CONTROL STRATEGY OF VSC-HVDC TRANSMISSION SYSTEMS

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ABSTRACT

Voltage Source Converter Based High Voltage Direct Current and Insulated Gate Bipolar Transistor is a Kind of HVDC Technology for power transmission in Long distance with high controllability operation modes. By using IGBT and PWM, this is more flexible than Classic HVDC. In this Paper, abrief overview of classic HVDC arepresentedand Topology of VSC-HVDC and Modeling aspects of that are expressed. Then, VSC-HVDC connecting two grids is studied as the Starting Point and this model is implemented in MATLAB program. Simulation results show that the performance of System under changing active and reactive power is perfect. Proper performance of the system for power flow improvement, ability to bidirectional power transmission, and independent control of active and reactive power are other results which are presented in this paper.

Key Words: *LCC-HVDC, TOPOLOGY ofHVDC, VSC-HVDC, PWM, GTO, IGBT.*

Introduction

HVDC transmission system used for stability, high power quality, low loss and also connecting networks with different frequency. LCC-HVDC Transmission system have few shortcoming, by using VSC-HVDC some of these fault are removed. Developments in high voltage and current self commutated insulator like GTO and IGBT based VSC, and use of polymeric cables make a good condition for VSC-HVDC in long distances. VSC-HVDC has some advantages compared with classic LCC-HVDC transmission system [1,2]

- Fast and independent control of active and reactive power.
- No communication between rectifier and inverter.
- Power flow control and capability to regulate voltage in the AC network by VSC.
- Each converter station is composed of a VSC. The amplitude and phase angle of the converter, AC output voltage can be controlled simultaneously.

For active power balance, one of the converters operates on constant DC voltage control and the other converter operates on constant active power control.

VSC as a double input and output control part has two inputs, phase angle(δ) and modulation factor(m) in PWM, and Two outputs ,active power(P) or DC Voltage and reactive power (Q)[3,4,5].By having a look on the researches that is brought in references and taking some key points, aVSC-HVDC systemis designed in MATLAB program and finallythe good results are acquired.In this section, the purposes and the performances of some of these researches will be explained.

For Example: In reference 1, power control strategy based on steady state in VSC-HVDC is suggested and this is studied by suitable conversion and variables substitution for active and reactive direct power control.In Reference 5, a VSC-HVDC system connecting two grids is studied and two different control strategies based on bidirectional power transmission are performed that is for industry.Reference 6, is an overview of power transmission systems and more over recent advances in this field have been conducted in different methods. In reference 8, discussion is about dynamic characteristics of the VSC-HVDC and at last a VSC-HVDC system is modeled. Table 1 shows the recent VSC-HVDC projects in the world[6].

Table 1: Recent VSC-HVDC Projects in the world

Semi-contactors	topology	Comments and reasons for choosing VSC-HVDC	Length of DC cables	DC voltage	AC voltage	Number of circuits	Power rating	Year of commission	Project name
IGBTs (series connected)	3-Level NPC	Controlled asynchronous connection for trading,Voltage control,Power exchange .	Back-to-Back HVDC Light Station	±15.9 KV	138KV (both sides)	1	36MW ±36MVAr	2000	Eagle Pass, USA
IGBTs (series connected)	2-Level	Wind Power, Demonstration Project. Normally synchronous AC grid With variable frequency control.	2× 4.3 Km Submarine	±9 KV	10.5 kV (both sides)	1	8MVA 7.2MW -3 to +4 MVAr	2000	Tjaereborg, Denmark
IGBTs (series connected)	2-Level	Length of land cable,sea crossing and non-synchronous AC systems.	2× 31 Km Underground 2× 74 Km Submarine	±150 KV	330KV - Estonia 400KV - Finland	1	350MW ±125 MVAr	2006	Estlink, Estonia-Finland
IGBTs (series connected)	2-Level	Offshore wind farm to shore.Length of land and sea cables.Asynchronous system.	2× 75 Km Underground 2× 128 Km Submarine	±150 KV	3800KV-Diele 170KV - Borkum2	1	400MW	2009	NORD E.ON1, Germany
IGBTs (series connected)	2-Level	Reduce cost and improve operation efficiency of the field.Minimize emission of green gases. gase	292Km Submarine Coaxial Cable	±150 KV	300KV -Lista 11KV-Valhall	1	78MW	2009	Valhall offshore ,Norway

Topology of HVDC

HVDC Converters together with lines or cables can be arranged in a number of configurationsas shown in fig.1 and fig.2. These topologies used based on controllability and reliability that each project required[5,6].

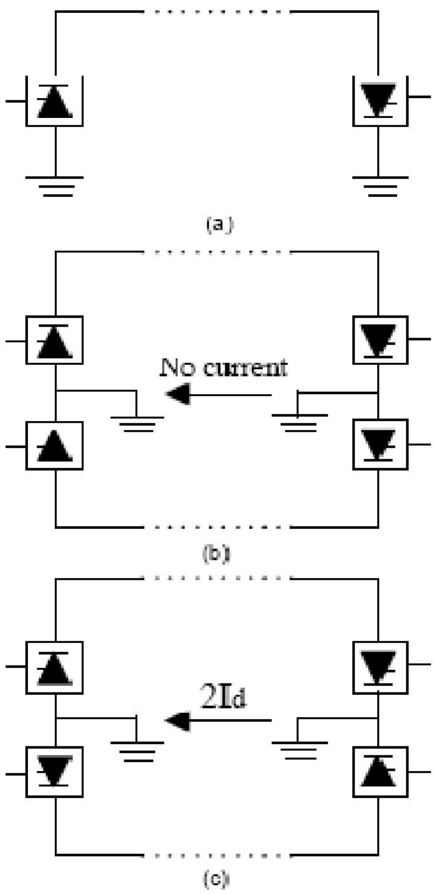

Figure.1: a)monopolar b) Bipolar c) Homopolar (HVDC system)

Monopolar system

In a monopolar system, two converters are connected by a single pole line and a DC voltage in negative or positive mode is operated on it.In Fig.1(a), a monopolar configuration is shown and the ground, sea and metallic return conductor may be used as the return path[5].

Bipolar system

The bipolar system uses two isolated conductors as positive and negative poles.Bipolar HVDC is the most commonly used transmission systems.A bipolar configuration is shown in Fig.1(b).Two poles can be operated independently. Under normal operation, the currents flowing in both poles are identical and there is no ground current while in case of failure of one pole, power transmission can be continued in the other pole which increases the reliability.

Homopolar system

In the homopolar system, two or more conductors have the negative polarityand can be operated with ground and a metallic return. This topology reduced the insulation costs. A homopolar configuration is shown in fig.1(c)

back-to-back system

In this configuration,two converter stations are located at the same side andtransmission line and cable is notneeded and more over this is used for connecting two asynchronous AC systems.A block diagram of a back-to-back system is shown in Fig.2(a).

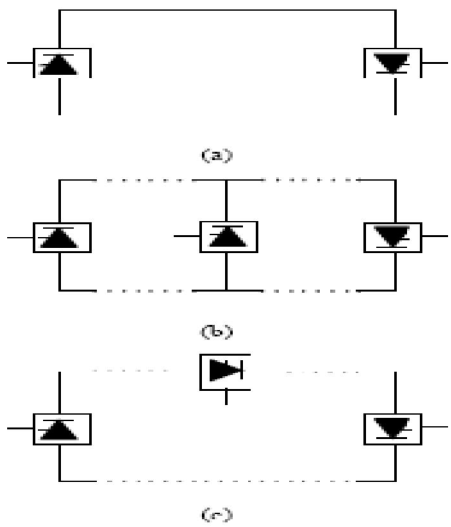

Figure. 2: a)Back to Back b) multiterminal in parallel c) multiterminal in series (HVDC systems)

Multiterminal system

In this topology, three or more HVDC converter stations are in different places and connected through cablesor transmission lines.The system can be parallel, where all converter stations are connected to the same voltage as shown in Fig2(b) or series multiterminal system, where one or more converter stations are connected in series in one or both poles as shown in Fig.2(c) [5,6].

VSC-HVDC and its components

The VSC-HVDC is a new DC transmission system.The new HVDC technology Known as (HVDC light) or (HVDC-Plus). A VSC-HVDC system consists of AC filters, transformers, Converters, phase reactors, DC capacitors and DC cables.A typical VSC-HVDC system, shown in Fig.3,[4,5].

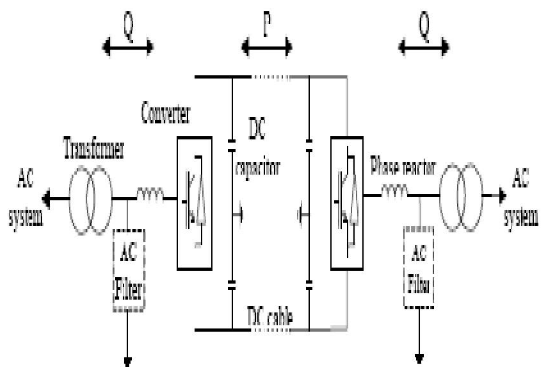

Figure. 3: VSC-HVDC system

Converters

VSCis the converter which uses IGBT(Insulated Gate bipolar Transistor)power semiconductors, one operating as a rectifier and the other as an inverter. Two converters are connected back-to -back or through a DC cable, depending on the application.

Transformer

Transformers are a connection between Theconverters and the AC system. These usually are used to convert the AC voltage of the system to desired level for converter.

Phase Reactors

The phase reactors are used for controlling both the active and the reactive power flow. The reactors can be operated as AC filtersto reduce the high frequency harmonic contents.

AC filters

To prevent incorrect function of AC system equipment, the harmonics have to be reduced so AC filters used for that.

DC Capacitors

On the DC side, there are two capacitors with the same size. DC capacitors are used to keep the power balance during transmission. Also, voltage ripple on the DC side is reduced by DC capacitor.

DC cables

Polymeric cables,a new developed type, are good choice for HVDC because they are resistant to DC voltage.Their mechanical strength, flexibility and low weight are other advantages of these cables.

Operation of VSC-HVDC

In a VSC-HVDC,each terminal considered as a voltage source converter while these terminals via series reactors are connecting to an AC network.

The converter is specified as a controlled voltage source u_v at the AC side and a controlled current source i_{DC} at the DC side.The controlled voltage source can be described by the following equation[5,7,8].

$$U_v = \frac{1}{2} u_{dc} m Sin(\omega t + \delta) + harmonicter. \quad (1)$$

In this equation,(m) is the modulation factor which is explained as the ratio of the peak value of the modulating wave to peak value of carrier wave, (ω) is the frequency , (δ) is the phase shift of the output voltage.

In a VSC-HVDC connection, the active power on AC side is equal to the active power transmitted from the DC side while Losses is neglected.

If one of two converters controls the active power while the other converter controls the DC voltage, The equality between Active power on AC side and power transmitted from DC side is demonstrated. Generation and Consumption of the reactive power can be used to control the AC voltage of the network.The active and reactive power are calculated according to following equations[9]:

$$P_{ac} = \frac{e_{ac} u_{ac}}{x_{ac}} \sin \delta_{ac} \quad (2)$$

$$Q_{ac} = \frac{e_{ac}^2}{X_{ac}} - \frac{e_{ac} u_{ac}}{x_{ac}} \cos \delta_{ac} \quad (3)$$

By considering to the equations (2), the active power flow between the AC system and the converter can be controlled by variation of the phase angle(δ) between the voltage generated by VSC and The AC voltage on transformer. In equation(3), the reactive power is determined by the u_{ac}.

VSC-HVDC Connecting two AC networks

The voltage and current relations of transformer at the network side are expressed as following equations: by(4) and (5).R_r,L_r , L_i,R_i are load resistance and inductance and i_r,i_i are currents in rectifier and inverter[5,9].

$$e_r^{abc} = R_r i_r^{abc} + L_r \frac{dir^{abc}}{dt_{abc}} + u_r^{abc} \quad (4)$$

$$e_i^{abc} = R_i i_i^{abc} + L_i \frac{di_i^{abc}}{dt} + u_i^{abc} \quad (5)$$

By acoording to the d-q version with assuming balanced operation of ac network ,voltage on the rectifier is given by:

$$\begin{bmatrix} e_r^a \\ e_r^b \\ e_r^c \end{bmatrix} = E_r \begin{bmatrix} \cos W_r t \\ \cos(w_r t - 120^\circ) \\ \cos(w_r t + 120^\circ) \end{bmatrix} \quad (6)$$

Similar equation exists for inverter side as well,while r replaced by i.equation(6) in d-q version is defined.

$$e_r^d = E_r, e_r^q = 0, e_i^d = E_i, e_i^q = 0 \quad (7)$$

The VSC-HVDC is Investigated and also the model in MATLAB Simulink implemented.Underneath, the block diagram of VSC-HVDC connecting two ac network is modeled through simulink power system in MATLAB software and shown inFig.4and based on control systems of rectifier and inverter, the simulationresults is represented.The Simulation results demonstrate that it has good stability and high control accuracy.

Power flow from network to either rectifier and inverter are positive as shown in figure1.By considering to instantaneous power , reactive power on rectifier and both real and reactive powers on inverter can be shown as[9]:

$$\begin{aligned} Q_r &= e_r^\beta i_r^\alpha - e_r^\alpha i_r^\beta \\ P_i &= e_i^\alpha i_i^\alpha + e_i^\beta i_i^\beta \\ Q_i &= e_i^\beta i_i^\alpha - e_i^\alpha i_i^\beta \end{aligned} \quad (8)$$

Modulation factor and the phase angle are estimated by equations below[9]:

$$\begin{aligned} M_i &= \frac{\sqrt{u_i^{\alpha^2} + u_i^{\beta^2}}}{V_{dci}/2} \\ M_r &= \frac{\sqrt{u_r^{\alpha^2} + u_r^{\beta^2}}}{V_{dcr}/2} \\ \delta_r &= \cos^{-1}\left[\frac{u_r^\alpha e_r^\alpha + u_r^\beta e_r^\beta}{\sqrt{u_r^{\alpha^2} + u_r^{\beta^2}} * \sqrt{e_r^{\alpha^2} + e_r^{\beta^2}}}\right] \\ \delta_i &= \cos^{-1}\left[\frac{u_i^\alpha e_i^\alpha + u_i^\beta e_i^\beta}{\sqrt{u_i^{\alpha^2} + u_i^{\beta^2}} * \sqrt{e_i^{\alpha^2} + e_i^{\beta^2}}}\right] \end{aligned} \quad (9)$$

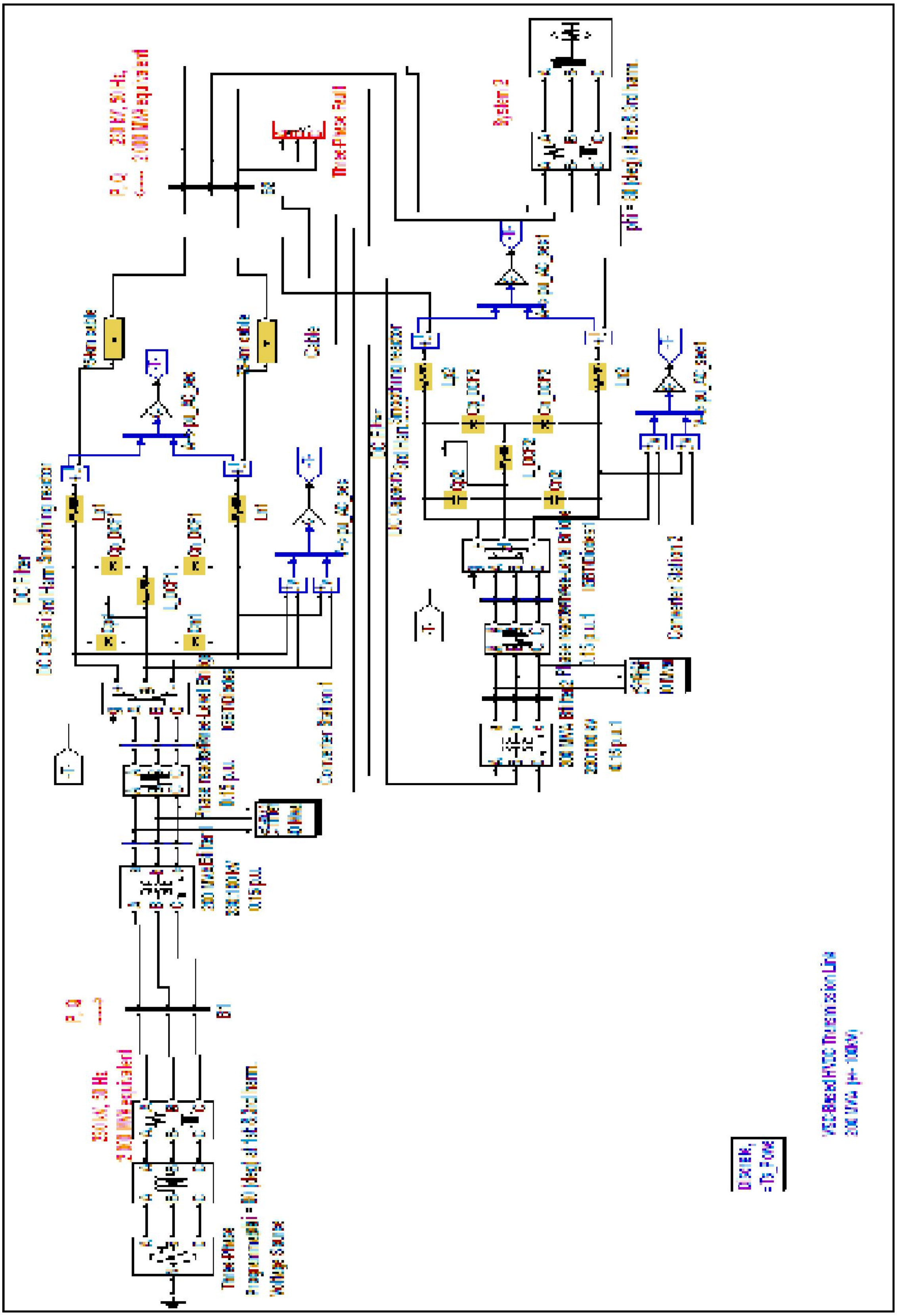

Figure.4: Block Diagram of VSC-HVDC Connecting Two AC Network

Analysis of simulation result

The simulation results of operationis related to the sample system shown inFig.4. On rectifier side, starting point is at T= 0.1s and decrease of V_{dc} is shown in Fig.6 and the amount of reactive power (Q_{rec})that is available for network take place at 0.1 pu shown in Fig. 7. It means that by decrease of dc voltage ,the required reactive power is determined for network. On the other hand for inverter,starting point is at T=0.3 sand also,Active power(P_{inv})at T=2.5 s flows to network and reduction of real power is shown in Fig.9 and the value of reactive power(Q_{inv}) which is flowed to network is 20 Mvar that is shown in Fig.10.According to Fig.11 and Fig.12, The ratio of the peak value of the modulating wave to the peak value of the carrier wave in either rectifier and inverter side is roughly equal to 1, That is shown the perfect operation of specified system.Simulation results show that the VSC-HVDC is capable for bidirectionally and rapidly power transmission and also, the system can regulate the AC voltage. Fast response of system, high quality of currents and AC voltage, independently active and reactive power control are other results of simulation.Trough the transmission, current limiting causes a decrease in DC voltage and so DC voltage controller helps to keep power balance and also is used for improvement of Dynamic of system.The simulation results demonstrate that the system has desirable stability and highly control accuracy.Figures 5 to 12 show the changes in controlled variable during process (horizontal axis is considered as time axis).

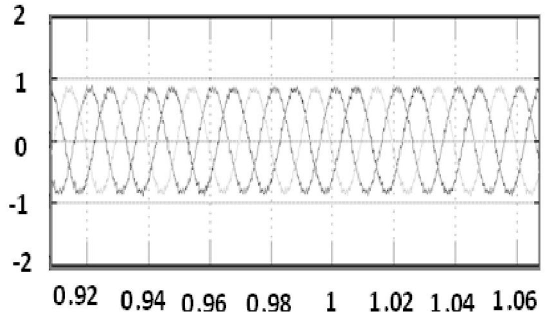

Fig.5: Three- Phase voltage on rectifier

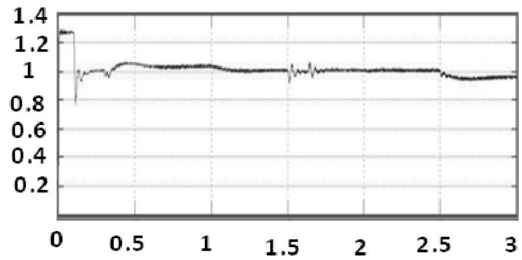

Fig.6: DC voltage on rectifier

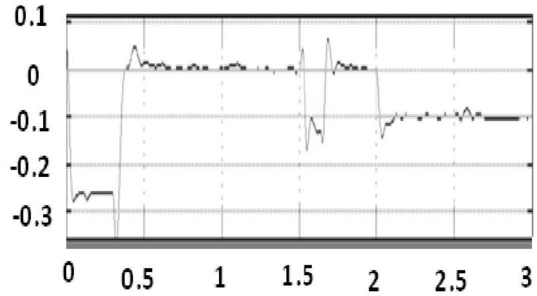

Fig.7:Reactive power variation on rectifier

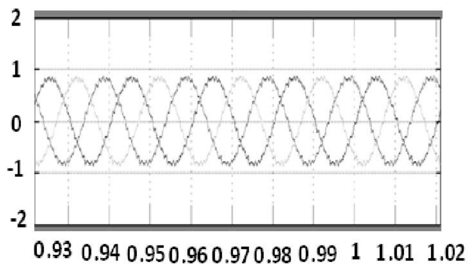

Fig.8: Three-Phase voltage on inverter

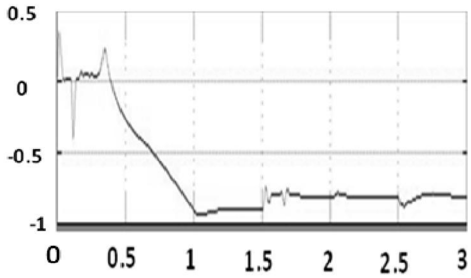

Fig.9: Real power variation on inverter

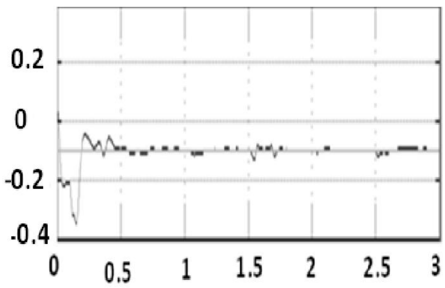

Fig.10: Reactive power variation on inverter

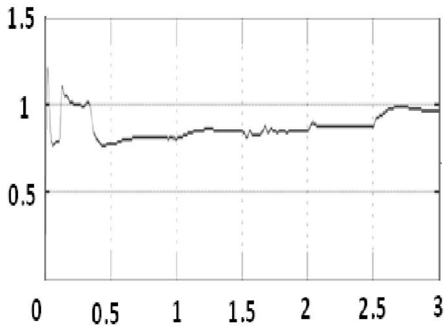

Fig.11: Modulatiofactor of rectifier

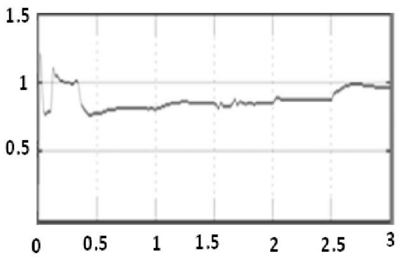

Fig.12: Modulation factor of inverter

Discussion

DC Voltage has effects on Active and reactive power changes. Therefor, DC voltage controller operates so that the fault is removed and DC voltage is regulated and this cause an improvement in powerflow in system.

- Active and reactive power have no effects on each other and this factor confirm the active and reactive power control, independently.
- Power flow with low loss and good operation of VSC-HVDC under active and reactive power changes in fault condition are main results of this strategy.
- Bidirectionally and rapidly power transmission capability in VSC-HVDC.
- Desirable stability, High control accuracy in the specified system.

Finding the perfect control strategy for DC system is the best way to improve the operation and stability because this is so important in economic analysis as well as technical part.

To install a VSC-HVDC system, Voltage and power stability in design and programming processes should be investigated accurately.

Conclusion

In this paper, power transmission strategy in VSC-HVDC connecting two networksis investigated and presented inMATLAB simulink and then the results are shown.Specified strategydepict the changes of active and reactive power and also DC voltage whichare main parameters in VSC-HVDC.Based on results, proper performance of VSC-HVDC isconfirmed under active and reactive power changes and undesirable condition.

References

Dasgupta, S., & Agnihotri, G. (2009). "A Control Strategy for a VSC-HVDC System in Steady State response," International Conference on Advances in Computing, Control and Telecommunication Technologies, pp. 564-569, 28-29.

Hidalgo, C. , Diaz, N. (2009). "Controller Design to Regulate the DC Voltage of a VSC Converter", Electrical Power and Energy Conference (EPEC), IEEE Trans on Power Systems, Bogota, Colombia, pp. 1-6, 22-23 October 2009.

Zhao, C. and Guo, C., (2009). "Complete Independent Control Strategy of Active and Reactive Power for VSC based HVDC System," Power & Energy Society General Meeting, IEEE Trans on Power Systems, Baoding, China.

Alanwang, Y. Boys, J.T & Patric Hu, (2008). "Modeling and Control of an Inverter for VSC-HVDC Transmission System With Passive Load ," International conference of Power control & system.

Du, C. (2007). "VSC-HVDC for industrial power systems," dept. of Energy and Environment, Chalmers University of Technology, Göteborg, Sweden, Ph.D thesis.

Flourentzou, N., Agelidis, V.& Demetriades, G. (2008). "VSC-Based HVDC Power Transmission Systems: An overview," ABB report, Sweden.

Jiang-Häfner, Y. , Duchén, H. , Lindén, K., Hyttinen, M. Fischer d., T. Tulkiewicz, A. Skyth & H. Björklund, (2002). "Improvement of Sub synchronous Torsional Damping using VSC HVDC," Power System Technology, International Conference, Ludvika, Sweden, pp. 998-1003.

Gu. Li, Ge. Li, H. Liang, C. Zhaoand M. Yin, (2006). "Research on Dynamic Characteristics of VSC-HVDC System," IEEE, Power Engineering Society General Meeting.

Mahjoub, A. & Mukerjee, R. (2008). "Modeling of controller for Voltage Source Converter based HVDC Transmission System," IEEE International Conference on Power and Energy, Malaysia, pp. 849-854, 1-3December 2008.