Voltage, change in reactive power, change in active power load and unbalance fault conditions.

A. Performance of Transients in DC Voltage

For simulating the transients in dc voltage, the operating dc voltage was first set to 1.0pu. At t=0.3sec, the dc voltage reference is increased to 1.5pu and again reduced back to 1.0pu at t=0.6sec. The waveforms of dc voltage, active and reactive power at both terminals. The receiving end converter is controlled for a constant active power, so behaving as a constant power load. Reactive powers at both ends are set to be zero in this case.

It can be observed from the response of Fig. 4 that change in dc voltage reference requires a change of current to maintain an active power balance. Hence we can see a change in load current maintaining the active power almost constant. However the change in references gives some transients in the active power as well, which is reflected in the d-component of current. It can be seen that the effect of transient is not present in the reactive power or q-component of current. Hence the decoupled control of active and reactive power is also ensured. The PI controller performs well in tracking the reference input.

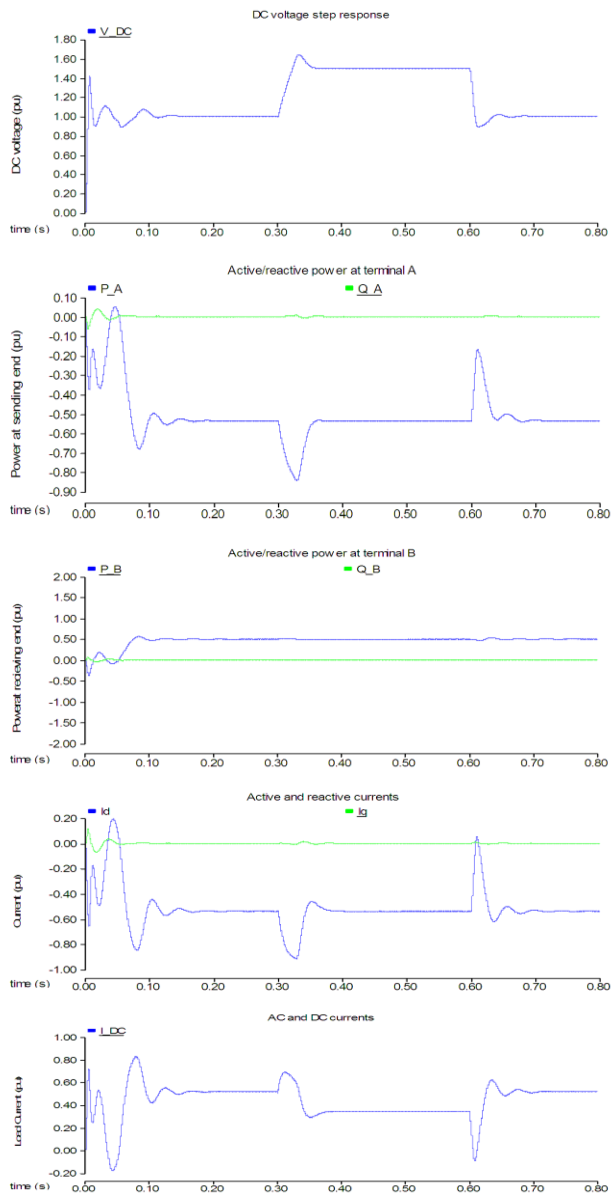


Fig. 4 Transient response for direct voltage reference changes

B. Performance of Change in Reactive Power

The dc voltage reference value is held at 1.0pu. The system is initially operating with a reactive power reference of 0.4pu and active power reference of 0.5pu. At t = 0.3sec, the reactive power reference is reversed to 0.4pu at the sending end whereas the reference at the receiving end is retained at constant 0.4pu. The responses of the system are shown in Fig. 5.

It is seen that the system works well even in case of change of direction of reactive power flow. There is a very small ripple in dc voltage during the transient in reactive power, which is again reflected in the d-current reference. The active power is maintained at the reference value constantly, and hence is the load current seen from the sending end. The change in reactive power is reflected in the change of q-component of current, whereas the d-component remains constant, showing the decoupling of the d and q axis components.

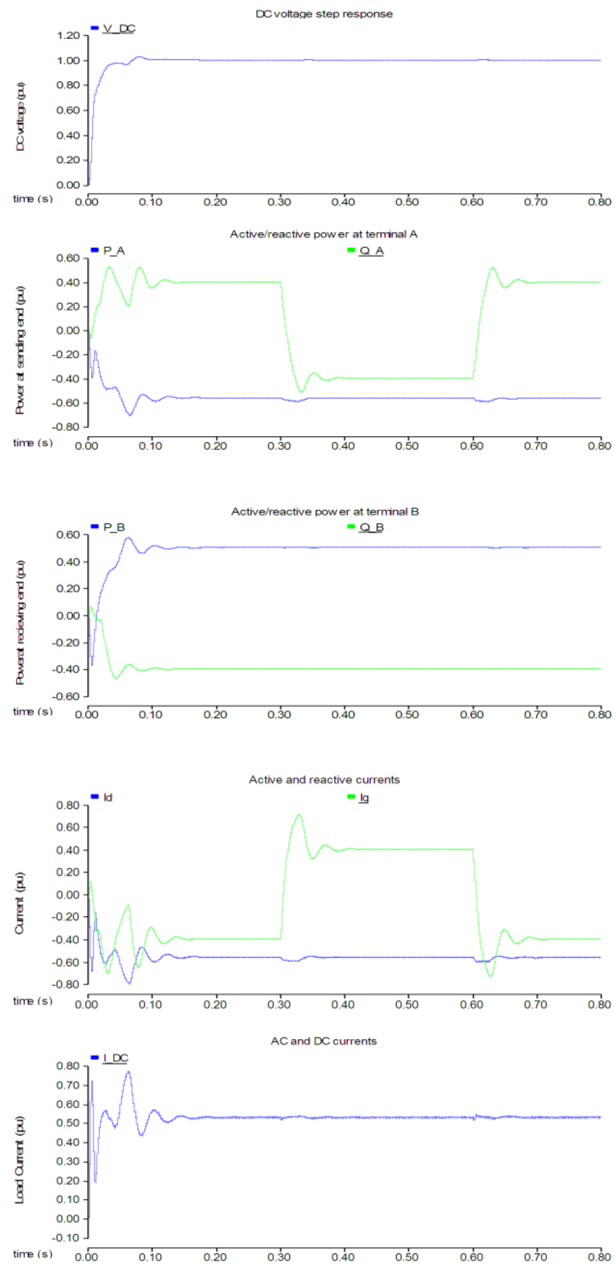


Fig. 5 Transient response for change in direction of reactive power at VSC-1.

C. Performance of Change in active power load

The dc voltage reference set at 1.0pu, the reactive power references set at 0.2pu and active power reference set at 0.5pu. The load at receiving end is changed from 0.5pu to -0.5pu. From the responses plot in Fig. 6, the system works stably with the reversal of active power as well. The change in active power is reflected in d-component of current and the load current magnitude and direction. Because of the decoupling, almost no effect is observed in the control of reactive power. The step change causes transients in dc voltage, but, the step change in active power causes a much higher transient than that with the change in reactive power.

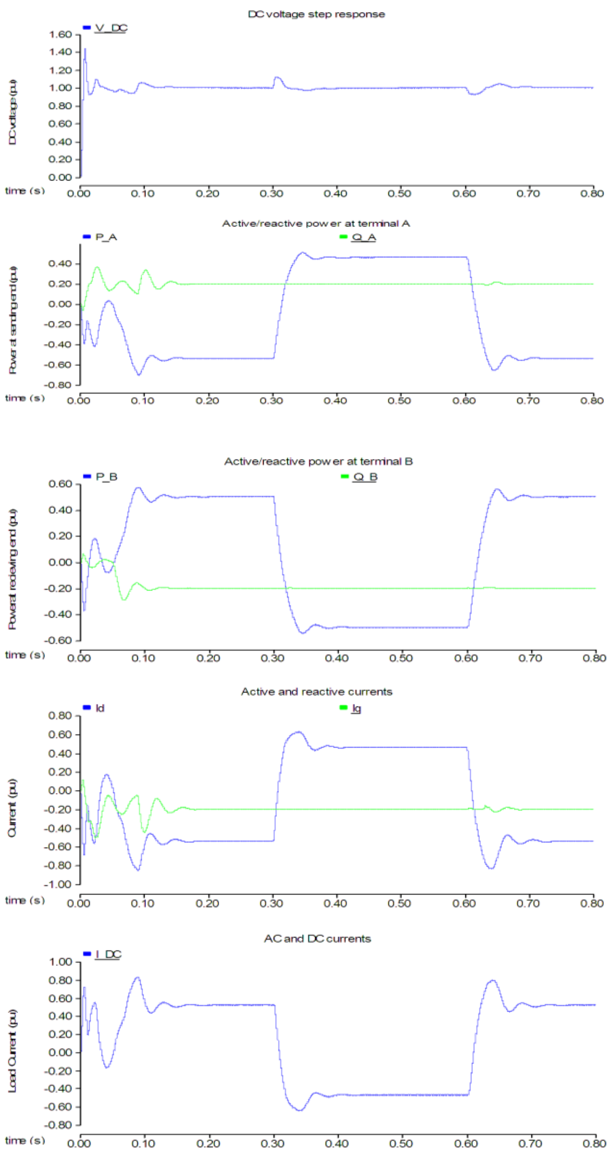
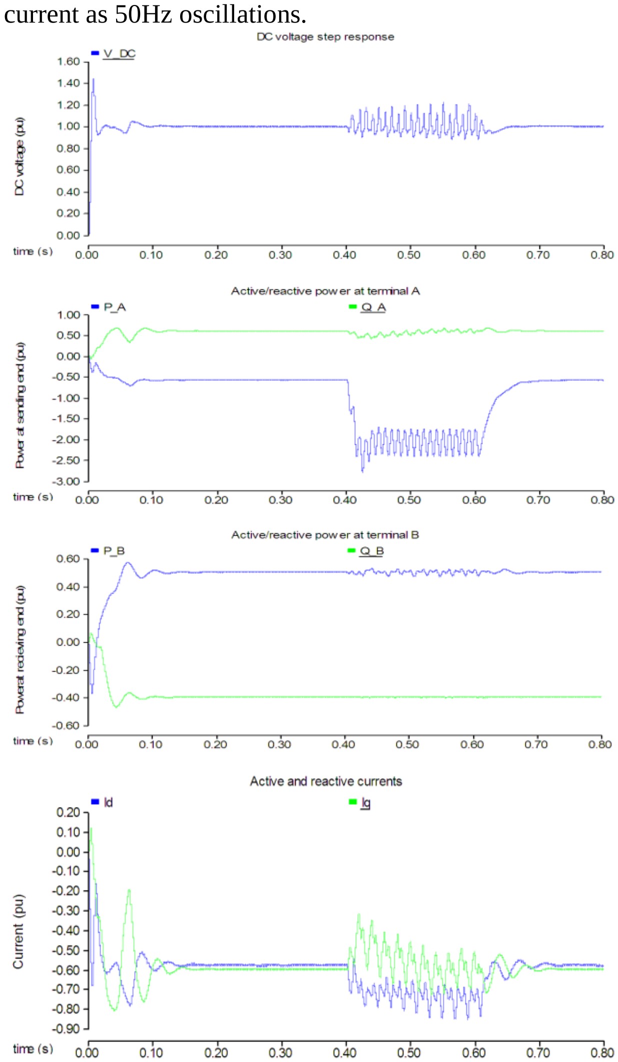


Fig. 6 Transient response for change in direction of active power at VSC-2

D. Performance of unbalance fault conditions

An unbalance fault is considered at the sending end of the HVDC link. The system is in balance condition with reference dc voltage at 1.0pu, reactive power references at 0.4pu and active power reference at 0.5pu. Unbalance fault is simulated through solid single line to ground fault near VSC1 at t = 0.4. After 0.2sec, the fault is removed and the system is back to normal operating conditions.

The response of the system under unbalance fault is shown in Fig. 7. It is seen that under unbalance conditions, the control scheme produces distorted currents and the distortion of the dc voltage increases as well. During the fault, the ripples of double the system frequency (100Hz) appear at the dc voltage and there is a significant increase in reactive power. The d and q components of currents are also oscillating at 100Hz and no longer are decoupled constant dc quantities. The oscillation appears in dc load current as 50Hz oscillations.



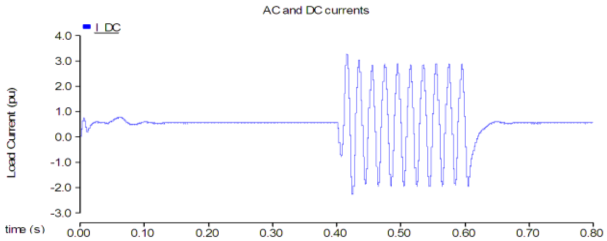


Fig. 7 Transient response for single phase to ground fault at VSC-1

5.0 CONCLUSION

A model of a VSC-HVDC system is presented in this paper. The control strategy is described and implemented in PSCAD/EMTDC. Tuning rules for the converter controllers have been established and tested through simulations. The control system of the VSC-HVDC is based on a fast inner current control loop controlling the ac current in combination with a number of outer controllers. Based on the mathematical model of three phase VSC in synchronous reference frame, transfer function of inner and outer control loop is formed. From the simulation results, it is concluded that the system response is fast; control accuracy can be achieved; and that the active power and the reactive power can be controlled independently and bi-directionally. It shows a very stiff DC link control which proves the robustness of the controller, but fast transient variations of the operating point of the converter will cause transients in the dc voltage. The current controller shows poor performance under unbalanced conditions. Further investigations of the control strategy and tuning rules are necessary for improvements in the controller performance.

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