Steady State Fault Analysis of VSC- HVDC Transmission 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. Transient instability caused by a system faults overcome due to the fast power run back capability of the VSC-HVDC transmission. VSC-HVDC prevents the system from transient instability by its instant power reversal ability. The voltage support capability of VSC system helps to protect the system from voltage collapse, hence losing of synchronism can be avoided. The entire work has been done in MATLAB/SIMULINK environment.*

Key Words: **VSC, High voltage direct current (HVDC), Modeling, Simulation, Fault Analysis, IGBT, PWM.**

1.INTRODUCTION

High Voltage Direct Current (HVDC) transmission is the future trend in bulk power transmission .Growth of electrical demand in large power systems has been increasing at a faster rate than the expansion of transmission facilities.. The increasing stress on transmission systems is typically manifested by decreasing voltage stability margins in many regions around the world as was the case in the 2003 Italy blackout [1]. Bulk power transfer can be carried out over long distance by a high voltage direct current (HVDC) connection is cheaper than by an HVAC transmission line [2]. The increasing demand for electric power has emerged the integration of renewable energy sources and advanced transmission technologies high voltage direct current (HVDC). The first voltage source HVDC converter was commissioned in 1997, Hellsjon, Sweden [3].

The semiconductors used are insulated gate bipolar transistors (IGBTs), and the converters are voltage source converters (VSCs) which operate with high switching frequencies (1-2 kHz) utilizing pulse width modulation. The VSC-HVDC technology has a higher control capability when compared with the classic alternative, since it can independently control the active and the reactive power exchanged with the connected AC network. Voltage source converters (VSC) have gradually become one of the most attractive solutions for interconnections between AC and DC networks. VSCs have been widely used in many applications, such as integration of renewable energy generation, high voltage direct current (HVDC) transmission and back to back systems, integration of energy storage systems and railway traction systems [4].

There is an additional degree of freedom which make it possible to control the reactive power and the active power independently. Application of such dc links is expected to solve power-quality related problems in industrial power systems.VSC –HVDC back–to-back arrangement is used when two asynchronous AC systems need to be interconnected for bulk power transmission or for AC system stabilization reasons[4].This arrangement includes a link consist of a back to back voltage sourced converters (VSCs), a common DC link, which includes a large DC capacitors and DC cables. The control strategy is being designed to coordinate the active power control between two station which is realized by controlling the DC side voltage of one converter where other converter control the active power. Automatic control of power flow between stations is the result of a constant DC voltage source gives "slack bus". AC voltage control and reactive power control will switched as per the requirement.

The active power flow can be controlled by dc voltage or the variation of frequency of ac side or set manually. Thus, the active power flow, the reactive power flow, the ac voltage, the dc voltage and the frequency can be controlled independently using VSC – HVDC. The main requirement in a power transmission system is the precise control of active and reactive power flow to maintain the system voltage stability [4].

VSC- HVDC transmission technology has many features such as independent controllability for active and reactive power, commutation failure free, and available for passive system power supply. The electric power grid is experiencing increased needs for enhanced bulk power transmission capability, reliable integration of large scale renewable energy sources, and more flexible power flow controllability [5].The lower stability of power system for frequently and quickly load change may reduce the power system restoration speed in the restoration course using conventional pure AC transmission line path [6]. The capability of rapidly control both active and reactive power independent of each other allows VSC- HVDC to enhanced transient stability, increase damping of electromechanical oscillations and improve voltage stability [7].

Each converter station is composed of a VSC. The amplitude and phase angle of angle of the converter AC output voltage can be controlled simultaneously to achieve a rapid, independent control of active and reactive power in all four quadrants. The control of both active and reactive power is bidirectional and continuous across the operating range. For active power balance, one of the converters operates on constant active power control. When dc line power is zero, the converters can be considered as independent STATCOM [8].

The VSC applications include but are not limited to HVDC and flexible AC transmission system (FACTS) devices such as STATCOM, SSSC, UPFC, wind generators and active filters. The VSC based HVDC system is a feasible option for high power transmission over long or short distances and the grid integration of renewable energy sources in existing transmission and distribution systems [9].

2. COMPONENTS OF VSC HVDC SYSTEM

VSC-HVDC is a new dc transmission system technology. The converters can be connected in back to back configuration or at either end of a transmission line or cable as schematically shown in figure [1]. It is based on the voltage source converter, where the valves are built by IGBTs and PWM is used to create the desired voltage waveform.

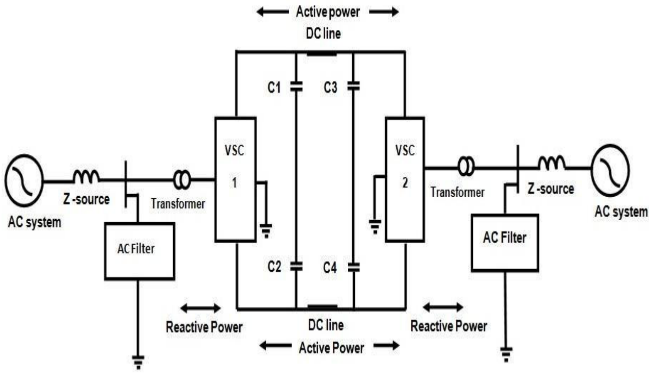

Fig. 1 Block diagram of VSC -HVDC system

2.1 Converters

Converters are made up of power electronic switches. Converters are the main building blocks of HVDC transmission. They perform the conversion from ac to dc (rectifier) at the sending end and from dc to ac (inverter) at the receiving end. HVDC converters are connected to the ac system by means of converter transformers. 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.

2.2 AC Filters

High-pass filter branches are installed to take care of the high order harmonics. With VSC converters there is no need to compensate any reactive power consumed by the converter itself and the current harmonics on the ac side are related directly to the PWM frequency. The amount of low-order harmonics in the current is small. Therefore the amount of filters in this type of converters is reduced dramatically compared with natural commutated converters.

2.3 DC Cables

The cable used in VSC-HVDC applications is a new developed type, where the insulation is made of an extruded polymer that is particularly resistant to dc voltage. Polymeric cables are the preferred choice for HVDC, mainly because of their mechanical strength, flexibility, and low weight.

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.

3. 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.

4. DYNAMIC MODELLING CASE STUDIES OF TWO-TERMINAL VSC- HVDC SYSTEM

To evaluate the effectiveness of the proposed control scheme, cases of Two-Terminal IGBT VSC-HVDC is developed in MATLAB. The power system simulator or

SimPowerSystem toolbox and Simulink are used for system modeling and simulation where VSC station 2 works in VQ control mode and VSC station 1 works in PQ control mode.

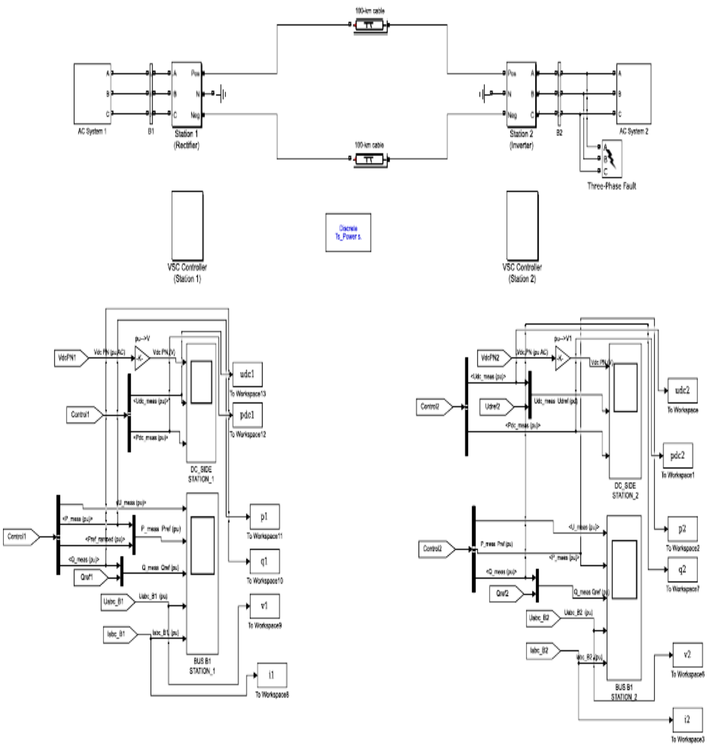

Fig. 2 Simulink model of the system

Case –I Start –Up and Steady State Responses of VSC-HVDC System

Fig. 3 -5 shows the start up and steady state responses of the VSC-HVDC system with reference commands $u_{dcref2} = 1$ p.u., $Q_{ref2} = -0.1$ p.u. for VSC 2 and reference commands $P_{ref1} = 1$ p.u., $Q_{ref1} = 0$ p.u. for VSC 1. Note that the DC capacitors have been charged to $\sqrt{2}U_s$ (U_s is the RMS value of the AC network line to line voltages) through the diode in the VSC before the start up of the VSCs. In order to prevent VSC-HVDC from overvoltage and over current during the start up, a ramp input P_{ref1} is given instead of step 1. VSC station 2 in VQ control mode will start at t=0 and VSC station 1 will start until the DC bus voltage reaches the 90 % of the DC base value. From simulation results in Fig 3-5 it can be seen that the VSC-HVDC system start softly and the output of the VSC station 1 exactly reach the set reference values in the steady state.

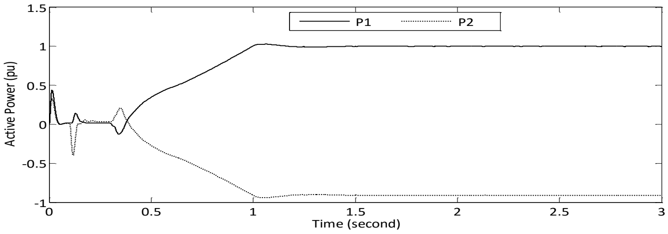

Fig. 3 Active power steady state and start-up response

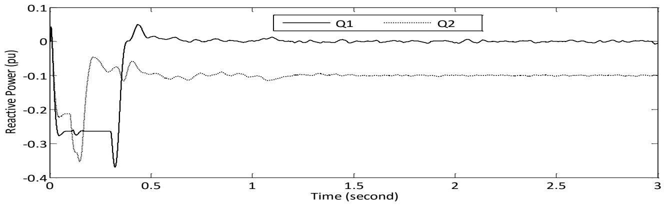

Fig. 4 Reactive power steady state and start-up response

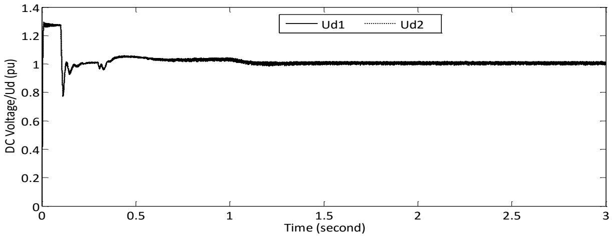

Fig. 5 DC Voltage steady state and start-up response

Case – II Active and Reactive Power Step Responses

Fig. 6 -8 shows the active and reactive power step responses. At the beginning active power is transmitted from VSC 1 to VSC 2. The reference active power P_{ref1} is reduced from 0.5 to -0.2 at the time t=1.5s, and it takes about 300 ms for the measured active power P_{meas1} at VSC 1 changes to -0.2. Correspondingly, the measured active power P_{meas2} at VSC 2 changes around from -0.4 p.u. to 0.21 p.u, at the same time active power reverses with the DC current direction change. There is the fluctuation in the reactive power Q1 and Q2 of the VSC 1 and VSC 2 at the time of step change. However they regain their steady state very quickly.

Obviously, the reactive power flow can be controlled at the each AC terminal and the reactive power and the active power control is independent. Notice that considering the loss in the transmission lines, the sending end active power equals the receiving end active power plus losses in the transmission lines.

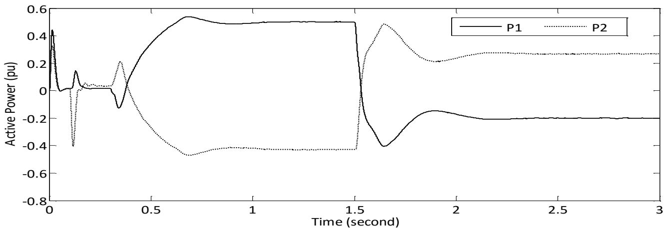

Fig. 6 Active power response as step changes

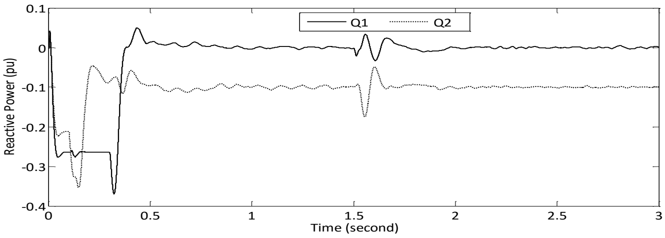

Fig .7 Reactive power response as step changes

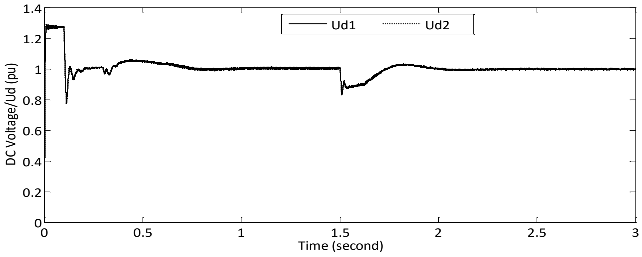

Fig .8 DC Voltage response as step changes

Case – III A Three Phase Voltage Sag at Station 1

Fig.9-13 shows a three phase voltage sag is applied at station 1 AC bus. The AC voltage sag with -0.1 p.u voltage amplitude is applied at the time between 1.3s and 1.65s. The result shows that the active and reactive power deviation which is shown in circle, from the first disturbance is less than 0.1 p.u and 0.2 p.u respectively. It takes about 100 ms to recover the steady state before the next perturbation initiation.

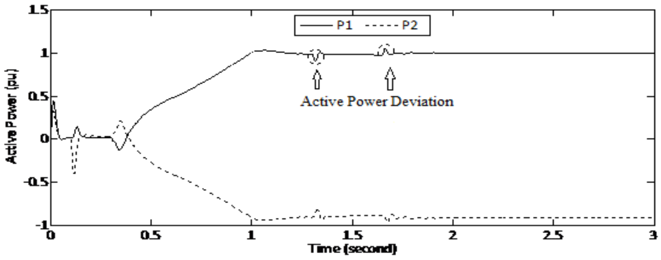

Fig .9 Active power response while voltage sag on AC bus 1 is applied.

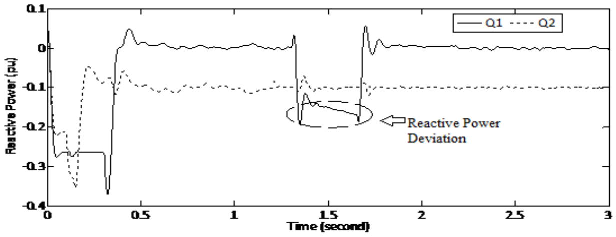

Fig.10 Reactive power response while voltage sag on AC bus 1 is applied.

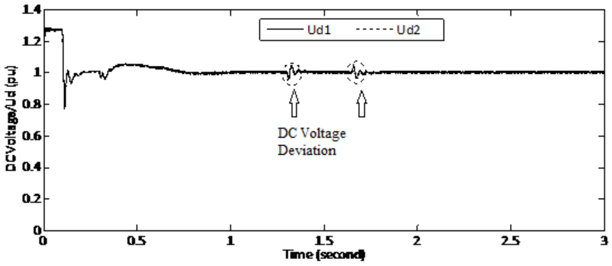

Fig .11 DC Voltage response while voltage sag on AC bus 1 is applied

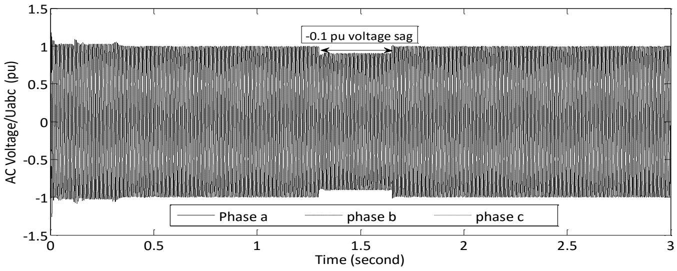

Fig .12 AC Voltage at station 1 when voltage sag is applied.

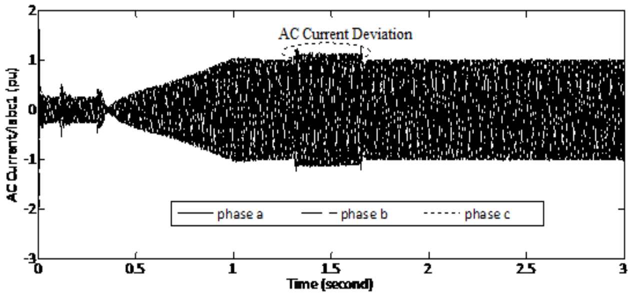

Fig .13 AC Current at station 1 when voltage sag is applied.

Case IV A Three Phase to Ground Fault at Station 2

Fig. 14-18 shows a three phase to ground fault is applied at station 2 AC bus. The fault is applied at t=1.5 s during 300 ms. Note that the during three phase fault, the transmitted power is almost zero. The system recovers well after the fault within 0.3 s.

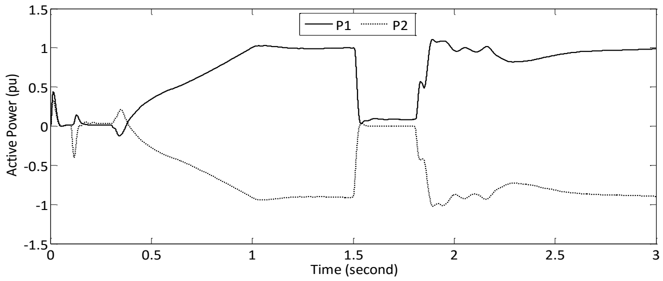

Fig .14 Active power response when three phase to ground fault applied at station 2

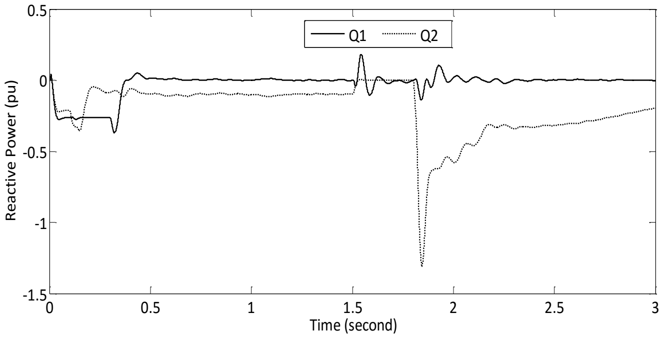

Fig .15 Reactive power response when three phase to ground fault applied at station 2

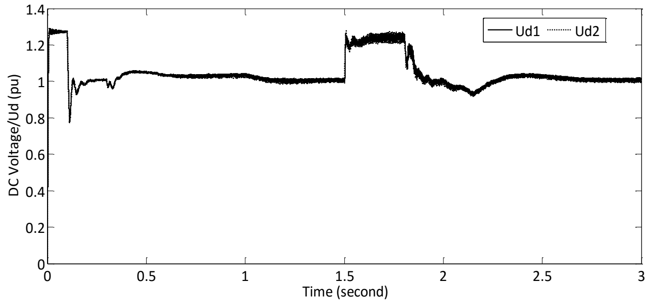

Fig .16 DC Voltage response when three phase to ground fault applied at station 2

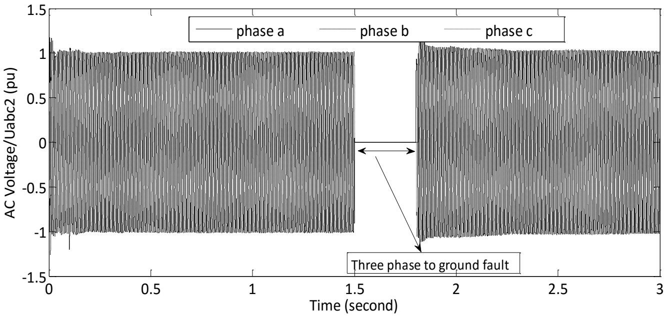

Fig .17 AC Voltage when three phase to ground fault applied at station 2.

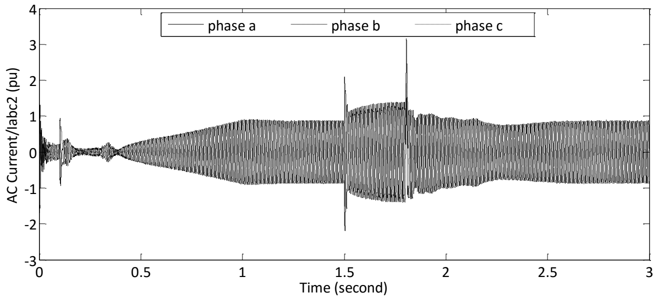

Fig .18 AC Current when three phase to ground fault applied at station 2.

5. CONCLUSIONS

(1) A steady state analysis of a VSC based HVDC system is derived, starting from the basic mathematical equations. The model consists of AC side equations, DC side equations and converter (AC-DC coupling) equations. Also the control systems are included in the model.
(2) The DC side equations have been generalized to multi-terminal HVDC systems for the topology, proposing a meshed DC system with every terminal consisting of one converter and with the possibility of connections within the DC system.
(3) Every terminal of the two-terminal HVDC system is defined on the type of station. The control parameters are tuned according to some predefined properties of the dynamic responses. Therefore, a linear control model is derived.
(4) The simulation results illustrate the fast system response and the influence of a change in the control references on different system variables.
(5) This thesis deals with the application of VSC-HVDC transmission for the improvement of power system stability. Simulation result reveals that faster, independent control of real and reactive power can greatly improve the stability of power system.
(6) Some application of VSC-HVDC like interconnection of asynchronous grids and benefits like black start capability, frequency support, and voltage regulation can be achieved. Voltage stability was improved and protect the system from voltage collapsing due to lake of reactive power.

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