Modeling, Control and Steady State Analysis of Back To Back VSC HVDC System

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Abstract— *This paper proposes a dynamic model of a VSC (voltage source converter) based Back to Back HVDC system and its control technique. From the system model, the corresponding relationship between the controlling and the controlled variables of the VSC is determined. The vector control technique is used to control the working of converters. The control structure consists of outer control loop and inner control loop. The outer loop controller controls the active and reactive power separately. The inner loop controller which is a fast working controller provides the reference d- axis and q- axis voltages which are required by the PWM for generating the triggering pulse. 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 steady state condition.*

Keywords— Inner loops Controller, outer loops Controller, Vector Control, VSC HVDC.

I. INTRODUCTION

Due to advancement of high power switching devices VSC HVDC system outperform the CSC HVDC system. VSC HVDC transmission system, a newly developed technology, is based on VSC technology. The VSC HVDC is capable of supplying power to both active and passive electrical systems operating conditions it is capable of supplying or absorbing reactive power [6, 7 and 8]. Using VSC and PWM makes possible fast and better control of power flow. And also mitigates harmonics in AC current and AC voltage effectively and improves power factors of the connected AC systems. For construction of VSC fully controlled semiconductor switch is used (e.g. IGBTs). The switching of VSC HVDC is controlled by Pulse Width Modulation (PWM). In this paper, a brief analysis is conducted of the operation principles and control patterns of VSC HVDC.

The paper is organized as follows:

- **Section II** 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 III** provides the operating principle of VSC HVDC.
- **Section IV** presents the vector control method for VSC HVDC.
- **Section V** presents the modeling of VSC HVDC system.
- **Section VI** provides the simulation results of the proposed system. The steady-state condition is established and operational performance and stability of the system is studied.

II. COMPONENTS OF VSC HVDC SYSTEM

The single line diagram as shown in Fig. 1 is the representation of a VSC HVDC system which interconnects two AC networks of same operating frequency for power transmission. The system consists of many equipment such as shunt connected C type high pass filters, converter transformers, reactors, VSCs and their control systems, three level DC capacitors and DC lines. In the following subsection there is description of some important components of VSC HVDC system and there functions.

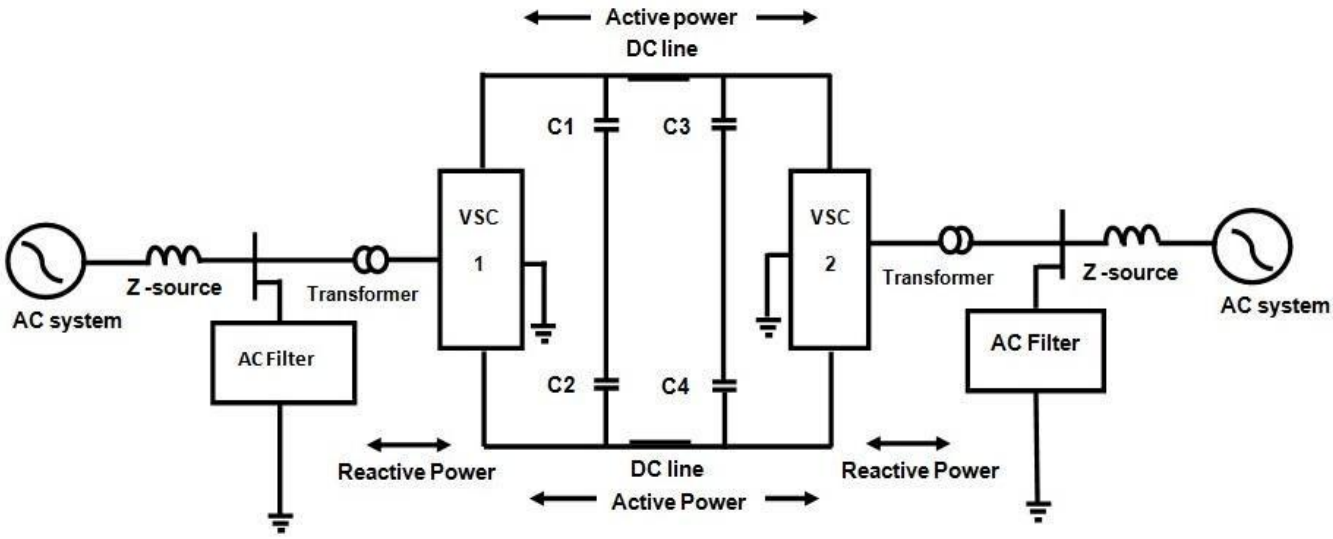

FIG. 1 BLOCK DIAGRAM OF VSC HVDC SYSTEM

2.1 Converters

Converters are the main building blocks of HVDC transmission. Converters are made up of power electronic switches. In this paper, voltage source converter (VSC) is used. The voltage source converter is equipped with self-commutated insulated gate bipolar transistor (IGBT). VSC technology can control active as well as reactive power without affecting each other. At each terminal of the converters, the reactive power can also be controlled independent of the dc transmission voltage. Unlike conventional HVDC transmission, the converters themselves have no reactive power demand and can actually control their reactive power to regulate ac system voltage just like a generator.

2.2 Shunt C Type High Pass Filters

Three phase harmonic filters having shunt capacitor are used in power system to decrease the distortion in voltage and to correct the power factor as at fundamental frequency harmonic filter provides reactive power support. Harmonic currents or harmonic voltages are generated by nonlinear power electronic converters, which are injected into power system and the order of harmonics generated is directly related to the PWM switching frequency of the semi-conductor switches. The current which is distorted produces harmonic voltage distortion when flow through system impedance. The distortion is reduced by harmonic filter by diverting harmonic currents in paths which having low impedance. Harmonic filters are designed in such way that they behave as capacitor at fundamental frequency, 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.

2.3 Three Level DC Capacitor Station

In VSC HVDC system two series connected three level DC capacitor station are employed across the DC terminals of converter with grounded midpoint. The PWM switching of high-power high-frequency switches generates the harmonics in the DC current flows in the transmission line. This generates the harmonics in the DC voltage which is strongly related to the converter AC voltage. The value of DC capacitor used can be small which may result in a faster converter response. The energy stored in the capacitor is released during transients which will help to stabilize the power flow on the DC transmission system.

2.4 PWM for VSC

To reduce the harmonics in the output voltage waveform Pulse-width modulation (PWM) is the most accepted switching technique.PWM is the basis for control in power electronics. In this paper uni-polar sinusoidal PWM is used.

III. OPERATING PRINCIPLE OF VSC-HVDC

In VSC HVDC, by using vector control method the active and reactive power can be controlled independently. The reactive power is controlled in each converter by the required AC voltage. The active power flow is controlled by the DC voltage.

The active power at VSC1 end and VSC2 end is given by

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

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

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

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

Where

P_1 -VSC1 side active power,

P_2- VSC2 side active power,

Q_1- VSC1 side reactive power,

Q_2- VSC2 side reactive power,

V_{S1},V_{C1}- VSC1 side bus voltage,

V_{S2},V_{C2}- VSC2 side bus voltage,

X_T- Transformer reactance,

δ_1- Load angle in VSC1 side,

δ_2- Load angle in VSC2 side.

The amplitude, phase angle and frequency of fundamental component of converter output AC voltage V_{C1} and V_{C2} are controlled using the SPWM technique. If the voltage at the DC side of the converter is V_{DC} which is assumed to be constant then the fundamental frequency component of converter output AC voltage can be derived from the following equation

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

Where

V_{DC} - voltage on DC side,

ω - angular frequency,

M_i -modulation index and

δ - phase angle between the converter output AC voltage and the AC bus voltage.

IV. CONTROL OF VSC HVDC SYSTEM

The VSC HVDC control system is typically consists of a vector controller. The vector controller is 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. In this paper 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.

V. MODELING OF VSC HVDC SYSTEM

5.1 Power System Modeling

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

5.2 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.

5.3 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.

5.4 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 this 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 are shown in the following diagrams.

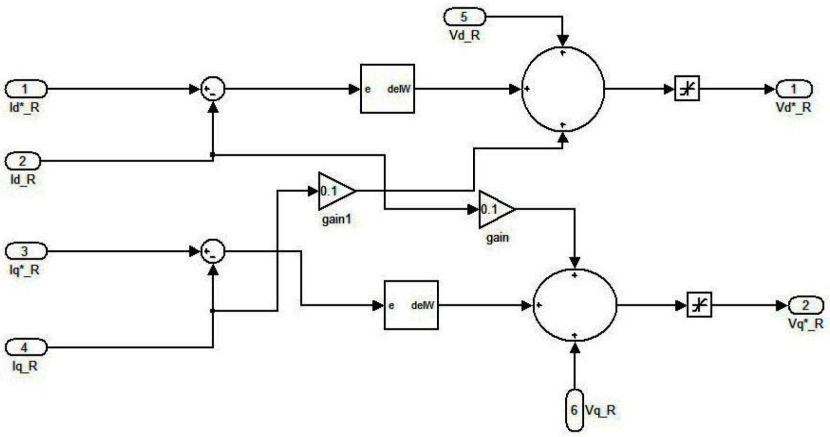

FIG. 2 VSC 1 SIDE INNER CURRENT CONTROL BLOCK OF PROPOSED VSC HVDC MODEL

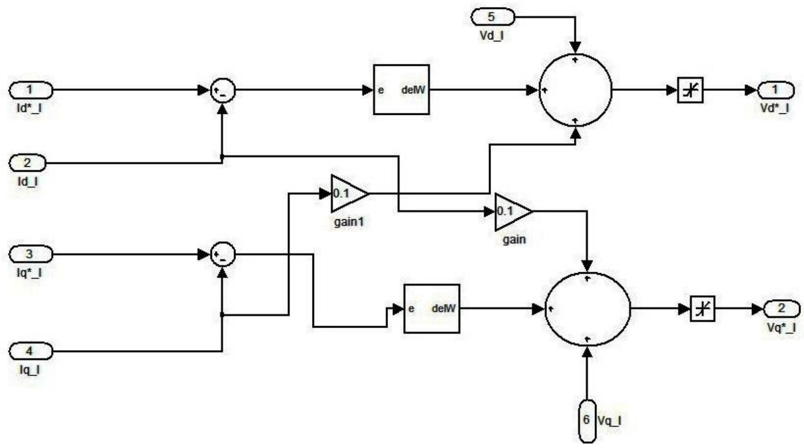

FIG. 3 VSC-2 SIDE INNER CURRENT CONTROL BLOCK OF PROPOSED VSC HVDC MODEL

VI. SIMULATION RESULTS AND ANALYSIS

In the Simulink model of VSC-HVDC system its control system use sinusoidal PWM method of frequency 1.35kHz, 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 system start-up, steady state conditions. The steady state operational performance assessment of the VSC HVDC system comprises of vector control technique is investigated by considering various operating conditions and reference values of system quantities.

In the operation the DC link voltage is maintained at 1 pu. There is a active power of 0.46 pu flows from VSC 1 side to VSC 2 side.

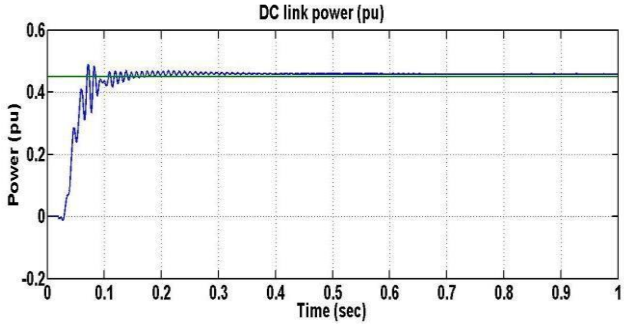

FIG. 4 0.46 pu ACTIVE POWER FLOW FROM VSC 1 TO VSC 2 SIDE

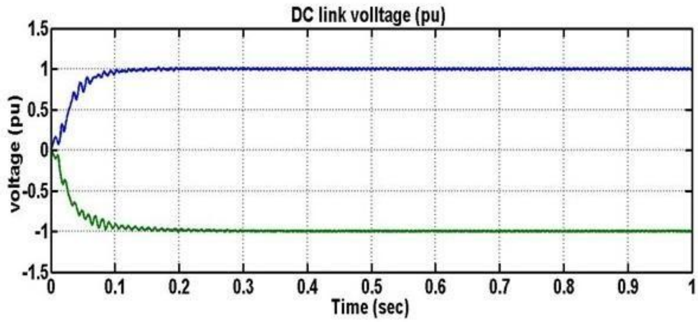

FIG. 5 DC VOLTAGE OF 1 pu IN DC LINK

From the Fig. 4 it is clear that the active power reaches its steady state value within 0.15 sec. Active power reach steady state value after initial negative and positive transients along the steady state value.

The Fig. 5 shows the voltage in pu between neutral and DC link and also it is clear from the above figure that the DC link reaches its reference voltage value within 0.15 sec.

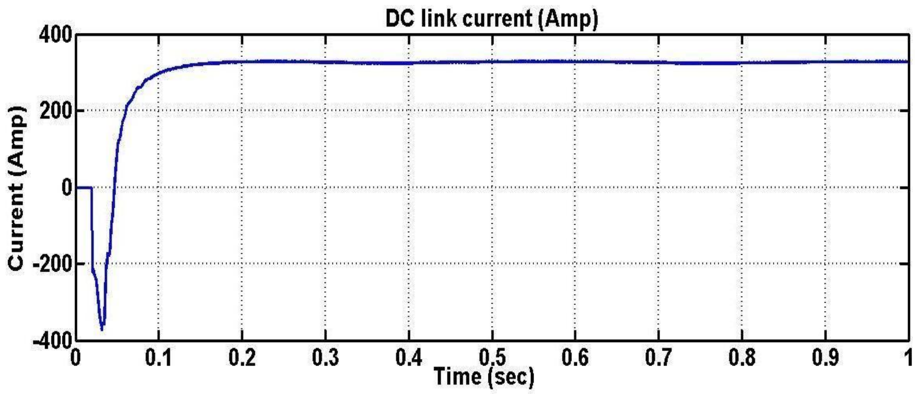

FIG. 6 DC LINK CURRENT

The Fig. 6 shows the current in the DC link and from the graph it is clear that the current reaches its steady state value of 326 amp within 0.15 sec.

VII. CONCLUSION

The development of VSC in last decade generated more research interest in its power system applications. The vector control method of the VSC HVDC is investigated and the performance is tested in steady state conditions. The vector control strategy which control active power, reactive power and DC voltage, are presented and evaluated for the VSC HVDC transmission system which connects two AC grids. From the results, it is concluded that the system is responding in a faster way, a better quality of AC parameters can be obtained and the reactive and active power can be controlled effectively. Vector control technique implements the feed forward closed loop control technique so that the coupling between electrical quantities is removed.

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