International Journal of Applied Power Engineering (IJAPE)
Vol.7, No.1, April 2018, pp. 59~64
ISSN: 2252-8792 DOI: 10.11591/ijape.v7.i1.pp59-64

Vector Control of VSC HVDC System under Single Line to Ground Fault Condition

Prabodha Kumar Rath, Kanhu Charan Bhuyan
Faculty in Electrical Engineering Department, CET, BBSR, India

Article Info

Article history:

Received Sep 6, 2017
Revised Jan 9, 2018
Accepted Feb 27, 2018

Keyword.

Inner loops controller
Outer loops controller
Vector control
VSC HVDC

ABSTRACT

This paper proposes a model of a VSC (voltage source converter) based back to back HVDC system and its control technique under fault condition. From the mathematical model of the system relationship between the controlling and the controlled variables is determined to control the system parameters. An appropriate vector control technique is used to control active and reactive power and to maintain DC link voltage. The proposed controlling unit consists of outer control loop and inner control loop which effectively damped out the system oscillation and maintains the system stability. The validity of the model and the feasibility of the control method have been proved by the simulation results. In this paper the system performance is studied under fault condition is studied.

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Corresponding Author:

Prabodha Kumar Rath
Faculty in Electrical Engineering Department,
Collage Engineering Trivandrum,
BBSR, India.
Email: prabodharath85@gmail.com

1. INTRODUCTION

The generation of electric power increases day by day to meet the demand of fast developing society. So to meet the increasing global power demand we have to focus on the R & D of new technologies for bulk power transmission with improved reliability and controllability. For last many years and so the high voltage direct current (HVDC) technology has been in operation and has been gaining in importance within the existing power grids as HVDC has more advantages in comparison to conventional AC transmission [1-3]. To have better controllability we use voltage source converter (VSC) based HVDC. The VSC based HVDC system is a relatively new technology in Electrical science. VSC based HVDC can be used for low and medium power transmission which can be connected to weak or even passive AC networks and depending on the system operating conditions it is capable of supplying or absorbing reactive power [4-7]. VSC-HVDC may be used to supply passive loads without local generation and can connect islanded loads or even passive AC systems. In this paper a single line to ground fault is created on converter I side and vector control method is use to control the active power, DC link voltage efficiently [3], [8-10]. The paper is organized as follows:

Section I provides an introduction to the topologies of VSC and the operating principle. A single line diagram of the VSC HVDC system is provided with detailed explanation of each element associated with the system.
Section II provides the operating principle of VSC HVDC.
Section III presents the vector control method for VSC HVDC.
Section IV presents the modeling of VSC HVDC system.
Section V provides the simulation results of the proposed system. A single line to ground fault is established and operational performance and stability of the system is studied.

2. COMPONENTS OF VSC HVDC SYSTEM

The Figure 1 shows the single line diagram of a VSC HVDC system. In the figure it is shown that two AC networks of same operating frequency are interconnected for power transmission. The VSC HVDC system consists of equipment such as C type high pass filters, converter transformers, reactors, VSCs and their control systems, three level DC capacitors and DC lines. Description of some important components of VSC HVDC system and there functions are given in the following subsection.

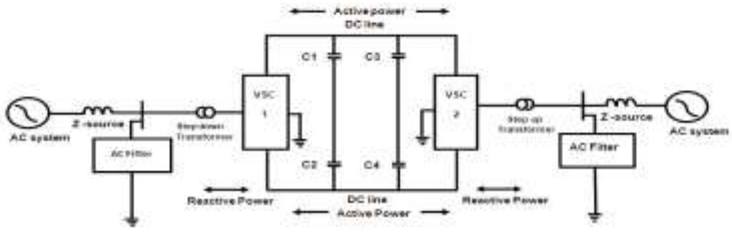

Figure 1. Block diagram of VSC HVDC system

2.1. Voltage source converter (VSI)

The key building units of HVDC transmission is the converters. Power electronic switches are used to made converters. Voltage Source Converter (VSC) is used in this paper. The voltage source converter is constructed with self-commutated Insulated Gate Bipolar Transistor (IGBT). VSC technology can control both active and reactive power independently and efficiently and the reactive power can be controlled at each terminal of the converters independent of the DC transmission voltage level. As there is no restriction on minimum network short circuit capacity there is freedom of placing the converters anywhere in the ac network. The transient support of the AC voltage at the converters terminal improve the voltage stability and also improve the transfer capability of the sending- and receiving-end AC systems, thereby improves the transfer capability of the DC link. Unlike conventional HVDC transmission, the converters themselves have no reactive power demand and can actually control their reactive power to regulate AC system voltage.

2.2. DC-capacitors

As shown in Figure 1, two series connected DC capacitors of same size are employed across the DC terminals of converter. Depending on the required DC voltage level and the acceptable DC ripple the size of the capacitor decided. For the generation of sinusoidal voltages on AC side of the converter the DC voltage should be adequate. The PWM switching of high-frequency switches generates the harmonics in the DC current flowing in the transmission line which generates the harmonics in the DC voltage which is strongly related to the converter AC voltage. By calculating the magnitude of ripple and the switching frequency of the semiconductor switches, the DC side capacitor ratings finalized.

2.3. Shunt C-type high pass filters

In power system to decrease the distortion in voltage and to correct the power factor three phase harmonic filters having shunt capacitor are used because of at fundamental frequency harmonic filter provides reactive power support. Due to function of nonlinear high power, high switching power electronic converters harmonic currents or harmonic voltages are generated, which are injected into power system. The order of harmonics generated is directly related to the PWM switching frequency of the semi-conductor switches. Flow of distorted current through system impedance causes production of harmonic voltage distortion. Harmonic filter reduces the distortion by diverting harmonic currents in paths which having low impedance. At fundamental frequency harmonic filters are designed to operate as capacitor, so that they are also used for producing reactive power required by converters and for power factor correction. To avoid parallel resonances C-type high-pass filter is used, it filtered low order harmonics and keep zero losses at fundamental frequency.

2.4. PWM for voltage source converter (VSC)

To reduce the harmonics in the output voltage waveform Pulse-width modulation (PWM) is the most accepted switching method. In PWM the comparison between a fundamental frequency modulating waveform and a fixed carrier frequency triangular waveform generates the firing pulses which are given to

VSC. The magnitude and phase angle of the generated fundamental frequency component of the converter output AC voltage can be controlled by varying the magnitude and phase angle of the modulating waveform.

In this paper uni-polar sinusoidal PWM is used. In case of uni-polar sinusoidal PWM technique, two same phase fundamental frequency modulating waveforms with opposite polarity are compared with the high switching frequency triangular waveforms. The output voltage switches between +Vdc/2 and zero or between zero and –Vdc/2, for this reason, this type of PWM scheme is called a PWM with a uni-polar voltage switching.

3. OPERATING PRINCIPLE OF VSC-HVDC

As shown in Figure1, the converter transformer which is connecting to AC network and voltage source converter can be modeled as an equivalent series resistance and reactance, but here the resistance is very small compared to the reactance so in power calculations resistance can be neglected. The active power flow in the transmission line depends on the phase shift between voltages of both sides which is due to transformer reactance. The voltage at sending end at AC bus is considered as a reference so the converter output AC voltage has phase shift with respect to the bus voltage. The magnitude and phase angle of converter output AC voltage is controlled by the VSC control system. The active and reactive power flow between the AC system and the converter depends on the magnitude of the voltages at both sides of the transformer, the transformer reactance and the phase angle between them. The active and reactive power flow between AC bus and converter AC terminals can be expressed as follows:

The active power at sending end and receiving end is given by

$$P_1 = \frac{|V_{S1}| \times |V_{C1}| \times \sin \delta_1}{X_{T1}} \tag{1}$$

$$P_2 = \frac{|V_{S2}| \times |V_{C2}| \times \sin \delta_2}{X_{T2}} \tag{2}$$

$$Q_1 = \frac{|V_{S1}|^2}{X_{T1}} - \frac{|V_{S1}| \times |V_{C1}| \times \cos\delta_1}{X_{T1}} \tag{3}$$

$$Q_2 = \frac{|V_{S2}| \times |V_{C2}| \times \cos\delta_2}{X_{T2}} - \frac{|V_{S2}|^2}{X_{T2}} \tag{4}$$

Here, P1 –VSC1 side active power, P2- VSC2 side active power, Q1- VSC1 side reactive power, Q2- VSC2 side reactive power, VS1,VC1- VSC1 side bus voltage, VS2,VC2- VSC2 side bus voltage, XT- Transformer reactance, δ1- Load angle in VSC1 side, δ2- Load angle in VSC2 side.

The amplitude, phase angle and frequency of fundamental component of converter output AC voltage VC1 and VC2 are controlled using the SPWM technique. If the voltage at the DC side of the converter is VDC which is assumed to be constant then the fundamental frequency component of converter output AC voltage can be derived from the following equation.

$$V_C(t) = V_{DC} M_i \sin(\omega t + \delta) \tag{5}$$

Here, VDC- voltage on DC side, ω - angular frequency, Mi -modulation index and δ - phase angle between the converter output AC voltage and the AC bus voltage.

4. CONTROL SCHEME OF VSC HVDC SYSTEM

In this paper, vector control method is used to control the active power, reactive power and DC- link voltage. The vector control consists of the inner control loop and the outer control loop. The outer control loop includes the DC voltage controller, the AC voltage controller, the active power controller, the reactive power controller. Here, vector control method is used for better control of the parameters. Active power and reactive power controlled quantities of VSC-HVDC are coupled to each other in such a manner that any change in one of the quantity affects the other and by using the vector control method the coupling between these quantities can be removed so that we have an independent control of each quantity. The vector control strategy consists of a cascade control system with faster inner controllers. The vector controller is accomplished by additional outer current controller which provides the reference values for inner controller. The outer controllers include active power controller, reactive power controller, AC voltage controller, DC voltage controller.

5. MODELING OF VSC HVDC SYSTEM

The power system components such as transformers, filters, VSC, DC capacitors and DC overhead cables are integrated in VSC HVDC model.

5.1. Modeling of AC networks

Two, 230 kV (RMS phase-phase), 100 MVA AC networks are connected through a VSC HVDC link. The weak AC systems connected here are balanced 3-phase sources at a fixed frequency of 50 Hz.

5.2. Modeling of converter transformer

The converter transformer works as a necessary element for power transfer between AC and DC systems. The transformer configuration used in the Simulink model is a Star ground- Delta which avoids the phase shifting between primary and secondary voltages. The rating of the converter transformer is 115 MVA, 230 KV primary voltage and 49 KV secondary voltage, 50 Hz.

5.3. Control system modeling

The controller comprises of measurement devices by which various parameters are measured including voltage, current, active power, reactive power, DC voltage and DC current at both ends of the DC system. In VSC HVDC model four different controllers, two at each end of VSC HVDC link are implemented. The inner current control blocks which provides the reference voltage to the outer control blocks.

5.3.1. Active power control

The active power control block consists of outer and inner current control loops. Active power reference is compared with the measured active power of the AC system and the resultant error is passed through a PI controller. The d-component of current controls the active power flow in the system so the output of the PI controller is a reference current (Id*_R). This reference current is compared with the d-component of actual AC system current (Id_R) and the generated error gives the voltage after passing through PI-controller. According to the vector control strategy this voltage is compared with system voltage (Vd_R) and cross coupling term to get the required controller output. The output of inner current control loop is a voltage component Vd*_R as shown in Figure 2.

5.3.2. Reactive power control

The reactive power controller consists of outer and inner current control loops. The q-component of the current controls the reactive power flow in the system. In the outer current control loop, reactive power reference is compared with the measured reactive power. The error is than passed through the PI-controller which gives output in the form of reference current (Iq*_R) for inner current control loop. This reference current is compared with the q-component of actual AC system current (Iq_R) and the generated error gives the voltage after passing through PI-controller. According to the vector control strategy, this voltage is compared with system voltage (Vq_R) and cross coupling term to get the required controller output. The output of inner current control loop is a voltage components Vq*_R as shown in Figure 2.

Now Vd*_R and Vq*_R is use to control the switching action of converter in the rectifier side of the VSC HVDC system.

Similarly Vd*_I and Vq*_I obtained to control the switching action of the converter on inverter side of the VSC HVDC system.

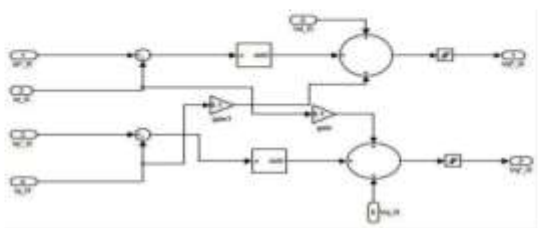

Figure 2. VSC 1 Side Inner Current Control Block Of Proposed VSC HVDC Model

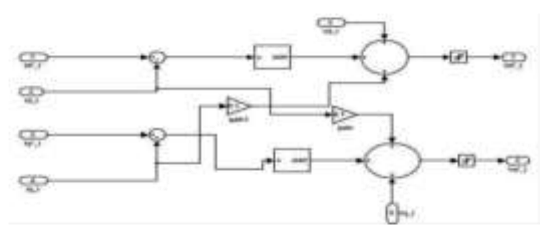

Figure 3. VSC 2 Side Inner Current Control Block Of Proposed VSC HVDC Model

6. SIMULATION RESULTS

In the Simulink model of VSC-HVDC system, its control system use sinusoidal PWM method of frequency 1.35 KHz, the model is simulated with a time of 7.406µs. By using a small time step it is possible to observe the system performance in detail during single line to ground fault condition. The following Table 1 presents VSC HVDC parameters system and their ratings.

Table 1. Simulation Parameters of VSC-HVDC Simulation Model

Parameters	Rating
System Power Level	100 MVA
Frequency	50 Hz
Converter Transformer Primary voltage	230 Kv
Converter Transformer Secondary voltage	49 kV
DC Voltage	± 40 kV
Switching Frequency of PWM	1350 Hz
AC Filter Rating	60 MVAR

Single line to ground fault created at high voltage side of transformer on the converter-1 side and the system responses are studied. A L-G fault is created in phase A at 0.3 sec for 0.1 sec i.e. for 5 cycles at high voltage side transformer on converter-1 side. Due to single line to ground fault the phase A voltage is 0 from 0.3 sec to 0.4 sec and during this fault time the phase current increases beyond its nominal value. We have distortion in the DC link current and DC link voltage. From the Figure 4 it is clear that after the removal of the fault the DC link current come back to its steady state value within .08 sec i.e. within 4 cycles. As shown in Figure 5 the DC link voltage reaches its steady state value within 0.08 sec (4 cycles).

The DC link power from converter I side to converter II side at 0.3 sec due to fault fluctuates and after the fault clearance the power reaches its reference value of 0.45 pu and it is shown in the Figure 6. The DC link power from converter II side to converter I side at 0.3 sec due to fault fluctuates and after the fault clearance the power reaches its reference value of -0.45 pu and it is shown in the Figure 7.

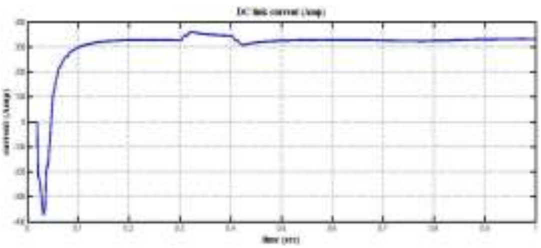

Figure 4. DC link current (Amp)

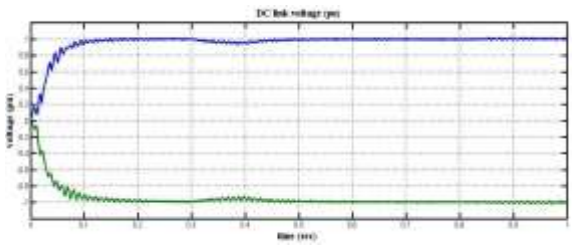

Figure 5. DC link voltage (pu)

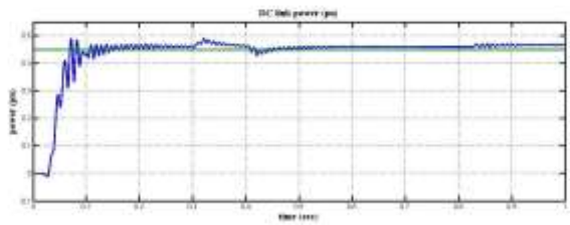

Figure 6. DC link power (pu)

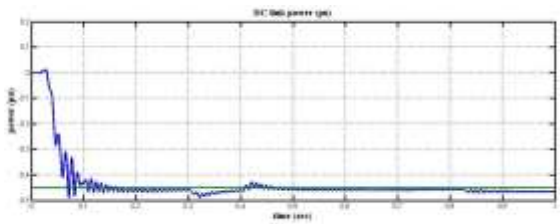

Figure 7. DC link power (pu)

7. CONCLUSIONS

Due to improvement of VSC technology its application in power system increases. Integrating SPWM in VSC to control its switching and integrating vector control in VSC HVDC system to control the active power, reactive power and DC link voltage power transmission is done effectively between two AC grid in fault condition.

The results show that the system response is fast, high quality AC voltages and currents can be obtained, and the active and reactive power can be controlled effectively under fault condition. During single line to ground fault at converter-1 side AC filter buses, DC voltage drops and shows some oscillation and reaches steady state value after clearance of fault.

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BIOGRAPHIES OF AUTHORS

Prabodha Kumar Rath received the M.Tech degree from S 'O' A university, Odishain Power System & Power Electronics in 2014. He is working as contractual faculty at College of Engineering and Technology; Bhubaneswar. His research interests include converters design and renewable energy system.

Dr. Kanhu Charan Bhuyan received the M.Tech degree from IIT, Delhi, India and the Ph.D degree from NIT, Rourkela. He is working as an Assistant Professor at College of Engineering and Technology; Bhubaneswar .His research interests are Control System, Fuel cell, Solar cell, wind energy, grid interfacing renewable energy. He has also interest in control schemes for DC-DC converter and DC-AC inverter.