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AN INNOVATIVE METHODOLOGY FOR ENHANCEMENT OF POWER TRANSMISSION CAPABILITY OF HVDC SYSTEM

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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 is 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 or for interconnections between asynchronous grids. The system planner must consider DC alternatives in transmission expansion. The factors to be considered are cost, technical performance and reliability. Power system operation conditions and topologies are time-varying and the disturbances are unforeseeable. These uncertainties make it very difficult to effectively deal with power system stability problems through a conventional controller that is based on a linearized system model. Therefore the UPFC with the proposed adaptive fuzzy logic controller approach is more effective than the UPFC with the conventional. The proposed work of this paper is to analyze for different types of faults, with the addition of UPFC the magnitude of fault current and oscillations of excitation voltage reduces. However to identify the improved transient stability analysis of UPFC with different controller strategies. By introducing FACTS controller into the HVDC system we can improve the power transmission capability and system stability. The results were analyzed by using MATLAB/SIMULINK.

Keywords: *High-Voltage Dc Transmission (HVDC), Flexible AC Transmission System (FACTS), Unified Power Flow Controller(UPFC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Fuzzy Logic Controller, Total Harmonic Distortion (THD).*

1. 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., voltage limitations and stability problems [2]. However, breaking innovations in semiconductor technology then enabled the manufacture of powerful thyristors and, later of new elements such as the gate turn-off thyristors (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. The HVDC technology, in turn, has provided the basis for the development of flexible ac Transmission system (FACTS) equipment that can solve problems in ac transmission [1].

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 High-Voltage DC transmission system (HVDC), FACTS devices, power transfer controllability, faults in HVDC system are discussed in this paper to explain how the greater performance of power network transmission with various control strategies [3-5].

2. HVDC AND FACTS

The 12-pulse bridge converter as shown in Fig.1 is the basic design for HVDC converters. On the dc side the converter is made up of two 6-pulse bridge converters connected in series. A YY- transformer connects one to the AC side, while a YD transformer connects the other. Each 6-pulse converters AC currents will then be phase shifted 30^0.

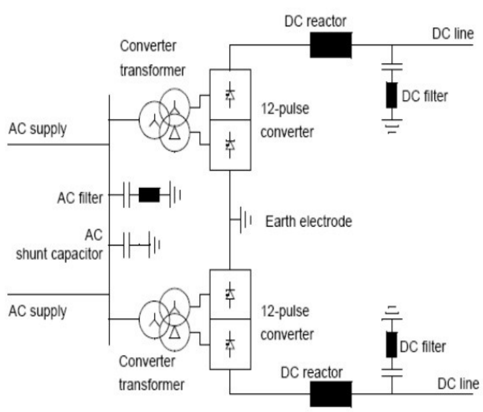

Fig.1.Block Diagram Of HVDC Converter Station.

The High-Voltage direct current (HVDC) transmission is an economic way for long-distance power delivery and/or interconnection of asynchronous systems with different frequencies. With the development of modern power systems, the HVDC system plays a much more important role in power grids due to its huge capacity and capability of long-distance Transmission. The electric power transmission was originally developed with direct current (DC).

However, the transmission systems used in most countries nowadays are alternating current (AC) due to the rapid development of transformers, synchronous generators, and induction motors. DC transmission now becomes practical and economical when power transmission for long-distance was involved [6-8]. 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 the power transfer capability of the network. It is generally a power electronics-based system. FACTS devices have well-known types which are used in many power systems in the world. ‘Single’ type controller is a type of FACTS controller that is installed in series or shunt in an AC transmission line, while ‘unified’ type controller is a combined converter type of FACTS controllers like STATCOM. The proposed work generally concluded that fuzzy logic could improve the performance of HVDC systems under various fault conditions or operating point changes, by decreasing the number of commutation failures, improving the commutation margin, or dampening oscillations [9].

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 influence stability and power flow [10].

DC transmission line control

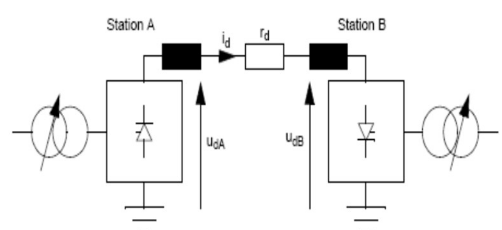

Fig.2. HVDC Transmission System With Monopolar Configuration.

The dc current flowing in the line can be calculated using Fig.2, which is obtained by subtracting the voltage difference between stations A and B, and r_d is the total resistance of the line's evaluated dc current.

$$i_d = \frac{u_{dA} - u_{dB}}{r_d} \quad (1)$$

Power transmitted to converter station B is denoted by

$$P_d = u_{dB}.i_d = u_{dB}.\frac{u_{dA}-u_{dB}}{r_d} \quad (2)$$

The expression for six pulse bridge converter is given by

$$u_d = u_{dio}.[Cos\alpha - d_{xN}.\frac{I_d}{i_{dN}}\frac{u_{dioN}}{u_{dio}}] \quad (3)$$

The following currents for master control can be derived from below equations.

$$I_{dc} = (V_{Rdc} - V_{Idc} - R_{dc}I_{dc})/L_{dc} \quad (4)$$

$$x_r = K_I(I_{RO} - I_{dc}) \quad (5)$$

$$x_1 = K_I(I_{RO} - I_{dc}) \quad (6)$$

$$P_{km} = \frac{V_{ndc}I_{ndc}}{S_n}V_{Rdc}I_{dc} \quad (7)$$

$$Q_{mk} = \sqrt{S_r^2 - [\frac{V_{ndc}I_{ndc}}{S_n}V_{Rdc}I_{dc}]^2} \quad (8)$$

$$P_{mk} = \frac{V_{ndc}I_{ndc}}{S_n}V_{Idc}I_{dc} \quad (9)$$

$$Q_{mk} = \sqrt{S_1^2 - [\frac{V_{ndc}I_{ndc}}{S_n}V_{Idc}I_{dc}]^2} \quad (10)$$

The assumptions for the algebraic equations are then

$$cos\alpha = x_R + K_p(I_{RO} - I_{dc}) \quad (11)$$

$$V_{Rdc} = \frac{3\sqrt{2}}{\pi}V_k cosa - \frac{3}{\pi}V_k cosa - \frac{3}{\pi_{IR}}I_{dc} \quad (12)$$

$$V_{Idc} = \frac{3\sqrt{2}}{\pi}V_m cos(\pi - \gamma) - \frac{3}{\pi}X_{tI}I_{dc} \quad (13)$$

$$S_I = \frac{3\sqrt{2}}{\pi}\frac{V_{ndc}I_{ndc}}{S_n}V_m I_{dc} \quad (14)$$

$$I_{IO} = \frac{V_m}{m_I} \quad (15)$$

A.UPFC

OPERATING PRINCIPLE OF UPFC

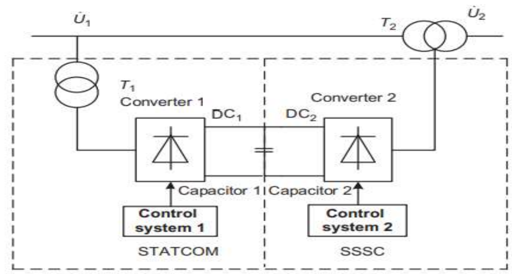

Fig.3. Shows A Basic Representation Of The UPFC Model In A Transmission Line.

The UPFC system is controlled by the two voltage source converter which can be also denoted by the shunt and series converter. The shunt converter and series converter can generate reactive power independently [11]. The independent control of real power and reactive power is essential to maintain the desired voltage level in a transmission system. The UPFC is connected in this system to achieve the independent control of real and reactive power. The real power is independently controlled by varying the angle of voltage injection of the UPFC. The reactive power is controlled by varying the magnitude of shunt voltage injected by the UPFC. The shunt-side VSC exchanges power with the transmission line via a parallel transform, thus realizing the active power transmission and reactive power compensation [12-14].

The purposes of regulation include (1) active power regulation, namely absorbing active power from the grid to compensate the active power consumed in the series side and active power loss of the whole UPFC system; (2) reactive power regulation, namely stabilizing the terminal voltage of the connection point by absorbing or emitting reactive power. To maintain a constant capacitor voltage in the dc side, the inflow and outflow active power of the UPFC should be equal, excluding internal losses throughout the UPFC device, otherwise, the dc capacitor will continuously be charged (or discharged), which makes capacitor voltage increase (decrease). Shunt-side VSC current can be decomposed into two parts, an active component, and a reactive component. The active component supplies the active power of the UPFC's series side. In different situations, the reactive component functions differently [15].

In the reactive power control mode, an inductive or capacitive reactive power control object in the shunt side is converted to the reference value of the reactive current, which is compared with the actual reactive current. The difference between the input value and reference value of the reactive current is converted into a voltage which is utilized as the input signal of the shunt VSC controller.

The shunt part can emit or absorb active power to maintain the stability of the dc capacitor voltage and compensate for active power loss inside the system [16]. The shunt converter is controlled by the shunt controller of UPFC which can perform the function of a variable reactive power source and it is also charging the dc link capacitor. This converter is connected to the transmission line through a shunt-connected transformer. On the other hand series converter is connected by the series transformer which can provide series or phase angle compensation thus the real power is injected into the system by the series branch and performs the main function of UPFC. The DC-link capacitor voltage will preferably be constant. In such a case, series can perform alone because series inverter only supplies/consumes reactive power, not real power [17].

Also, the two VSC's can work independently of each other. So in that case, the shunt converter is operating as a STATCOM that generates or absorbs reactive power to regulate the voltage magnitude at the injection point. Instead, the series inverter is operating as SSSC regulates the current flow, and hence the powers flow on the transmission line [11]. The UPFC has many possible operating modes. (1)VAR control mode:-The reference input is a simple VAR request that is maintained by the control system regardless of bus voltage variation. (2) Automatic voltage control mode:-The shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value with defined slope characteristics the slope factor defines the per unit voltage error per unit of inverter reactive current within the current range of the converter. In particularly, the shunt inverter is operating in such a way to inject a controllable current into the transmission line and the series converter is used to inject a controllable voltage Vse in the transmission line [26-27].

The Harmonic distortion originates in the nonlinear characteristics of devices and loads on the power system. The harmonic distortion is measured in a single quantity as Total Harmonic Distortion (THD). The voltages and currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate is called inter harmonics [18]. It can be found in networks of all voltage levels. The main sources of inter harmonics waveform distortion are power electronic circuits such as static frequency converters, cyclo converters, induction furnaces, and arcing devices. Power line carrier signals are also coming in this category. These harmonics result in failure or misoperation of consumer types of equipment.

The output of the inverter contains odd harmonics. The PWM is considered such that lower-order harmonics are eliminated. Higher-order harmonics are harmless since their magnitude is negligible. The output does not contain even harmonics since the output has odd symmetry. THD is the ratio of harmonic voltage to the fundamental voltage.

A. STATCOM (Static Synchronous Compensator)

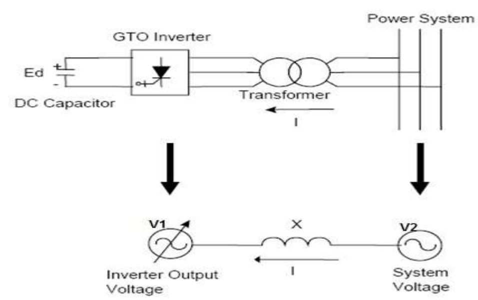

Fig.4. Shows The STATCOM Equivalent Circuit.

The Fig.4 shows the equivalent circuit of a STATCOM system. The GTO converter with a dc voltage source and the power system is illustrated as variable ac voltages in this figure. These two voltages are connected by a reactance representing the transformer leakage inductance [19]. A static synchronous compensator (STATCOM) is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network STATCOM reactive power output is independent of voltage magnitude – i.e. constant current even under low voltage limit. With the commercial breakthrough of high power gate turn-off devices, the road is paved for an additional step forward in the flexibility of AC transmission and distribution systems: STATCOM, or the Static Synchronous Compensator [20].

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The name is an indication that STATCOM has a characteristic similar to the synchronous condenser, but as an electronic device, it has no inertia and is superior to the synchronous condenser in several ways, such as better dynamics, a lower investment cost, and lower operating and maintenance costs. The use of a STATCOM is that the reactive power provision is independent of the actual voltage on the connection point [21-23]. A STATCOM structure is based on Voltage Source Converter (VSC) topology and utilizes either Gate-Turn- off Thyristor (GTO) or Isolated Gate Bipolar Transistors (IGBT) devices. The STATCOM is a very fast-acting, electronic equivalent of a synchronous condenser.

3. CONTROL STRATEGIES

A. PI Controller

The HVDC transmission system traditionally uses the PI controller to control the converter systems. In a two-terminal system, the current margin rule is used, where the rectifier is equipped with a current controller (CC) and the inverter side is equipped with a constant extinction angle (CEA) controller. The inverter system also has a current controller in parallel with a CEA.

An error signal, i.e which is a difference between the measured dc and the reference current, feeds into the PI controller. The proportional and the integral gains of the PI controller act on the error and produce the desired alpha order for the converter. The optimal gain calculation of the PI controller is difficult because the HVDC transmission system is uncertain and nonlinear. Consequently, combined field tests and simulation studies are conducted to fine-tune these gains [24].

B. Fuzzy Logic-Controller

A fuzzy logic-based mechanism is integrated with the PI controller to update the PI controller gains depending on the system's contingencies. The PI controller gains are tuned online by the fuzzy logic using the error and the error rate. The gain tunings are guided by the following basic rules. If both the error and the error rate are positive (or negative), increase the gain by a large positive. If the error is positive and the error rate is negative (or vice versa) decrease the gain by a medium negative. If the error or error rate is zero, increase the gain by a medium positive. If both the error and the error rate are zero, no changes in gain are required [25].

The first step of the fuzzy logic-based controller applications is fuzzification. The inputs to a fuzzy logic-based controller are crisp numbers and need to be fuzzified using membership functions. After fuzzification, a degree of membership between 0 and 1 is assigned. Once the inputs are fuzzified, the degree of membership for each input is known. Now the rules can be applied to achieve the output fuzzy set of the controller. The rules in a fuzzy logic system work in parallel and the output fuzzy set could be influenced by more than one rule. Outputs from all rules are combined to form the aggregated output fuzzy set, which is the input for the defuzzification process. The output of the defuzzification process is a single number for each set of inputs. The commonly used defuzzification methods are centroid, bisector, middle of maximum, largest of maximum, and smallest of maximum.

4. RESULTS AND DISCUSSIONS

Fig.3. shows HVDC system with UPFC the real power output in the line is controlled to obtain steady-state condition when system harmonics is introduced. 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. 5 to Fig. 20 shows the simulation results of HVDC system when Line-line-Line, Line to Line, Double Line to Ground and Line to ground with and without UPFC. From the simulations results, it is observed that when different types of faults i.e. three phase., Line to Line, 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.

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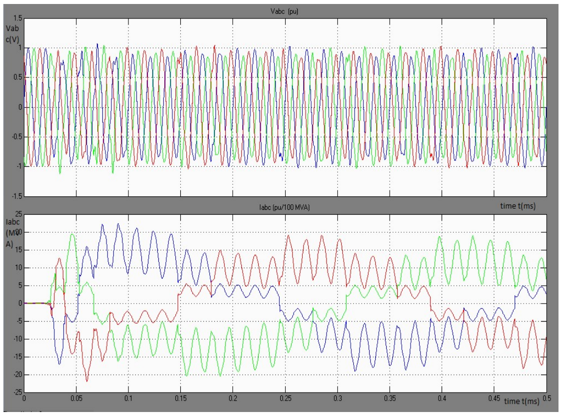

Fig.5. Simulation Results Of Line Voltages And Currents Of HVDC System.

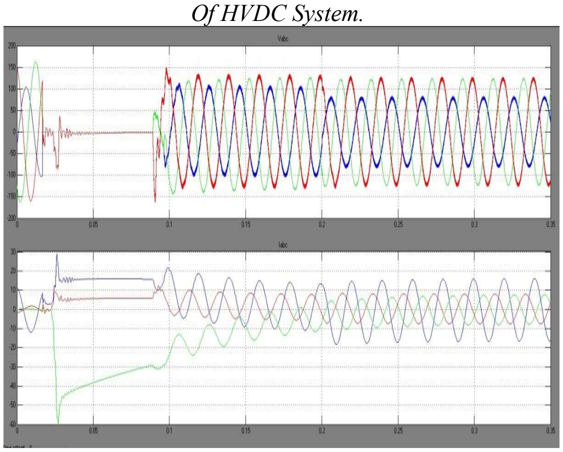

Fig.6. Simulation Results Of HVDC System When LLL Fault On Inverter Side.

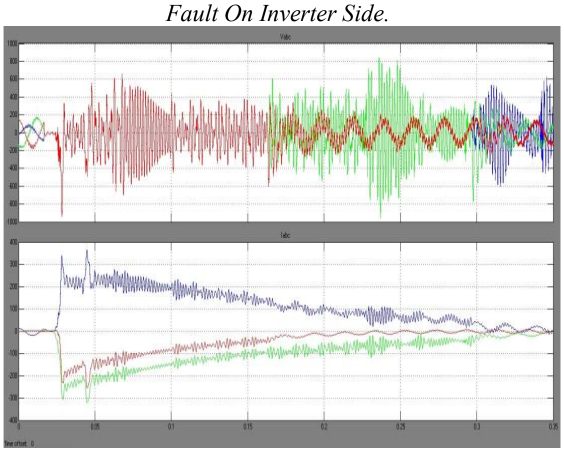

Fig.7. Line Voltages And Line Currents With LLL Fault Using UPFC With PI Controller.

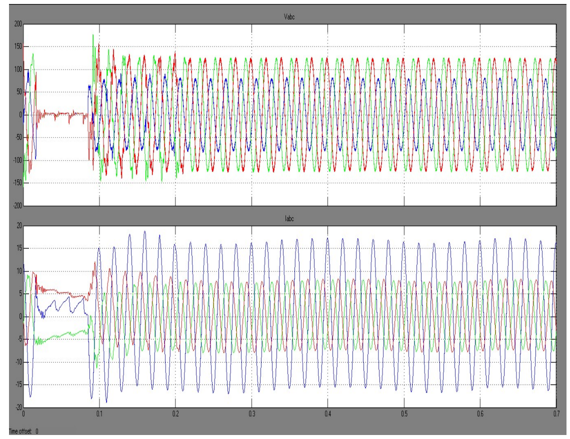

Fig.8. Line Voltages And Line Currents With LLL Fault Using UPFC With FL Controller.

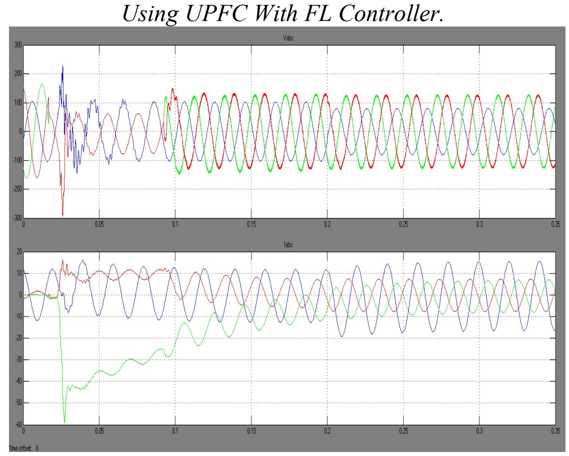

Fig.9. Line Voltages And Line Currents With LL Fault Using UPFC With PI Controller.

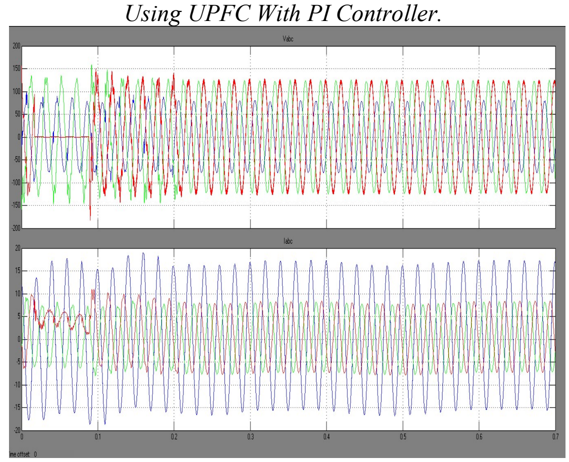

Fig.10. Line Voltages And Line Currents With LL Fault Using UPFC With FL Controller.

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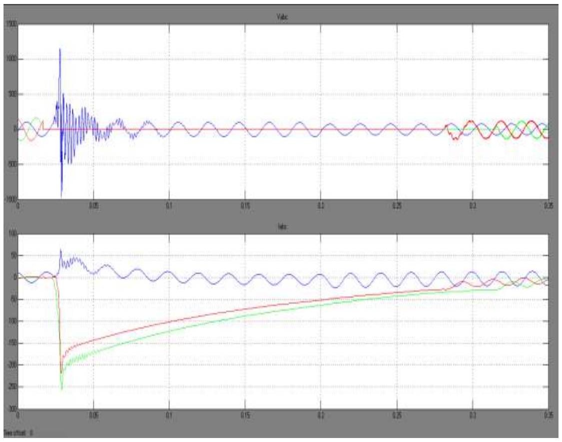

Fig.11. Line Voltages And Line Currents With LLG Fault Occurs On Inverter Side.

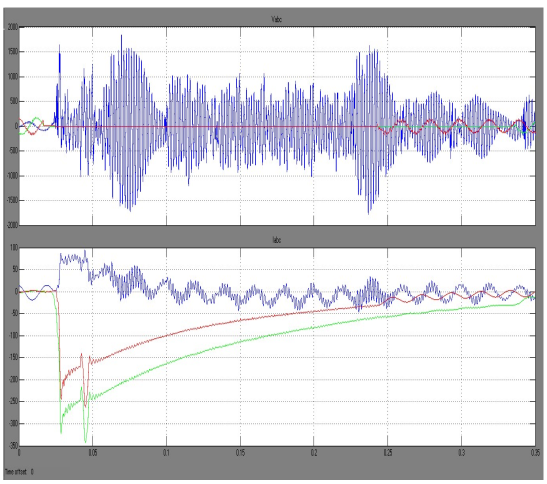

Fig.12. Line Voltages And Line Currents With LLG Fault Using UPFC With PI Controller

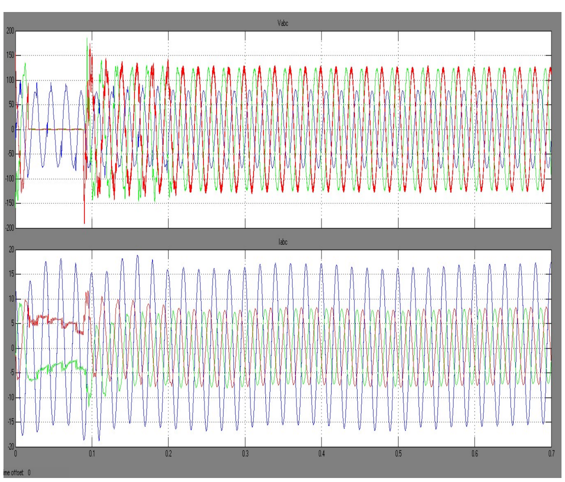

Fig.13. Line Voltages And Line Currents With LLG Fault Using UPFC With FL Controller.

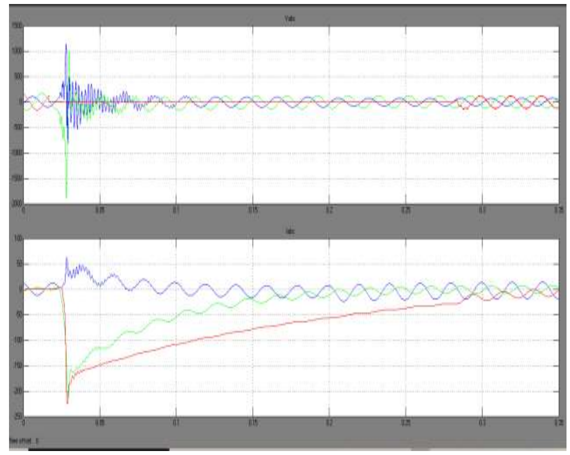

Fig.14. Line Voltages And Line Currents With LG Fault Occurs On Inverter Side.

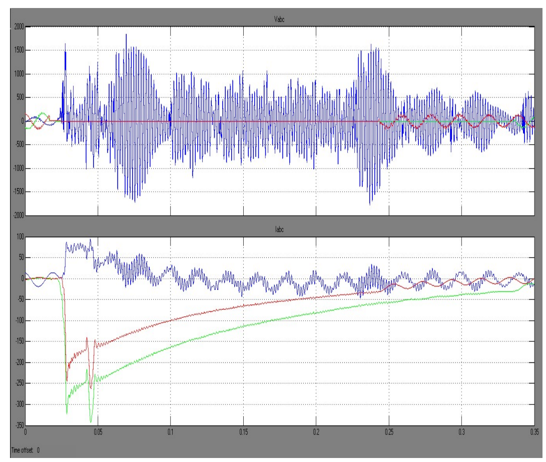

Fig15. Line Voltages And Line Currents With LG Fault Using UPFC With PI Controller.

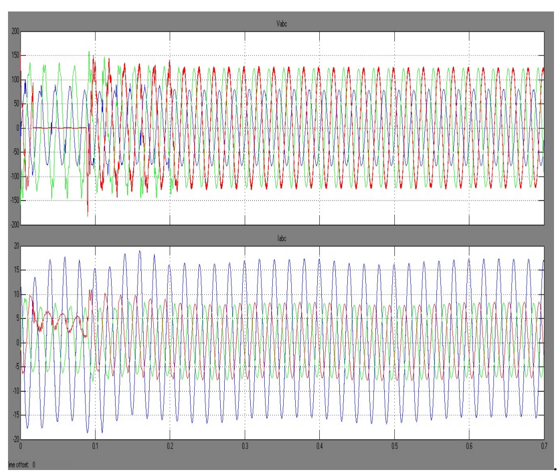

Fig.16. Line Voltages And Line Currents With LG Fault Using UPFC With FL Controller.

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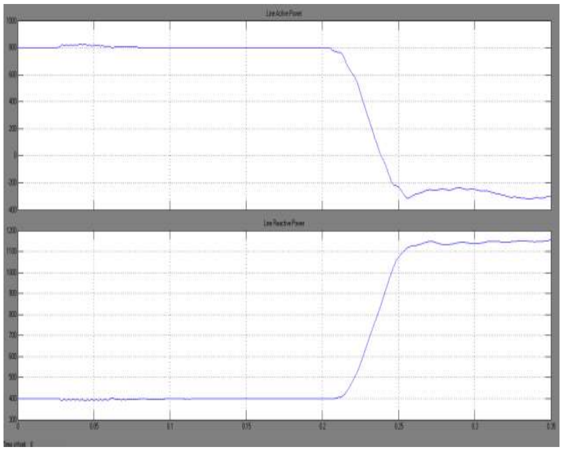

Fig.17. Simulation Result For Line Active And Reactive Powers Of HVDC System Using PI Controller.

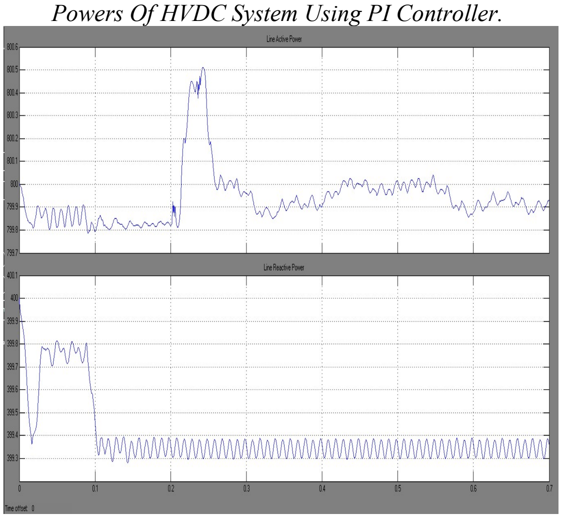

Fig.18. Simulation Result For Line Active And Reactive Powers Of HVDC System Using FLC Controller.

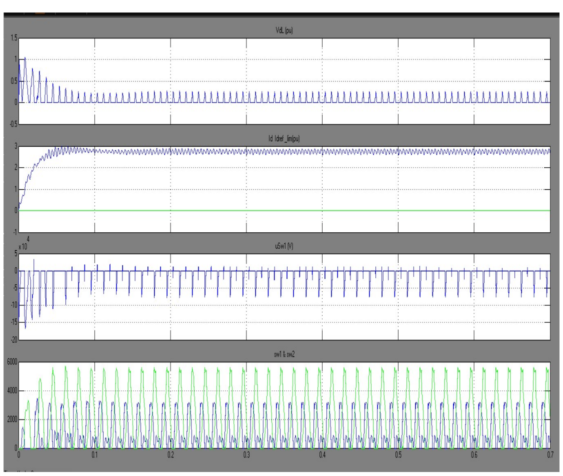

Fig.19. Rectifier Side Performance Under Fault Condition.

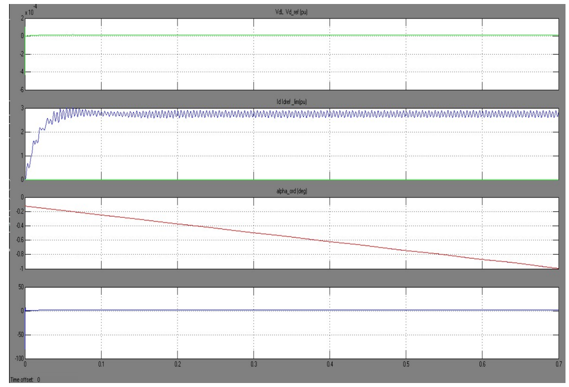

Fig.20. Inverter Side Performance Under Fault Condition.

5. CONCLUSION

The results were obtained by simulating the fuzzy logic-based UPFC of HVDC system performance under various conditions. This research work is aimed mainly two control techniques, which is PI controller and fuzzy logic controller when compared to the PI controller technique fuzzy logic controller is best to reduce the harmonics and ripple contents in the voltage and current waveforms. The performance of current waveforms using a PI controller is more dents and crests with continuous oscillations but with proper utilization of fuzzy logic controller for modulation of HVDC system with UPFC for accurate and fast dc return. Using fuzzy logic controller the peak overshoots are compensated, unlike conventional controllers.

The Matlab/simulation result it shows the superiority and robustness of VSC-based HVDC with UPFC controller has been proved that when there is a small disturbance/fault in the power system, the UPFC with the proposed adaptive fuzzy controller is more effective than the UPFC with the conventional approach. It is concluded that a vast improvement takes place in total harmonic distortion i.e. due to nonlinear load as well as a fault in the transmission line without UPFC. The THD is more which latterly decreased by using UPFC, simultaneously, the UPFC can respond rapidly and recover under fault condition accordingly the controlled real and reactive power were analyzed.

This method is more convenient and innovative to improve the control strategies of HVDC system under fault conditions which will enhance the power transfer capability and reduced line losses with reduced THD and also the problems related to oscillations and overshoot can handle more effectively.

REFERENCES:

[1] L. Gyugyi, "Dynamic compensation of ac transmission lines by solid- state synchronous voltage sources," *IEEE Trans. on Power Delivery*, vol. 9, no. 2, Apr. 1994.

[2] S. Arabi and P. Kundur, "A versatile facts device model for power flow and stability simulations," *IEEE Trans. on Power Systems, vol.* 11, no. 4, Nov. 1996.

[3] V. Ajjarapu and C. Christy, "The continuation power flow: A tool for steady state voltage stability analysis," *IEEE Trans. on Power Systems*, vol. 7, no. 1, Feb. 1992.

[4] Hideaki Fujita, Yasuhiro Watanabe, and Hirofumi Akagi, "Control and Analysis of a Unified Power Flow Controller" *IEEE Transactions on Power Electronics*, Vol.14, No. 6, November 1999.

[5] C.V.Thio, J.B. K. L. Kent, "Commutation failures in HVDC transmission systems", *IEEE Trans. Power Del.*, vol.11, no.2, pp.946-957, Apr.1996.

[6] K. R. Padiyar and A. L. Devi, "Control and simulation of static con- denser," in Proceedings of 1994 *IEEE Power Electronics Conference and Exposition*—ASPEC '94, 1994.

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

[8] V.K. Sood, N. Kandil, R.V. Patel, and K. Khorasani, "Comparative evaluation of neural network based and PI current controller for HVDC transmission," *IEEE Transactions on Power Electronics*, Vol. 9, No. 3, May 1994.

[9] L. Gyugyi, C.D. Schauder, and K. K. Sen, "Static synchronous series compensator: A solid-state approach to the series compensation of transmission lines," *IEEE Trans. Power Delivery*, vol. 12, no. 1, pp. 406–413, 1997.

[10] F.Z. Peng, H. Akagi, and A. Nabae, "A new approach to harmonic compensation in power systems-A combined system of shunt passive and series active filters," IEEE Trans. Ind. Applicat., vol. 26, no. 6, pp. 983–990, 1990.

[11] Y. Xue, X.P. Zhang, and C. Yang, "Elimination of commutation failures of LCC HVDC system with controllable capacitors," IEEE Trans. Power Syst., vol. 31, no. 4, pp. 3289–3299, Jul. 2016.

[12] Christian Melin and Boris Vidolov, (2003) " Two Rule Based Linguistic Fuzzy Controllers", IEEE transaction on fuzzy System, Vol.11, pp.79-87, February.

[13] D.H.Kwon, Y.J.Kim, and S.I.Moon, "Modeling and analysis of an LCC HVDC system using DC voltage control to improve transient response and short-term power transfer capability," *IEEE Trans. Power Del.,* vol. 33, no. 4, pp. 1922–1933, Aug. 2018.

[14] S. Tamai, H. Naitoh, F. Ishiguro, M. Sato, K. Yamaji, and N. Honjo, "Fast and predictive HVDC extinction angle control," *IEEE Trans. Power Syst.*, vol. 12, no. 3, pp. 1268–1275, Aug. 1997.

[15] Narain G. Hingorani, L. Gyugyi, "Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems", *IEEE Press*, 2000.

[16] L. Gyugyi, "Unified power-flow control concept for flexible ac trans- mission systems," Proc. Inst. Elect. Eng., vol. 139, pt. C, pp. 323–331, July 1992.

[17] 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.

[18] T. Nakajima, (2002). "Operating experiences of STATCOMs and a three terminal HVDC system using voltage sourced converters in Japan," in Proc. *IEEE Power Eng. Soc. T&D Conf. Exhib.*, Sep., Vol. 2, pp. 1387-1392.

[19] J. Kuang and B. T. Ooi, (1994). "Series connected voltage-sourced converter modules for forced commutated SVC and dc-transmission," *IEEE Trans. Power Del.*, Vol. 9, No. 2, pp. 977-983, Apr.

[20] S. Rigby and R. G. Harley, "An improved control scheme for a series capacitive reactance compensator based on a voltage source inverter," in *IEEE/IAS* Annul. Meeting, 1996, pp. 870–877.

[21] Q. Yu, S. D. Round, L. E. Norum, and T. M. Undeland, "Dynamic control of a unified power flow controller," in *IEEE PESC'96*, pp. 508–514.

[22] Y. Jiang and A. Ekstrom, "Optimal controller for the combination system of a UPFC and conventional series capacitors," *in EPE'97*, vol. 1, pp. 372–337.

[23] ZHAO, Cheng-yong, Jin-feng LI, and Guang-kai LI. "VSC-HVDC Control Strategy Based on Respective Adjustment of Active and Reactive Power [J]."Automation of Electric Power Systems 9 (2005): 005.

[24] Diaz, Nelson L., Fabian H. Barbosa, and Cesar L. Trujillo. "Analysis and design of a

nonlinear fuzzy controller applied to a VSC to control the active and reactive power flow." *Electronics, Robotics and Automotive Mechanics Conference, 2007*. CERMA 2007. IEEE, 2007.

[25] Weidong, Wang Hui Wang Yaonan Xu. "Investigation of a Power Flow Controller of SSSC Based on Self-Tunning PI Controller with Fuzzy Logic [J]."*Transactions of China Electro technical Society 7* (2004): 013.

[26] Asplund, G., Eriksson, K Svensson, K. (1997). “DC Transmission based on Voltage Source Converters”, *CIGRE SC14 Colloquium on HVDC and FACTS in South Africa*.

[27] R. Andersen, L. Xu, P. Horton, and P. Cartwright, (2002). "Topologies for VSC transmission," *IEE Power Engineering Journal*, Vol. 16, pp. 142-150, June.