ENHANCEMENT OF POWER TRANSMISSION CAPABILITY OF HVDC SYSTEM USING FACTS CONTROLLERS

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ABSTRACT

The necessity to deliver cost effective energy in the power market has become a major concern in this emerging technology era. Therefore, establishing a desired power condition at the given points are best achieved using power controllers such as the well known High Voltage Direct Current (HVDC) and Flexible Alternating Current Transmission System (FACTS) devices. High Voltage Direct Current (HVDC) is used to transmit large amounts of power over long distances. The factors to be considered are Cost, Technical Performance and Reliability. A Flexible Alternating Current Transmission System (FACTS) is a system composed of static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability of the network. It is generally a power electronics-based system. A Unified Power Flow Controller (or UPFC) is a FACTS device for providing fast-acting reactive power compensation on high-voltage electricity transmission networks. The UPFC is a versatile controller which can be used to control active and reactive power flows in a transmission line. The focus of this paper is to identify the improved Power Transmission Capability through control scheme and comprehensive analysis for a Unified Power Flow Controller (UPFC) on the basis of theory, computer simulation. The conventional control scheme cannot attenuate the power fluctuation, and so the time constant of damping is independent of active- and reactive-power feedback gains integrated in its control circuit. The model was analyzed for different types of faults at different locations, keeping the location of UPFC fixed at the receiving end of the line, With the addition of UPFC, the magnitude of fault current and oscillations of excitation voltage reduces. Series and Shunt parts of UPFC provide series and shunt injected voltage at certain different angles.

KEYWORDS: Flexible ac transmission system (FACTS), High-voltage dc transmission (HVDC), FACTS devices, Power transfer controllability, PWM, Faults in HVDC System

I. INTRODUCTION

The rapid development of power systems generated by increased demand for electric energy initially in industrialized countries and subsequently in emerging countries led to different technical problems in the systems, e.g., stability limitations and voltage problems. However, breaking Innovations in semiconductor technology then enabled the manufacture of powerful thrusters and, later of new elements such as the gate turn-off thrusters (GTO) and insulated gate bipolar transistors (IGBT). Development based on these semiconductor devices first established high-voltage dc transmission (HVDC) technology as an alternative to long-distance ac transmission. HVDC technology, in turn, has provided the basis for the development of flexible ac Transmission system (FACTS) equipment which can solve problems in ac transmission. As a result of deregulation, however, Operational problems arise which create additional requirements for load flow control and needs for ancillary services in the system. This paper summarizes Flexible ac transmission system (FACTS),High-Voltage DC Transmission (HVDC), FACTS devices, Power transfer controllability, Faults in HVDC

System are discussed in this paper to explain how greater performance of power network transmission with various line reactance can be achieved.[1,2].

(a) Reduced maintenance (b) Better availability
(c) Greater reliability (d) Increased power
(e) Reduced losses (f) Cost-effectiveness

During the state of power exchange in interconnected lines to a substation under variable or constant power, the HVDC converters comprehends the power conversion and later stabilizes the voltage through the lines giving a breakeven margin in the power transmission. The first large-scale thyristors for HVDC were developed decades ago. HVDC became a conventional technology in the area of back-to-back and two- terminal long-distance and submarine cable schemes [3]. However, only few multi terminal schemes have been realized up to now. However, further multi terminal HVDC schemes are planned in the future (Fig. 1). The main application area for HVDC is the interconnection between systems which cannot be interconnected by AC because of different operating frequencies or different frequency controls. This type of interconnection is mainly represented by back-to-back stations or long-distance transmissions when a large amount of power, produced by a hydropower plant, for instance, has to be transmitted by overhead line or by submarine cable. HVDC schemes to increase power transmission capability inside of a system have been used only in a few cases in the past. However, more frequent use of such HVDC applications can be expected in the future to fulfill the requirements in deregulated [4, 6].

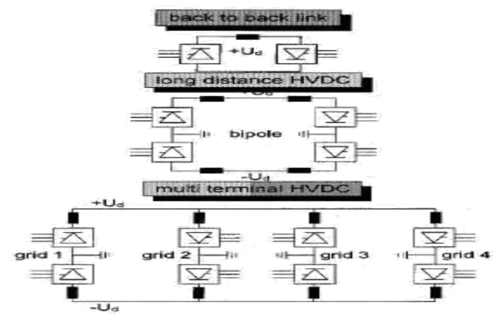

Fig 1 Various types of HVDC Connections

Static var compensators control only one of the three important pameters (voltage, impedance, phase angle) determining the power flow in ac power systems: the amplitude of the voltage at selected terminals of the transmission line. Theoretical considerations and recent system studies (1) indicate that high utilization of a complex, Interconnected ac power system, meeting the desired objectives for availability and operating flexibility, may also require the real time control of the line impedance and the phase angle. Hingorani (2) proposed the concept of flexible ac transmission systems or FACTS, which includes the use of high power electronics, advanced control centers, and communication links, to increase the usable power transmission capacity to its thermal limit. [5].

When using carrier based Pulse Width Modulation (PWM), its switching frequency has to be increased (typically, 33 times fundamental frequency even higher) [17], which cause considerable power losses. It reduces the total efficiency and economy of the UPFC-HVDC project. And they are also the Impediments for equipment aimed at the green, renewable Sector. Therefore, with regard to PWM technology suited for UPFC-HVDC, how to reduce switching frequency and possess good harmonics performance, excellent transient control capability simultaneously become critical. And this is exactly the aim of the paper. The paper presents an innovative hybrid PWM technology, which comprises a combination of a first PWM with a first switching pattern and a second PWM with a second switching pattern. Hence during a first mode of operation, which may be a steady-state operation, the converter is controlled by the first PWM and during a second mode of operation, which may be a transient operation, the converter is controlled by the second PWM. An intelligent detection function which enables the modulation and the corresponding control system will smoothly switch from the first PWM to the second PWM and vice-versa when a disturbance causing a transient occurs.

The development of FACTS-devices has started with the growing capabilities of power electronic components. Devices for high power levels have been made available in converters for high and even highest voltage levels. The overall starting points are network elements influencing the reactive power or the impedance of a part of the power system. The series devices are compensating reactive power. With their influence on the effective impedance on the line they have an influence on stability and power flow. The UPFC provides power flow control together with independent voltage control [7]. The main disadvantage of this device is the high cost level due to the complex system setup. The relevance of this device is given especially for studies and research to figure out the requirements and benefits for a new FACTS-installation. All simpler devices can be derived from the UPFC if their capability is sufficient for a given situation.[8].

II. HVDC AND FACTS

2.1 HVDC Converters and Functionalities for Power Transmission Enhancements.

During the state of power exchange in interconnected lines to a substation under variable or constant power, the HVDC converters comprehends the power conversion and later stabilizes the voltage through the lines giving a break even margin in the power transmission [9, 4]. The operation of HVDC filters any system harmonics developed in the network and improves the power transmission to the receiving end by independently adjusting the real and reactive power control. The significance of HVDC controller considered as part of FACTS family device is a structure of the back-to-back converter that governs the conversion of ac-dc-ac; like FACTS [9,12,14]. HVDC is assigned for frequency and phase independent short or long distance overhead or underground bulk power transmission with high speed controllability [9, 4]. This provides greater real power transmission and less maintenance. It reduces the chances of installing power cables Especially in difficult transmission that travels under water [4, 10]. By making use of the back-to-back converters, power transmission under non-synchronous ac systems is easily adaptable. The installation of smoothing reactor the DC Current and reactive power compensation at the sending and Receiving-ends smoothing reactor and AC harmonics filter as Shown in Fig. 1. The installation of HVDC also depends on the dc voltage and current ratings desired in the network that Yields for optimum converter cost. The converters terminate. The DC overhead lines or cables that are linked to AC buses and network [9].HVDC used for submarine cables connection will normally have 12-pulse converters as shown in Fig. 1 and Fig. 3. The bridge converter circuit contains delta and Wye type transformer. The transformer windings filter out system harmonics that occur by using the 6-pulse Graetz bridge converter [10]. Passive filters involved components like reactors, capacitors and resistors are the ones that remove the Harmonics [9]. For instance harmonics filtration Insulated Gate Bipolar Transistor (IGBT) or gate-turn-off thyristors (GTO) are the passive filters used for HVDC connection [9].

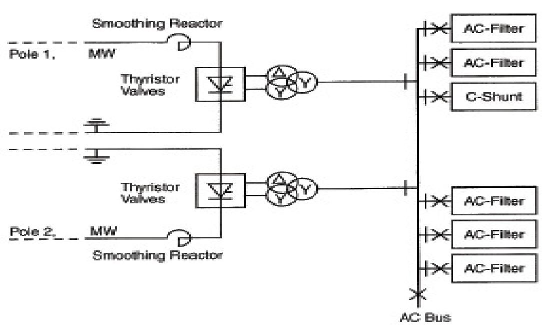

Fig. 2 HVDC terminal station in cable transmission [1]

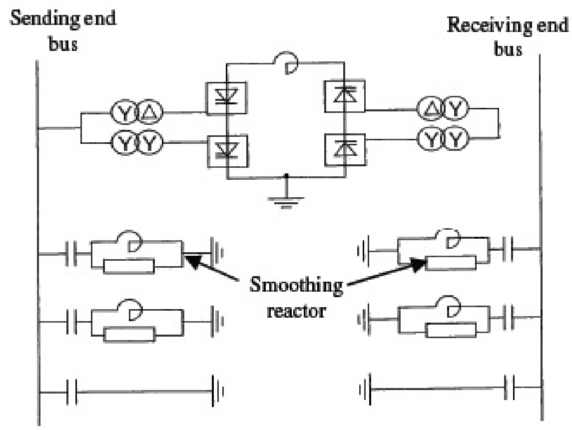

Fig.3 Schematic diagram of HVDC back-to-back converter station [9].

The operation of HVDC is restricted when network system contains low short circuit ratios. Therefore, insulation in the HVDC is essential in such cases. However, this does not
Restrict the converter stations operation. The HVDC insulation must withstand the stress produced in ac and dc voltages to allow full operation of HVDC in the lines. In addition to this Graetz's theory is applied into the system to measure system harmonics occurring in the system to further allow energy conversion in the HVDC system.

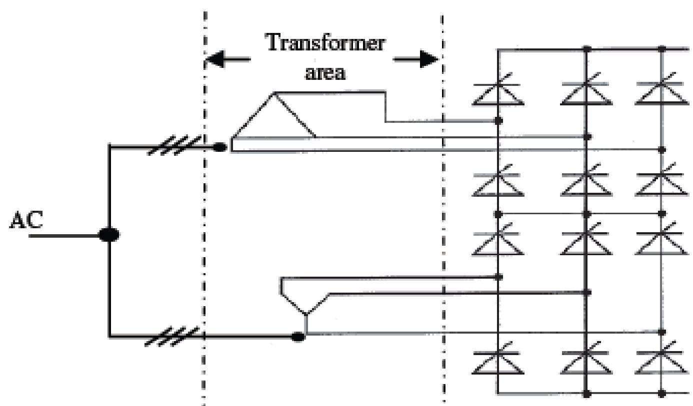

Fig. 4 Transformers and valve in 12-pulse bridge converter

2.2 Operation Condition of HVDC converter

Rectification of voltage-current using the sending-end converter, pole 1 filters the system harmonics and 'noises' Occurring in the transmission. When power is filtered, the Conversion from DC is direct back into the AC line at the Receiving-end of the HVDC pole 2 (Fig. 2). This sequence Operated instantaneously when matching the AC and DC Voltages during the conversion process. Requirements for this Conversion must have adequate impedance either on the AC or DC side of the HVDC [10], see Fig. 3. The availability of the Smoothing inductors is to control the pulses of constant current flows into the transformer's secondary windings. This is because the transmission current has pulses travels from the Primary side of the transformer, which have specific types of Connection and ratio [9]. Thyristor schemes are more feasible in the converters. HVDC and FACTS used this scheme to generate automated switching for close accuracy in their voltage conversion. The HVDC rectifier produces commutation effects when power is fired into the pulses from the thyristor. The rectified power is only then sent to the inverter for power inversion back to the AC line with the required frequency at the receiving-end.
For an optimal converter utilization and low peak inverse Voltage across the converter valves, typical 3-phase bridge Converter is normally used. Simple transformers that installed in the lines resist voltage variation and high direct voltages when insulated. The assumption and representation of HVDC block-set are expressed in equations (5) to (17) for MATLAB.

$$I_{dc} = (V_{Rdc} - V_{Idc} - R_{dc} I_{dc}) / L_{dc}$$ ----------------------------(1)

$$x_r = K_I (I_{RO} - I_{dc})$$ --- (2)

$$x_I = K_I (I_{RO} - I_{dc})$$ ---(3)

$$P_{km} = \frac{V_{ndc} I_{ndc}}{S_n} V_{Rdc} I_{dc}$$ ------------------------(4)

$$Q_{mk} = \sqrt{S_r^{\,2} - [\frac{V_{ndc} I_{ndc}}{S_n} V_{Rdc} I_{dc}]^2}$$ ------------------------------------ (5)

$$P_{mk} = \frac{V_{ndc} I_{ndc}}{S_n} V_{Idc} I_{dc}$$ --- (6)

$$Q_{mk} = \sqrt{S_I^{\,2} - [\frac{V_{ndc} I_{ndc}}{S_n} V_{Idc} I_{dc}]^2}$$ --------------------------------- (7)

The assumptions for the algebraic equations are then

$$\cos\alpha = x_R + K_P (I_{RO} - I_{dc})$$ --(8)

$$V_{Rdc} = \frac{3\sqrt{2}}{\Pi} V_k \cos\alpha - \frac{3}{\Pi} V_k \cos\alpha - \frac{3}{\Pi_{IR}} I_{dc}$$ --------------------(9)

$$I_{RO} = \frac{V_k}{m_R}$$ ---(10)

$$V_{Idc} = \frac{3\sqrt{2}}{\Pi} V_m \cos(\Pi - \gamma) - \frac{3}{\Pi} X_{tI} I_{dc}$$ ---------------------------(11)

$$S_I = \frac{3\sqrt{2}}{\Pi} \frac{V_{ndc} I_{ndc}}{S_n} V_m I_{dc}$$ ---(12)

$$I_{IO} = \frac{V_m}{m_I}$$ --(13)

TABLE 1: HVDC data format in MATLAB

S.NO	VARIABLE	DESCRIPTION	UNIT
1	k	Sending bus(SE)	Int
2	m	Receiving end (RE)	Int
3	S_n	Power rating	MVA
4	V_{nk}	Voltage rating at (SE)	KV
5	V_{nm}	Voltage rating at (RE)	KV

6	f_n	Frequency rating	Hz
7	V_{ndc}	DC voltage rating	KV
8	I_{ndc}	DC current rating	KA
9	X_{tr}	Transformer reactance (rectifier)	p.u
10	X_{ti}	Transformer reactance (inverter)	p.u
11	M_r	Tap ratio (rectifier)	p.u
12	M_i	Tap ratio (inverter)	p.u
13	K_I	Integral gain	1/s
15	K_p	Proportional gain	p.u/p.u
15	R_{dc}	Resistance of the DC connection	ohm
16	L_{dc}	Inductance of DC connection	H
17	$\alpha_{r\max}$	Max. firing angle	Deg
18	$\alpha_{r\min}$	Min. firing angle	Deg
19	$\gamma_{\mathrm{Im}ax}$	Max. extinction angle	Deg
20	$\gamma_{\mathrm{Im}in}$	Min. extinction angle	Deg
21	$I_{ro\max}$	Max. reference current (rectifier)	p.u
22	$I_{ro\min}$	Min. reference current (rectifier)	p.u
23	$I_{io\max}$	Max. reference current (inverter)	p.u
24	$I_{io\min}$	Min. reference current (inverter)	p.u

This expression represents a single DC line circuit with two AC/DC converters connected as a RL circuit. The MATLAB has PI controllers to control the extinction angle and also the firing angle of the HVDC [6]. The type of HVDC used and available in MATLAB is a thyristor based model.

2.3 Flexible AC Transmission System (FACTS)

The objective of incorporating FACTS is into the power system lines are similar to HVDC but greater flexibility are involved like improving real power transfer capability in the lines, prevention of sub-synchronous resonance (SSR)oscillations and damping of power swings [9]. FACTS devices have four well- known types which are used in many power systems in the world [9, 4, 10]. ‘ Single ’ type controller is the types of FACTS that installed in series or shunt in an AC transmission line, while ‘ unified ’ type controller are the combined converters type of FACTS controllers like UPFC and HVDC. The size of a controller is dependent on the requirements of the network and desired power transmission at loading point Voltage Source Controller (VSC) is sinusoidal voltage and is used in power system and other application. The quality of the sine wave is dependent on the size or amount of the power electronics installed. The following types of FACTS devices are VSC type based controllers:

(a) Shunt controller: example device, STATCOM emulates like a variable inductor or can be a capacitor in shunt or parallel connection in the transmission line. This type of device is capable of imitating inductive or capacitive reactance in turns to regulate line voltage at the point of coupling. Shunt controller in general controls the voltage injection [4].
(b)Series controller: example device, SSSC emulates like a variable inductor or a capacitor in series with a transmission line and it imitates inductive or capacitive reactance in turn to regulate effective line reactance between the two ends. Series controller in general controls current injection [4].
(c) Shunt-series controller: can be a standalone controller as STATCOM and SSSC. This type of controller is a reactive compensator with the exception of producing its own losses. It is also recognized as "unified" controller and requires small amount of power for DC circuit exchange occurring between the shunt and series converters [4]. See Fig.2 for shunt- series controller.

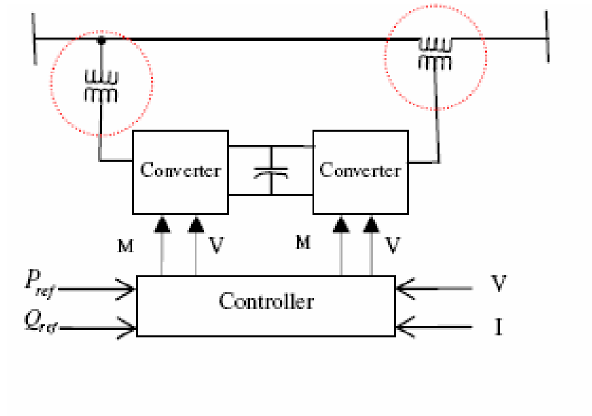

Fig. 5 Series-shunt compensator, UPFC

III. SIMULATION RESULTS

The rectifier and the inverter are 12-pulse converters using two Universal Bridge blocks connected in series. The converters are interconnected through a 110-km line and 0.78H smoothing reactors as shown in Fig 5(a).The converter transformers (Wye grounded/Wye/Delta) are modeled with Three-Phase Transformer (Three-Winding) blocks. The transformer tap changers are not simulated. The tap position is rather at a fixed position determined by a multiplication factor applied to the primary nominal voltage of the converter transformers (0.90 on the rectifier side,0.96 on the inverter side).
The HVDC transmission link uses 12-pulse thyristor converters. Two sets of 6-pulse converters are needed for the implementation stage. AC filters and DC filters are also required to minimize harmonics.

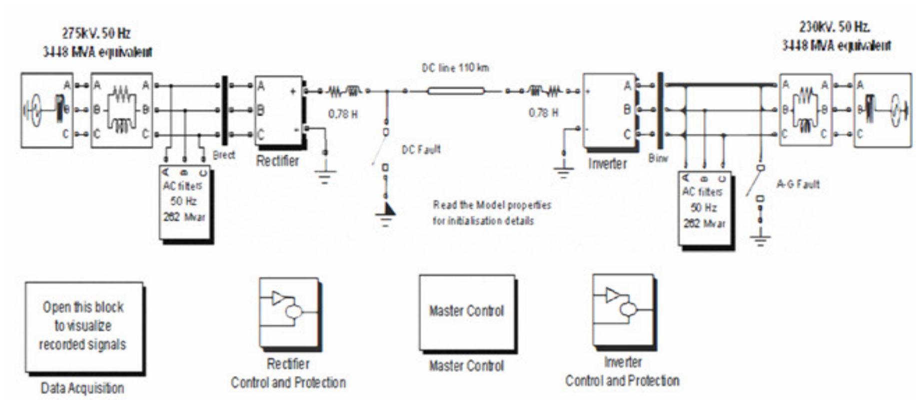

Fig. 5(a) Simulink diagram of the HVDC Circuit

The firing-angle control system is configured based on two 6-pulse converters in series, one of which is operated as a modified HVDC bridge. The HVDC power converters with thyristor valves will be assembled in a converter bridge of twelve pulse configuration. This is accomplished by star-star

connection and star-delta connection. Reduction of harmonic effects is another factor of investigation. Here, MATLAB/SIMULINK program is used as the simulation tool.
Two 6-pulse Graetz bridges are connected in series to form a 12-pulse converter. The two 6-pulse bridges are 275Kv, 60 Hz totally identical except there is an in phase shift of 30° for the AC supply voltages. Some of the harmonic effects are cancelled out with the presence of 30° phase shift. The harmonic reduction can be done with the help of filters. The firing angles are always maintained at almost constant or as low as possible so that the voltage control can be carried out. Six or eight of equal rating bridges are the best way to control the DC voltage. More than these numbers of series bridges are not preferable due to the increase in harmonic content. The control of power can be achieved by two ways i.e., by controlling the current or by controlling the voltage. It is crucial to maintain the voltage in the DC link constant and only adjust the current to minimize the power loss. The rectifier station is responsible for current control and inverter is used to regulate the DC voltage. Firing angle at rectifier station and extinction angle at inverter station are varied to examine the system performance and the characteristics of the HVDC system. Both AC and DC filters act as large capacitors at fundamental frequency. Besides, the filters provide reactive power compensation for the rectifier consumption because of the firing angle.
The main circuit of an UPFC is rated at 10 kVA and its circuit parameters are represented in Fig .5. The main circuit of the series device consists of three single-phase H-bridge voltage-fed Pulse Width Modulation (PWM) inverters. A PWM control circuit compares reference voltage VC with a triangular carrier signal of f_{sw}=1 kHz in order to generate twelve gate signals. An equivalent switching frequency is 2 kHz, which is twice as high as f_{sw} because three H-bridge PWM inverters are used. The AC terminals of the PWM inverters are connected in series through matching transformers with a turn ratio of 1:12. Since the rms voltage of the series device is 12 V, a kilovolt ampere rating of which is 11% of the controllable active power of 10 kW flowing between Vs and Vr.
Fig. 5(a), Shows HVDC system with UPSC the real power Output in the line is controlled to obtain steady-state condition. when system harmonics is introduced. The weak power Transmission normally occurring in long transmission lines was studied using MATALB. The diagram given in Fig. 5 shows the computational layout of HVDC which is simulated for damping system harmonics and rectification as well as with power inversion in its converters. Simulation of HVDC System carried out using MATLAB / SIMULINK with UPFC and Simulation results was presented to create oscillations with the line current and power waveforms during the power transmission. Fig 7 to Fig 14 shows the simulation results of HVDC system when three phase , Line to Ground and double line ground with and with out UPSC. From the simulations results , it is observed that when different types of faults i.e. three phase ., Line to Ground and Double Line to ground occurs the system are having more oscillations and system takes more time to reach the steady state operation.. By using UPFC the system reduces oscillation and thereby enhanced the power transfer capability of HVDC system.

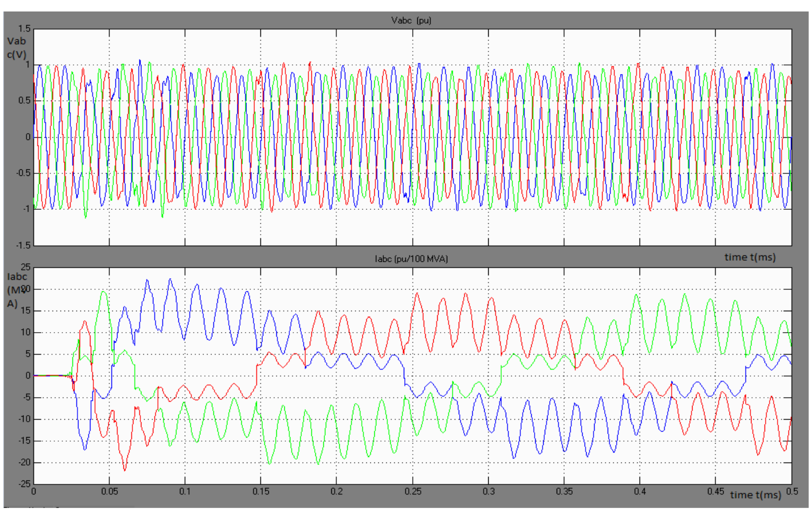

Fig: 6 Simulation Result HVDC system

In Fig. 6, fault is created in phase A of the rectifier bus at t=0.03sec, it results in unbalancing of the phase voltages and generates harmonic oscillations in DC voltages and currents. The DC voltages and currents of the rectifier are distorted and attain peak values up to 0.9 per unit and 0.016per unit respectively at time t=0.12sec.

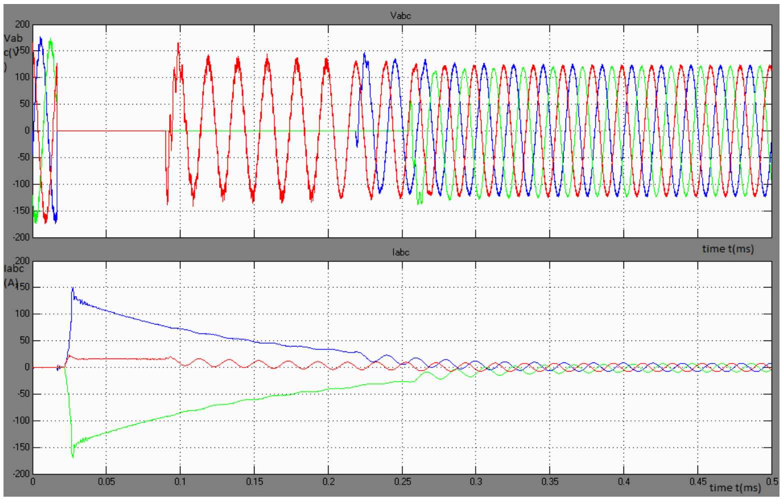

Fig.7 Simulation Result HVDC system when three phase fault occurs on Inverter

In Fig .7, it is observed that a 3-phase fault is created in the inverter side of HVDC system. The PWM controller activates and clears the fault. The fault clearing can be seen first by a straight line of '0' voltage between t=0.03sec to t=0.08sec. Before the fault a Vabc=0.17pu and Iabc=0.15pu. After the fault is cleared at t=0.3sec, the recovery is slow and there are oscillations in DC voltage and current of the magnitude 0.13pu and 0.1pu respectively. The rectifier DC voltage and current oscillate and settles to the prefault values in about 3 cycles after the fault is cleared.

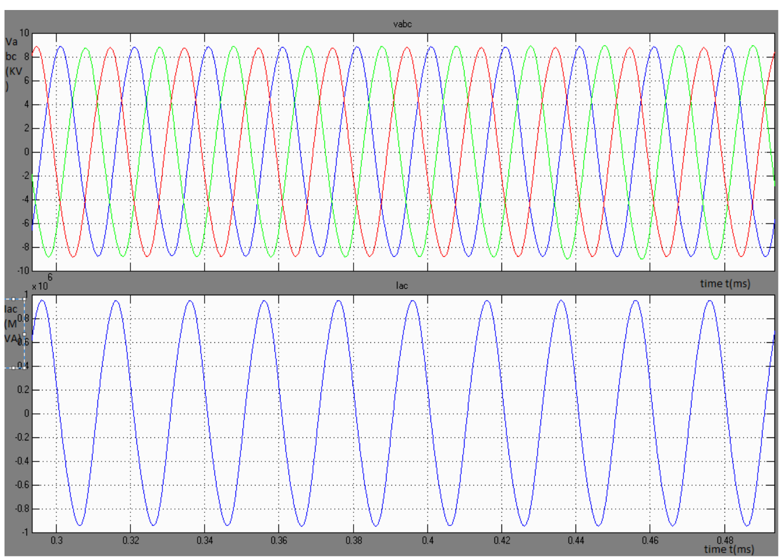

Fig 8 Simulation Result HVDC system when three phase facult occurs on Inverter with UPSC

From Fig 8,it is observed that different types of faults i.e., three phase, line to ground and double line to ground is created in the inverter side of HVDC system at t=0.15 sec. When these faults occur in the system, it takes more time to reach the steady state operation. The PWM controller activates and clears the fault. Further, with the addition of UPFC the system reduces oscillations and get pure sinusoidal waveform at voltage Vabc=0.9 p. u and current Iabc=0.95 p.u at time t=0.15 sec.

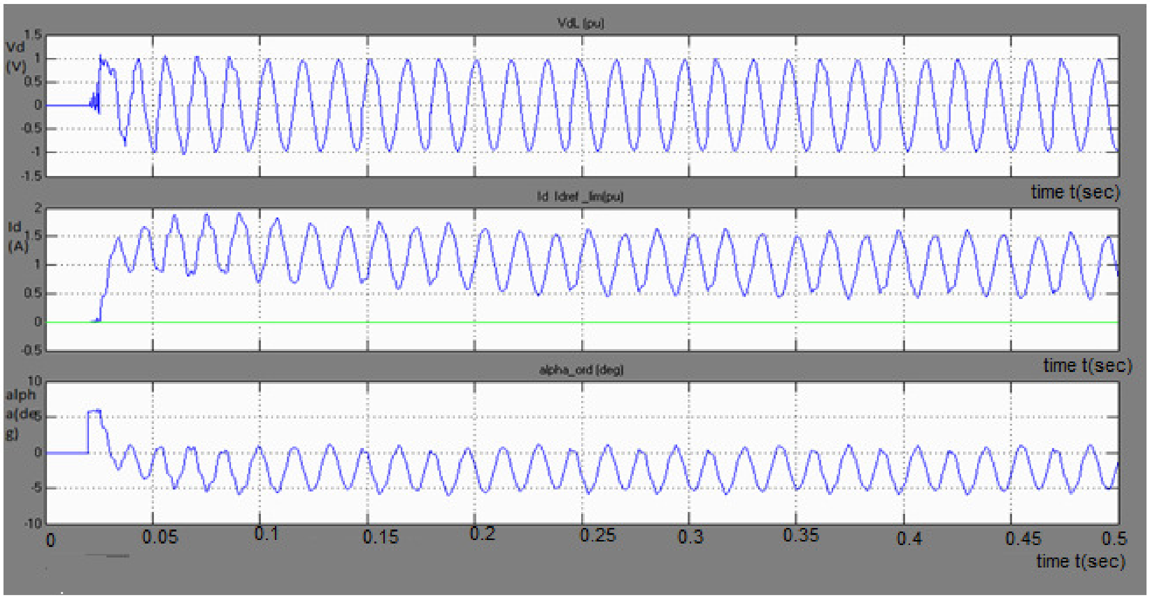

Fig 9 Simulation Result for steady state operation of HVDC system on rectifier side.

At the rectifier side, when the fault is applied at time t=0.03sec, voltage and current magnitudes are of the order of 1pu and 1.5pu respectively and alpha angle is equal to 7 degrees which is shown in Fig 9.If alpha angle is changed to higher value the system takes longer time to reach steady state .If alpha value increases, current value decreases. The waveforms obtained at rectifier side are same for different types of faults.

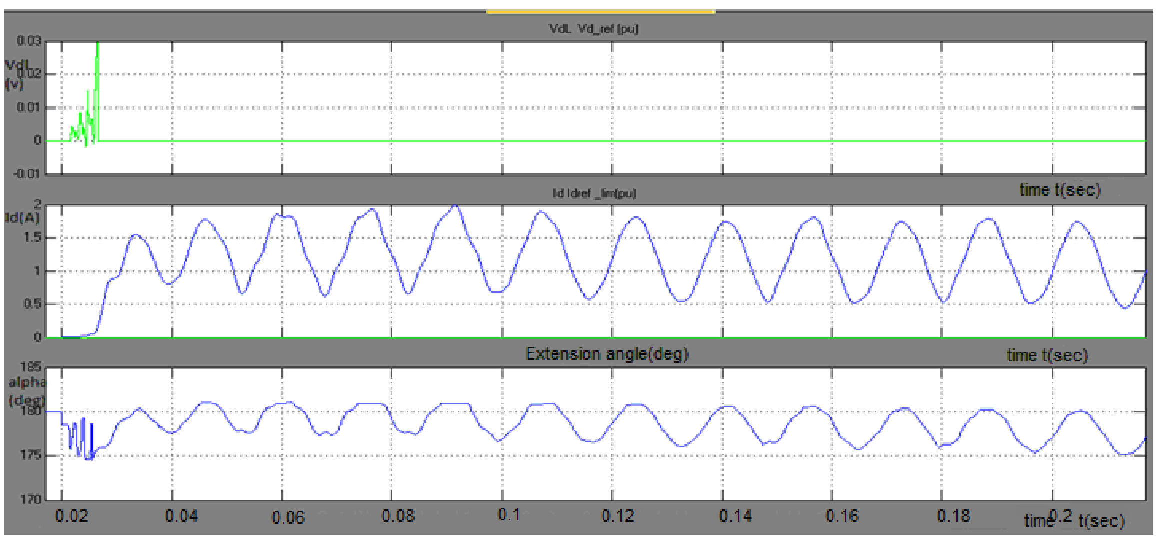

Fig 10 Simulation Result for steady state operation of HVDC system on Inverter side

At the inverter side, when the fault is applied at time t=0.02sec,voltage and current magnitudes are of the order of 0.03pu and 0.8pu respectively and extension angle is equal to 180 degrees which is shown in Fig . 10. The waveforms obtained at inverter side are same for different types of faults.

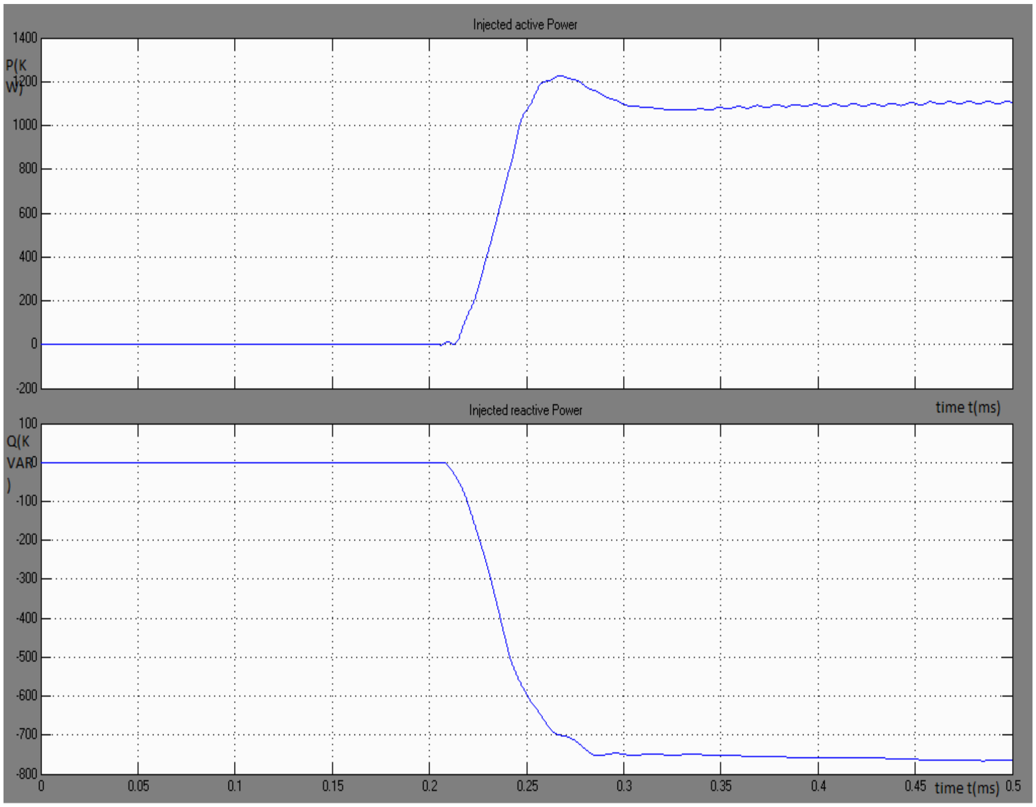

Fig 11 Simulation Result for Injected active and reactive powers of HVDC system

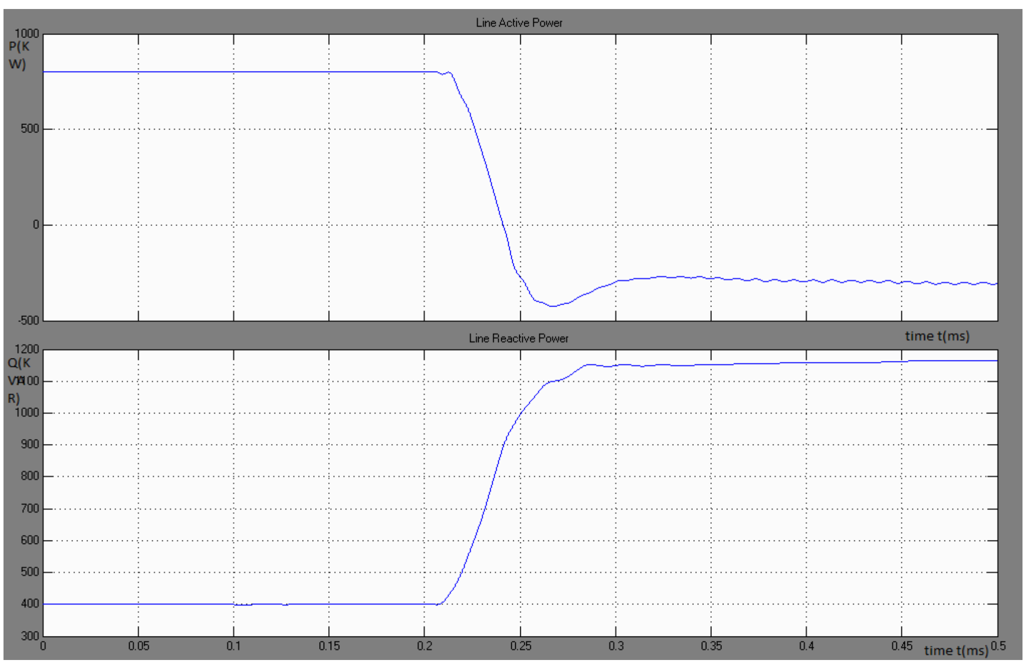

Fig 12 Simulation Result for line active and reactive powers of HVDC system

In Fig 12, when a fault is created at time t=0.21sec, the active and reactive power is maintained at 800KW and 400KVAR respectively from time t=0sec to t=0.21sec.At time t=0.27sec both active and reactive power attain stability and becomes steady state. It is observed that no power fluctuations occur in P and Q after t=0.27sec.By trial and error, the integral gain is set to be 5, so that the steady state errors are reduced for P and Q.

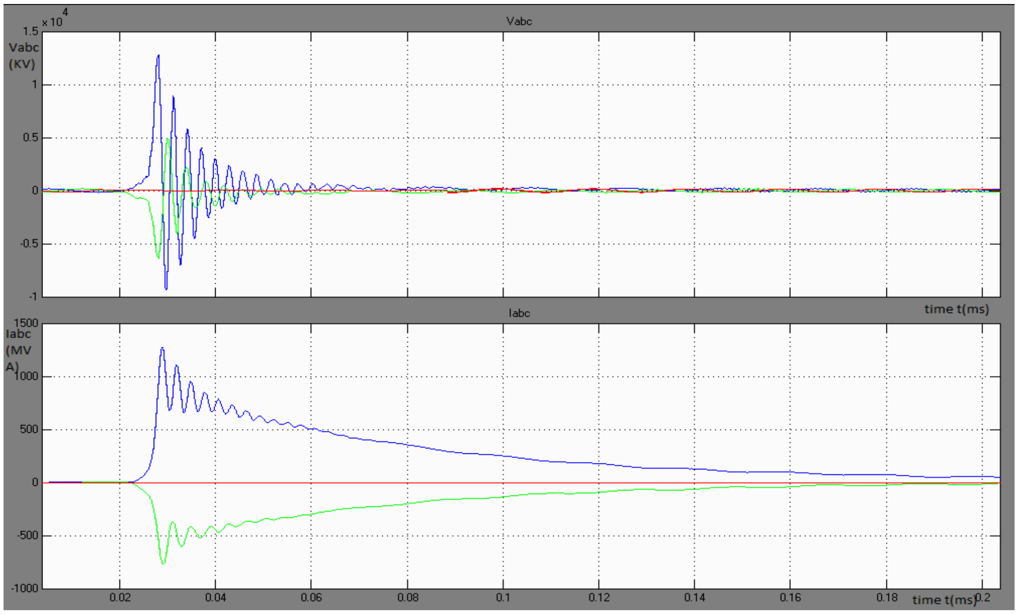

Fig.13 Simulation Result HVDC system when Line to Ground facult occurs on Inverter side

In Fig 13, it is observed that a Line to Ground fault is created in the inverter side of HVDC system at time t=0.025sec. The PWM controller activates and clears the fault. Before the fault a V_{abc}=0.14pu and I_{abc}=0.013pu. After the fault is cleared at t=0.08sec, the recovery is slow and there are oscillations in DC voltage and current of the magnitude 0.2pu and 0.05pu respectively.

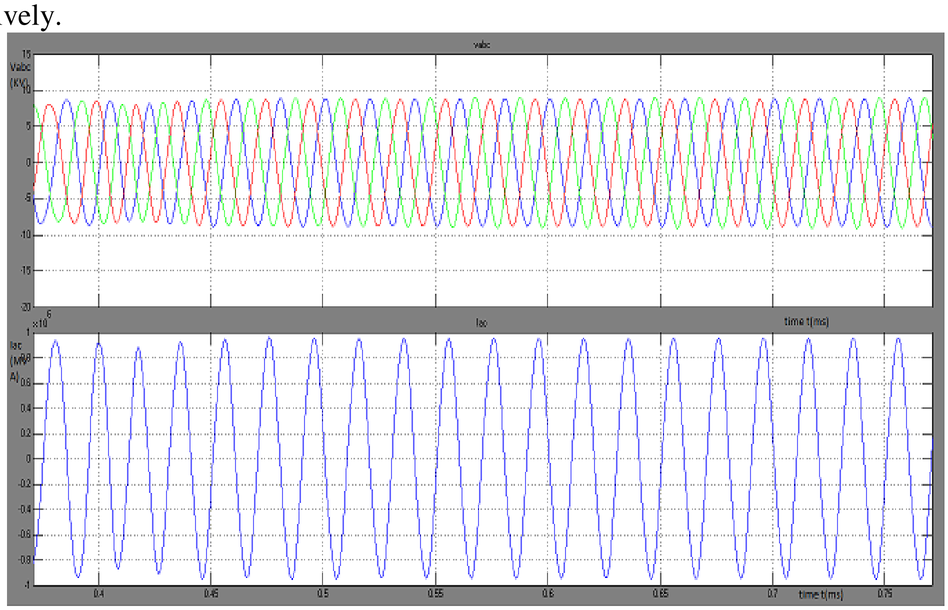

Fig 14 Simulation Result HVDC system when Line to Ground faculty with UPSC

From Fig 14,it is observed that different types of faults i.e., three phase, line to ground and double line to ground is created in the inverter side of HVDC system at t=0.15 sec. When these faults occur in the system, it takes more time to reach the steady state operation. The PWM controller activates and clears the fault. Further, with the addition of UPFC the system reduces oscillations and get pure sinusoidal waveform at voltage Vabc=0.9 p. u and current Iabc=0.95 p.u at time t=0.15 sec.

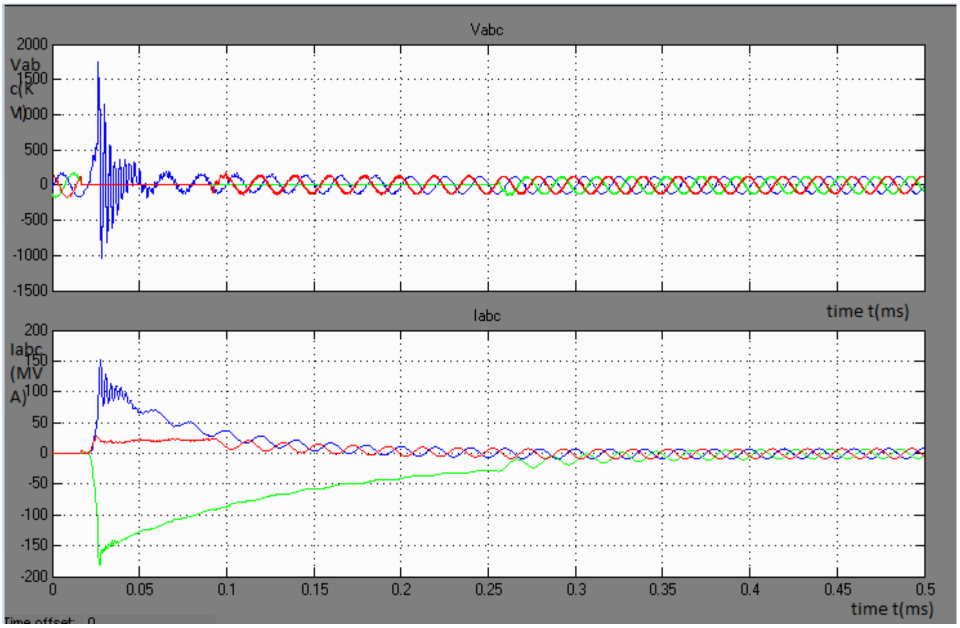

Fig.15 Simulation Result HVDC system when Double Line to Ground facult occurs on Inverter side

In Fig 15, it is observed that a Double Line to Ground fault is created in the inverter side of HVDC system at time t=0.02sec. The PWM controller activates and clears the fault. Before the fault a Vabc=0.17pu and Iabc=0.15pu. After the fault is cleared at t=0.33sec, the recovery is slow and there are oscillations in DC voltage and current of the magnitude 0.33pu and 0.1pu respectively

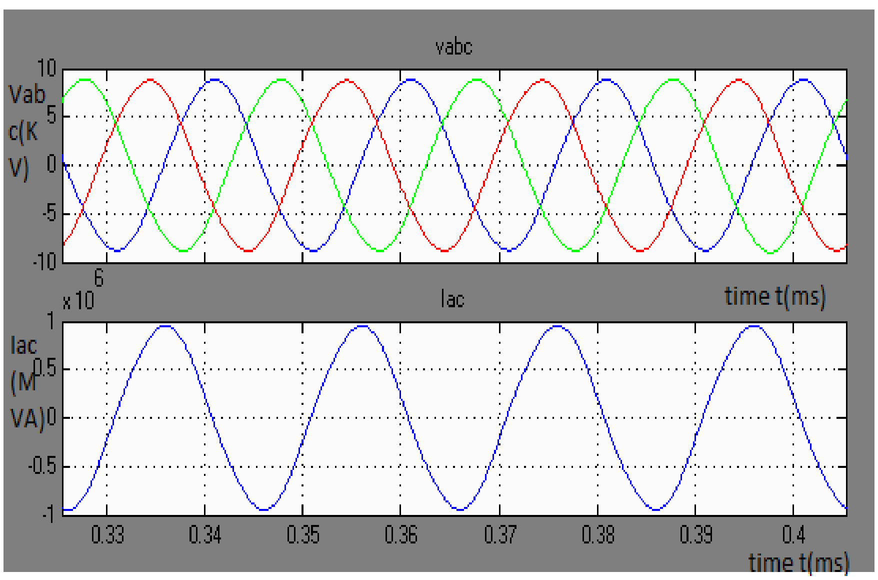

Fig 16 Simulation Result HVDC system when Double Line to Ground faults with UPSC

IV. Conclusion

According to results that UPFC improves the system performance under the transient and the normal conditions. However, it can control the power flow in the transmission line, effectively. With the addition of UPFC, the magnitude of fault current reduces and oscillations of excitation voltage also reduce. The "current margin" is essential to prevent misfire of the thyristor valves. DC filters and AC filters can not only eliminate the harmonic effects but also reduce the total harmonic distortion (THD) as well. The current waveform in the case of a conventional controller has a lot of crests and dents and suffers from prolonged oscillations, whereas by using PWM controller, DC current fast returns to its nominal value. The overshoot in case of the PWM controller is slightly less than conventional controllers. It is more economical for the HVDC transmission system to transfer more power as the power factor is almost near to unity and the energy loss is low. UPFC, however, has shown its flexibility in easing line congestion and promoting a more controllable flow in the lines. HVDC can be very useful for long transmission lines. It is more recommended in networks or interconnected lines that have high variation of power demands and complicated network connections with different power frequencies. UPFC in general is good for promoting line load-ability and pool through interconnected network buses more effectively. UPFC can be very useful for deregulated energy market as an alternative choice for more power generation to the load area.

REFERENCES

[1]. E.M. Yap, Student Member, IEEE School of Electrical and Computer Engineering, RMIT University, Melbourne, AU

[2]. Hideaki Fujita, *Member, IEEE,* Yasuhiro Watanabe, and Hirofumi Akagi, *Fellow, IEEE,* "Control and Analysis of a Unified Power Flow Controller" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 14, NO. 6, NOVEMBER 1999

[3]. Lee Wei Sheng, Ahmad Razani and Neelakantan Prabhakaran, Senior Member, IEEE "Control of High Voltage Direct Current (HVDC) Bridges for Power Transmission Systems" Proceedings of 2010 IEEE Student Conference on Research and Development (SCOReD 2010), 13 - 14 Dec 2010, Putrajaya, Malaysia

[4]. N.G. Hingorani, L. Gyugyi, "Understanding FACTS," New York: IEEE Press, 2000, pp. 2, 29, 135, 300 and 417.

[5]. Padiyar, HVDC Power Transmission System. New Delhi, India:Wiley Eastern, 1993

[6]. W.Kimbark, Direct Current Transmission. New York: Wiley,1971, vol. I.

[7]. Gyugyi, L., "A Unified Power Flow Control Concept for Flexible AC Transmission Systems," IEE PROCEEDINGS-C, Vol. 139, No.4,july 1992.

[8]. M. H. Haque, Senior Member, IEEE " Application of UPFC to Enhance Transient Stability Limit".

[9]. J.W. Evan, "Interface between automation and Substation," Electric Power substations engineering, J.D. Macdonald, Ed. USA: CRC Press,2003, pp. 6-1 (Chapter 6).

[10]. J. Arillaga, "Flexible AC Transmission technology," Y. H. Songs, and A.T. Johns, Ed. UK: Stevenage, Herts IEE., 1999, pp. 99.

[11]. S.H. Hosseini, A. Sajadi and M.Teimouri, "Three phase harmonic load flow in an unbalanced AC system. Including HVDC link," Power Electronics and Motion Control Conference, IPEMC 2004. The 4th International, vol. 3, pp. 1726-1730, Aug. 2004.

[12]. E.M. Yap, M. Al-Dabbagh and P.C Thum, "Using UPFC Controller in Mitigating Line Congestion for Cost-efficient Power Delivery, "submitted at the Tencon 2005, IEEE conference, May 2005.

[13]. E.M. Yap, M. Al-Dabbagh, "Applications of FACTS Controller for Improving Power Transmission Capability," submitted at the IPEC 2005, IEEE conference, May 2005.

[14]. R. S. Tenoso, L.K. Dolan, and S. A. Yari, "Flexible AC Transmission systems benefits study," Public Interest Energy Research (PIER), Resource energy, Trn: P600-00-037, California, Oct 1999.

[15]. X.-P. Zhang, "Multiterminal Voltage-Sourced Converter Based HVDC Models for Power Flow Analysis", IEEE Transactions on Power Systems, vol. 18, no. 4, 2004, pp.1877-1884.

[16]. D J Hanson, C Horwill, B D Gemmell, D R Monkhouse, "ATATCOM-Based Reloadable SVC Project in the UK for National rid", in Proc. 2002 IEEE PES Winter Power Meeting, New York City, 7- 31 January 2002. uip_2.pd.

[17]. F. Schettler, H. Huang, and N. Christl, "HVDC Transmission Systems Using Voltage Sourced Converters: Design and Application." Conference Proceedings, IEEE Summer Meeting 2000, Paper No. 2000 SM-260, vol. 2, pp. 716-720.

[18]. Sheng Li, Jianhua Zhang, Guohua Zhang C Jingfu Shang, Mingxia Zhou CYinhui Li "Design of Integrative Fuzzy Logic Damping Controller of VSC-HVDC" IEEE/PES Power Systems Conference and Exposition,(PSCE '09), pp1-6.

[19]. A. K. Moharana, Ms. K. Panigrahi, B. K. Panigrahi and P. K. Dash, Senior Member, IEEE "VSC Based HVDC System for Passive Network with Fuzzy Controller" International Conference on Power Electronics, Drives and Energy Systems,(PEDES '06), pp 1 – 4.

[20]. Guo-Jie Li, T. T. Lie, Yuan-Zhang Sun, Si-Ye Ruan, Ling Peng, Xiong Li "Applications of VSC-Based HVDC in Power System Stability Enhancement" 7th Int. Conf. Power Engineering (IPEC 2005), pp 1-6.

[21]. K.H. Chan J.A. Parle N. Johnson E. Acha "Real-Time Implementation of a HVDC-VSC Model forApplication in a scaled-down Wind Energy Conversion System (WECS)" Seventh International Conference on AC-DC Power Transmission, 2001, pp 169-174.

[22]. H. *C* . Lin "Intelligent Neural Network based Dynamic Power System Harmonic Analysis".lntemational Conference on Power system Technology – (POWERCON 20) Nov. 2004,pp 244-248.

[23]. Miguel Torres , Jose Espinoza, and Romeo Ortega "Modeling and Control of a High Voltage Direct Current Power Transmission System based on Active Voltage Source Converters" 30th IEEE Annual Conf. of the Industrial Electronics Society 2004,pp 816-821.

[24]. Ruihua, Song Chao, Zheng Ruomei, Li Xiaoxin, Zhou "VSCs based HVDC and its control strategy" IEEE/PES Transmission and Distribution Conference & Exhibition,2005,pp 1-6.

[25]. Yongsheng Alan Wang, John T Boys, and Aiguo Patrick Hu, Senior Member, IEEE "Modelling and Control of an Inverter for VSC-HVDC Transmission System with Passive Load" IEEE Int. Joint Conf. on Power System Technology and Power India Conference (POWERCON 2008), pp 1-6.

[26]. Sheng Li, Jianhua Zhang, Jingfu Shang, Ziping WU,Mingxia International Conference on Zhou "A VSC-HVDC Fuzzy Controller for Improving the Stability of AC/DC Power System" Int. Conf. on Electrical Machines and Systems (ICEMS 2008), pp 1-6.

[27]. Ke Li, and Chengyong Zhao,"New Technologies of Modular Multilevel Converter for VSC-HVDC Application" Asia-Pacific Power and Energy Engineering Conference (APPEEC 2010), pp 1-4.

[28]. Hua WENG, Zheng xu, Member, IEEE, Zhendong DU "Inverter Location Analysis for Multi-infeed HVDc Systems". International Conference on Power System Technology, 2010, pp 1-6.

[29]. Guanjun Ding, Ming Ding and Guangfu Tang "An Innovative Hybrid PWM Technology for VSC in Application of VSC-HVDC Transmission System" IEEE Electrical Power & Energy Conference 2008, pp 1-8.

[30]. Hua Li, Fuchang Lin, Junjia He,Yuxin Lu, Huisheng Ye, Zhigang Zhang "Analysis and Simulation of Monopolar Grounding Fault in Bipolar HVDC Transmission System" IEEE Power Engineering Society General Meeting, 2007, pp 1-5.

[31]. Jie Yang&Jianchao Zheng Guangfu Tang& Zhiyuan He "Characteristics and Recovery Performance of VSC-HVDC DC Transmission Line Fault" Asia-Pacific Power and Energy Engineering Conference (APPEEC-10),pp1-4.

[32]. H. Jm, V.K. Sood, and W. Chen "Simulation Studies of A HVDC System with Two DC Links" IEEE Region 10 Conf. on Computer, Communication, Control and Power (TENCON'93),pp 259-262

[33]. Jing Yong, Wu Xiaochen, Du Zhongming, Jin Xiaoming, Wang Yuhong, D. H. Zhang and J. Rittiger "Digital Simulation of ACDC Hybrid Transmission System" 9th IET International Conference on AC and DC Power Transmission,(ACDC 2010), pp 1-5.

[34]. Yong Chang, Hairong Chen CGaihong Cheng Cand Jiani Xie "Design of HVDC Supplementary Controller Accomodating Time Delay of the WAMS Signal in Multi-Machine System" IEEE Power Engineering Society General Meeting, 2006.

[35]. Paulo Fischer de Toledo, Jiuping Pan, Kailash Srivastava, WeiGuo Wang, and Chao Hong "Case Study of a Multi-Infeed HVDC System" IEEE Joint International Conference on Power System Technology and Power India. (POWERCON2008),pp1-7.

[36]. Chengyong Zhao, Chunyi Guo "Complete-Independent Control Strategy of Active and Reactive Power for VSC Based HVDC System" IEEE Power & Energy Society General Meeting (PES '09), pp 1-6.

[37]. E. Chiodo, D. Lauria, G. Mazzanti, and S. Quaia "Technical Comparison among Different Solutions for Overhead Power Transmission Lines" Int. Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM 2010), pp 68-72.

[38]. Hui Ding,Yi Zhang,Aniruddha M. Gole, Dennis A. Woodford, Min Xiao Han, and Xiang Ning Xiao"Analysis of Coupling Effects on Overhead VSC-HVDC Transmission Lines From AC Lines With Shared Right of Way" IEEE Trans on Power Delivery, Vol. 25, No. 4, Oct 2010, pp 2976-2986.

[39]. Jinliang Kang, Haifeng Liang,Gengyin Li,Ming Zhou, Member, and Hua Yang "Research on Grid Connection of Wind Farm Based on VSC-HVDC" International Conference on Power System Technology 2010, pp 1-6.

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