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Design and Analysis of Unified Power Flow Controller in Matlab/Simulink by using Fuzzy Logic

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***Abstract*—Flexible Ac Transmission System devices are power electronic based controllers which can control transmission system voltage, current, impedances and phase angle rapidly. Unified power flow controller (UPFC) is an advanced and versatile device of flexible ac transmission systems (FACTS), to control the real and reactive power flow, and to enhance the system stability in the transmission line. This paper discusses the designing of advanced control techniques for the operation of UPFC. The hysteresis controller and up-to-date pi extended fuzzy controller have been designed and tested for controlling series and shunt part of UPFC respectively. As well as the parameters & transmission line lengths has been changed to a different dimension and the results were analyzed by using *MATLAB* software. *MATLAB/ SIMULINK* results indicate that the *TOTAL HARMONIC DISTORTION (THD)* of the Circuit is much reduced, if a fault introduced in the transmission line the voltage recovery occurs by the injected UPFC voltage through a series transformer. Therefore power factor is improved to a great extent. At the same time it controls the efficient flow of real and reactive power in the transmission line in a précised method.**

***Index terms*— Flexible Ac Transmission System(FACTS), Unified Power Flow Controller(UPFC), Static synchronous compensator (STATCOM), Static synchronous series compensator (SSSC), Fuzzy Controller, hysteresis controller, proportional integral(PI)controller, Total Harmonic Distortion (THD) and Power Factor (PF)**

I. INTRODUCTION

The modern power grid is a complicated mesh structure and sometimes suffered from severe congestions [1]. Furthermore, due to the lack of an effective control device (hardware), the grid network has to be/ been overbuilt with lots of excessive capacity, still calling for new lines. Now a days with the increasing demand of electric power, the existing transmission networks are found to be feeble which results in a deprived power quality of unreliable supply system. In order to expand or enhance the power transfer capability of existing transmission network and to full fill the demands of the interconnected systems the concepts of FACTS (Flexible AC transmission system) is developed [2]. FACTS controllers are capable of controlling the network condition in a very fast manner and this feature of FACTS can be exploited to improve the stability of a power system [3-4].

According to *IEEE*, *FACTS* device is "a power-electronic based system and other static equipment that provide control of one or more ac-transmission system parameters to enhance controllability and increase power-transfer capability".

Unified power flow controller *(UPFC)* is such a multi-variable power system *FACTS* controller, now a day it is important to analyze its effect on power system operation [5].

The usual form of the *UPFC* device is consists of two voltage source converters, which are connected through a common DC link capacitor. The first voltage source converter known as static synchronous compensator *(STATCOM)* injects an almost sinusoidal current of variable magnitude at the Point of connection. The second voltage source converter known as static synchronous series compensator (SSSC) injects a sinusoidal voltage of variable magnitude in series with the transmission line [6].

The real power exchange between the converters is carried out through the common DC link capacitor. In the UPFC, the STATCOM and the SSSC are simply connected at their terminals so that each can act as the appropriate real power source or the sink for the other [7]. From the industrial point of view, the unified power flow controller promises reduction in equipment size, simplified design and improvements in system performance [8].

The Controllers adjust the UPFC inputs by appropriate processing of the input error signal (speed deviation), and consequently provides an effective damping. In recent years, the study of UPFC control schemes has attracted increasing attentions, and many approaches have been applied to UPFC controller design, such as robust control, fuzzy control methods [9-10].

The main objective of this paper is to study the performance of UPFC under different uncertain parameters and to design a PI extended Fuzzy logic Controller which meets the design specification is satisfied over the entire parameter set.

A. *Objectives*

The objectives of this paper are to:

- Mathematical analysis of the system before and after UPFC connected in the transmission line.

- Design and Simulation of the UPFC Simulink model with hysteresis and fuzzy controller for controlling series and shunt part of the UPFC respectively.
- Analyze the active and reactive power control through the transmission line and analysis of total harmonic distortion (THD) using computer simulation.
- Analyze the system with fault

II. OPERATING PRINCIPLE OF UPFC

A. *Operating Principle*

The UPFC system is controlled by the two voltage source converter which can be also denoted by the shunt and series converter. Shunt converter and series converter can generate reactive power independently.

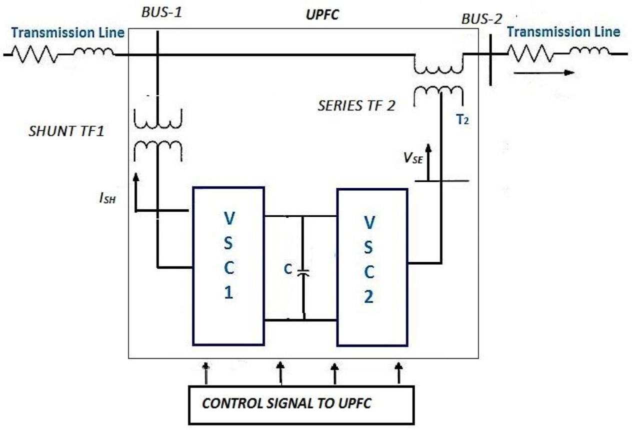

Fig.1. Basic representation of UPFC model present in transmission line

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 charge 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 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 case series can perform alone because series inverter only supplies/consumes reactive power not real power.

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 regulate 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 a 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 Particular, 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 V_{se} in the transmission line.

B. *Mathematical Analysis of UPFC*

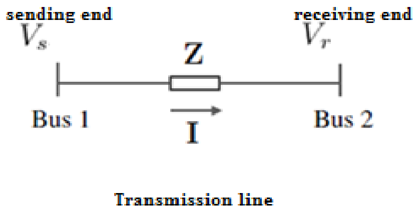

Fig.2. Schematic diagram of Transmission line without UPFC

Here

$V_s = Ve^{-j\emptyset 1}$ is the voltage and phase angle at the sending end

$V_r = Ve^{-j\emptyset 2}$ is the voltage and phase angle at the receiving end

& $I = \frac{V_S - V_r}{Z}$ is the current Phasor, Z is the complex impedance of the line.

The complex AC power transmitted to the receiving end bus can be calculated as follows:

$$S = V_r I^*$$

By neglect the line resistance and capacitance and represent the line as purely inductive, i.e. $Z = JX$ the power transfer across the line is therefore:

$$S = V_r \left[\frac{V_S - V_r}{Z}\right]^*$$

Now

$$\delta = \varphi 2 - \varphi 1$$

δ is called the power angle, which is the phase difference between the voltages on bus 1 and bus 2.

We can see that active and reactive power transfer can be characterized as follows:

$$P = \frac{V_S V_r}{X} \sin \delta \qquad (1)$$

$$Q = \frac{V_r}{X} (\cos \delta - V_r) \qquad (2)$$

After using UPFC the above equation (1) & (2) can be modified as

$$P - jQ_r = V_r \left(\frac{V_s + Vse - Vr}{jX}\right)$$

Where $V_s = Ve^{j\frac{\delta}{2}}$

$V_r = Ve^{-j\frac{\delta}{2}}$

The total real power is

$$P(\delta, \rho) = P_0(\delta) + P_{se}(\rho)$$

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$$P(\delta,\rho) = \frac{V^2}{X}\sin\delta - \frac{VV_{se}}{X}(\cos\frac{\delta}{2} + \rho) \qquad (3)$$

And Reactive power is

$$Q(\delta,\rho) = Q_0(\delta) + Q_{se}(\rho)$$

$$Q(\delta,\rho) = \frac{V^2}{X}(1-\cos\delta) - \frac{VV_{se}}{X}(\sin\frac{\delta}{2} + \rho) \qquad (4)$$

$P(\delta,\rho)$ & $Q(\delta,\rho)$ represents real and reactive powers in the transmission line with *UPFC.*

III. Controller Design Strategy

A. Series Contoller

The hysteresis controller can be made with either a current- or a voltage loop [12]. Here a reference signal is compared with the actual signal with in the hysteresis band, and generates a pulse signal which is used as the input pulse to the series converter.

In the series controller the sending end voltage and injecting voltages from the transformer were compared to generate the error signal which will create a pulse signal.

In this proposed model for the series controller sending and receiving end voltages were compared with each other to generate the pulse. Equation (5), (6), (7) represents the three phase sending end voltages for phase A, phase B and phase C respectively.

$$V_a = V_M \sin wt \qquad (5)$$

$$V_b = V_M \sin(wt - \frac{2\pi}{3}) \qquad (6)$$

$$V_c = V_M \sin(wt + \frac{2\pi}{3}) \qquad (7)$$

Where V_a, V_b, V_c are sending end voltages for Phase A, phase B and phase C respectively

$$e_1 = V_a - V_{a\,comp} \qquad (8)$$

$$e_2 = V_b - V_{b\,comp} \qquad (9)$$

$$e_3 = V_c - V_{c\,comp} \qquad (10)$$

Where e_1, e_2 and e_3 are the error signal of voltages from which pulses are generated. The below figure shows the Simulink model of series converter.

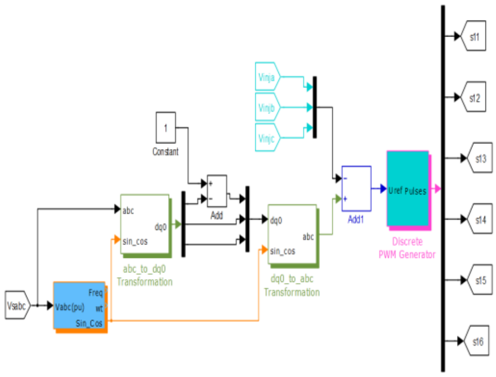

Fig.3. Simulation model of series controller

B. Shunt Controller(Fuzzy Logic Controller)

The shunt control system is based on PI extended fuzzy logic. Fuzzy Logic controller [13] is a one type nonlinear controller and automatic controller. The decision-making process makes use of acceptance, ambiguity, inaccuracy and fuzziness approaching human reasoning in the decision-making process to offer a very satisfactory performance which does not need mathematical model [14].

In the shunt controller the sending end current and load side current were compared and passed through a PI &fuzzy block to generate the error signal which will create a pulse signal.

During the past several years, *FUZZY LOGIC CONTROLLER (FLC)* has emerged as one of the most attractive area of research for the application of fuzzy set theory. The proposed control system is based on the *MAMDANI* fuzzy model which consists of four main parts. The input membership functions are fuzzified based on rule bases and the interfacing system, from which the outputs are produced which are defuzzified and are applied to the main control system.

1) MEMBERSHIP FUNCTION

Fuzzy system uses different shapes of MF's, those are Triangular, Gaussian, Trapezoidal, sigmoid, etc. Membership functions is the range of inputs and outputs for the fuzzy controller. For instance, the fuzzy block and membership functions for the input and output fuzzy controller are shown in Figure

2) TRIANGULAR MEMBERSHIP FUNCTION

The simplest and most commonly used membership functions are triangular membership functions due to the presence of peak point and these are Symmetrical and asymmetrical in shape. Trapezoidal membership functions are also symmetrical or asymmetrical has the shape of truncated triangle.

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3) FUZZY INTERFACE SYSTEM

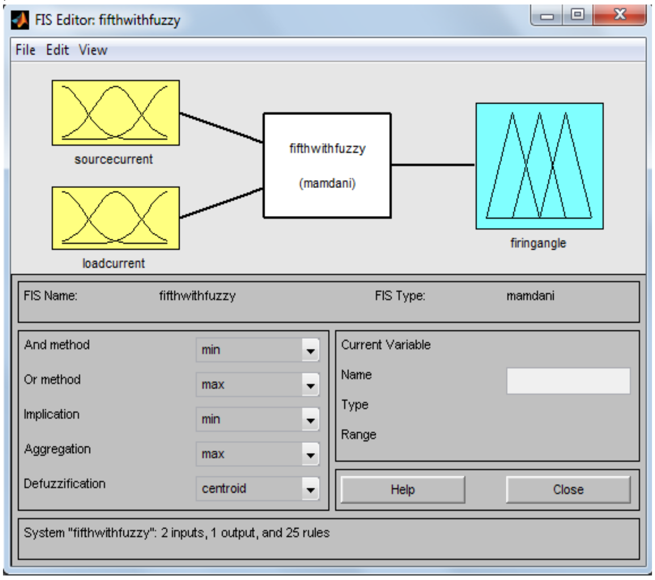

Fig.4. fuzzy interface system

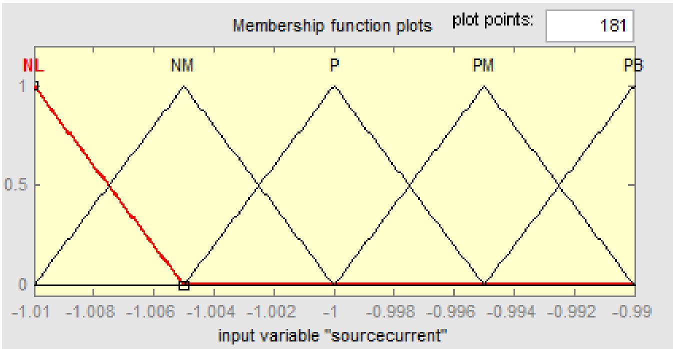

Fig.5. Member ship function for input variable-1(Sending end current)

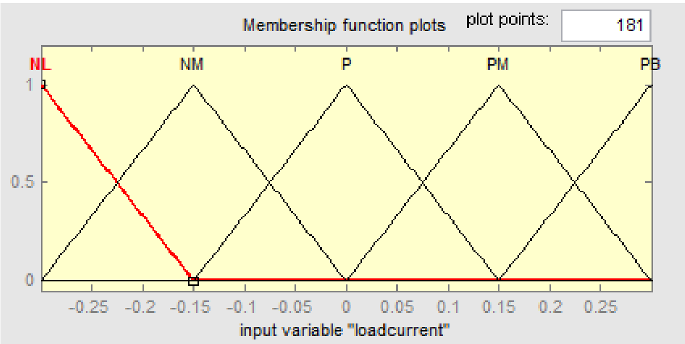

Fig.6. member ship function for input variable-1(receiving end current)

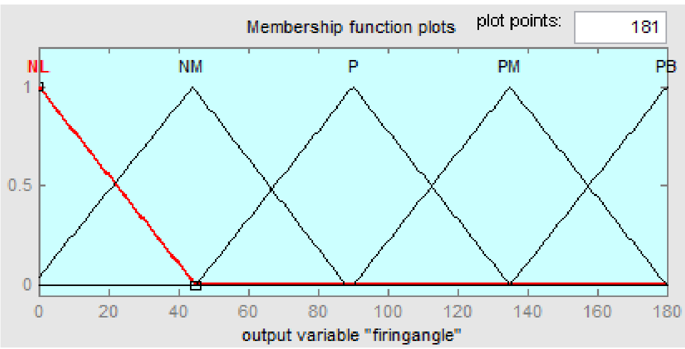

Fig.7. member ship function for output variable

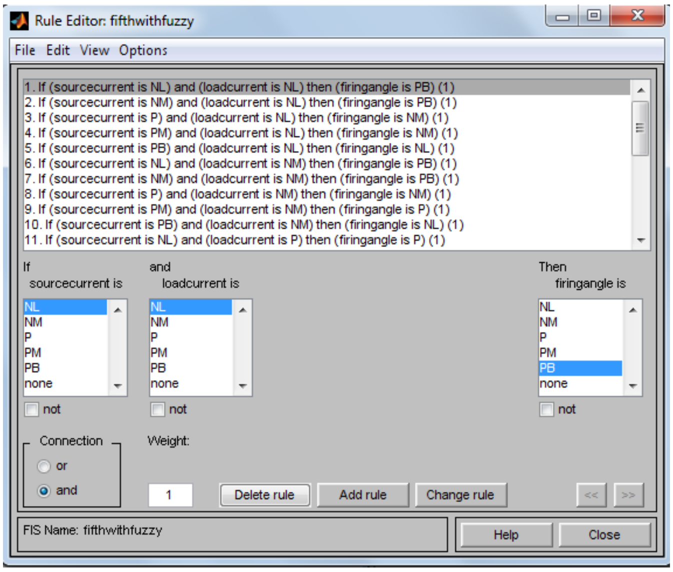

Fig.8. Fuzzy Rule Editor

3) RULE BASE AND INFERENCE ENGINE

Rule base are if-then rules that associates the fuzzy output to the fuzzy input based on the operator's intelligence to achieve a good control. The fuzzy subset on thirty rules with different membership functions is shown in Table I. The fuzzy inference is the process of mapping an input space to an output space by computing the firing strength of each rule based on the degree of match of the defined fuzzy sets by using "max-min" inference technique. In this study mamdani's fuzzy inference method has been used.

	Sending End Current					
		NL	NM	P	PM	PB
Load Current	NL	PB	PB	NM	NM	NL
	NM	PB	PB	NM	P	NL
	P	P	PM	NM	NM	P
	PM	NM	P	NM	NM	PM
	PB	NL	NM	NM	NL	NL

Fig.9. Fuzzy Membership Function Rule used in this paper

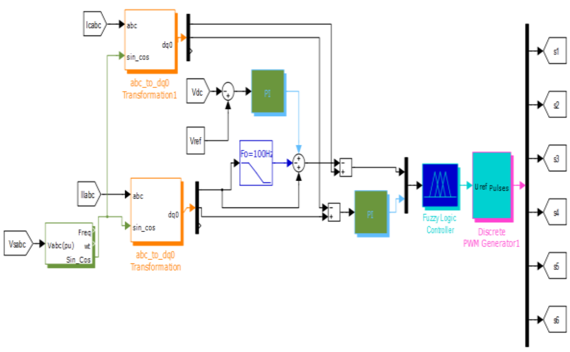

Fig.10. Simulation model of shunt converter

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IV. MATLAB SIMULINK MODELLING AND SIMULATION RESULT

This model shows the simulation of UPFC connected in the *300 KV* line with equivalent transmission line impedances, transformers and loads for interconnected power system.

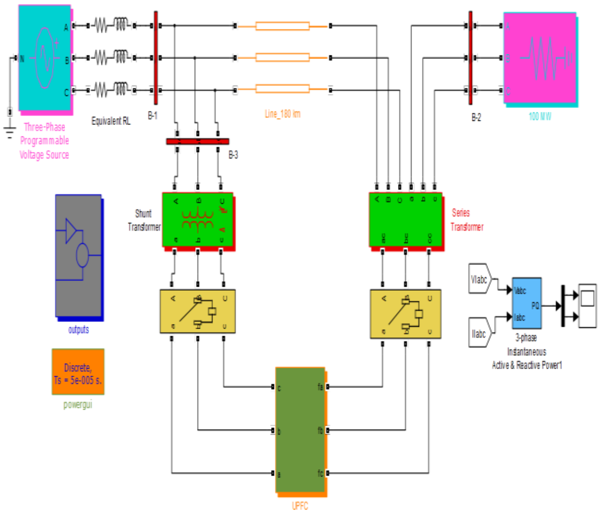

Fig.11. Proposed Simulation model of UPFC

The Fig-12 shows that the sending and receiving end voltage wave forms of the transmission line without using UPFC. Here the receiving end voltage magnitude is zero for the duration of time 0.1 to 0.2 sec, where three phase fault occurred. Due to the absence of controller the transmission line unable to regain the voltage profile.

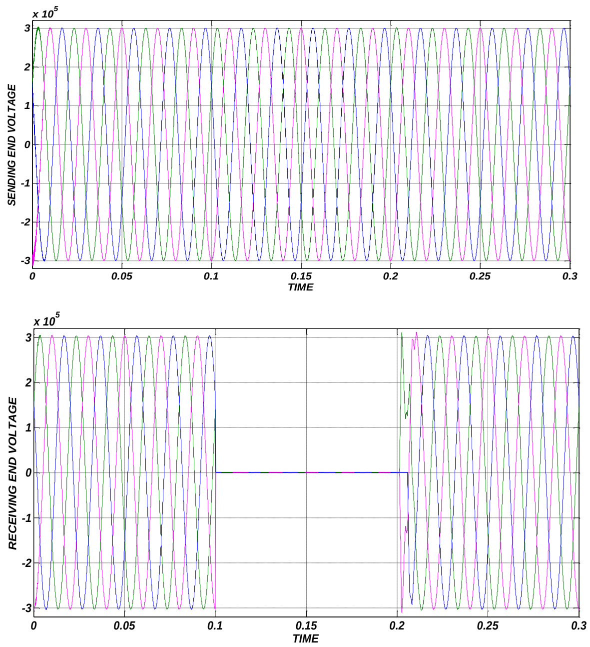

Fig.12 Sending end & Receiving end voltage without UPFC

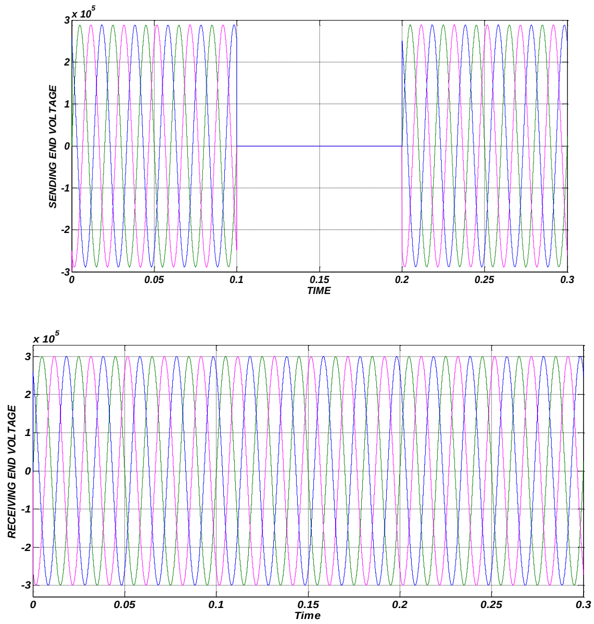

Fig.13 Voltage Recover at fault condition with UPFC

The above waveform represents that due to the presence of fault at transition time 0.1sec to 0.2sec in the transmission line the sending end voltage magnitude is zero, after injecting the UPFC voltage the magnitude of the voltage recovered up to its maximum permissible level under the fault condition.

The below Simulation results shows that the flow of controlled real and reactive power in the transmission line after using *UPFC.*

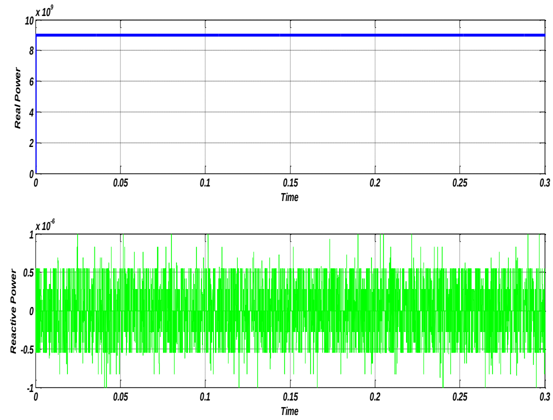

Fig.14 Real & Reactive power flow in Transmission line With UPFC

Total harmonic distortion is an intricate and often confusing concept to grasp. However, when broken down into the basic definitions of harmonics and distortion, generally loads are linear or nonlinear. This type of load is going to affect the power quality of the system. This is due to the current draw of each type of load. Linear loads draw current that is sinusoidal in nature so they generally do not distort the waveform most of the household appliances are categorized as linear loads [15]. Non-linear loads, however can draw current that is not perfectly sinusoidal since the current waveform deviates from a sine wave, voltage waveform distortions are created.

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The below wave form represents the distortion level of voltages with UPFC and without UPFC under fault period which indicates the reduction of THD done by using proposed *PI EXTENDED FUZZY* controller. That is it reduces from 2.64% to 0.40%.

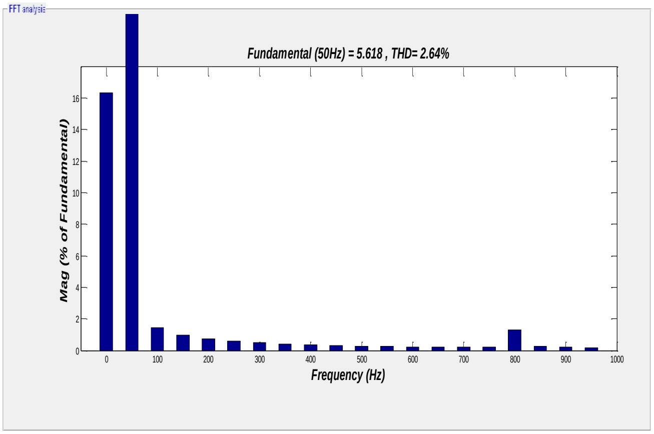

Fig.15 THD Analysis without *UPFC* with fault

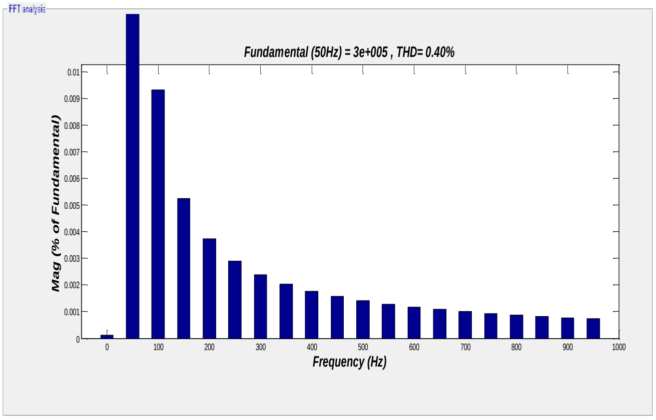

Fig.16 THD Analysis with *UPFC* with fault

V. CONCLUSION

Unified Power Flow Controller (UPFC) is mainly used to maintain and improve power system operation as well as stability. The proposed model is then simulated in Matlab platform on a power system including fault in the transmission line with & without UPFC. The simulation results show, superiority and robustness of UPFC Controller has been proved that when there is small disturbance/fault in the power system, the UPFC with proposed adaptive fuzzy controller is more effective than the UPFC with the conventional. From the result it is concluded that a vast improvement takes place in total harmonic distortion i.e due to nonlinear load as well as fault in the transmission line without *UPFC*, THD is 2.64% which latterly decreased to 0.40%by using *UPFC*, simultaneously, the UPFC can respond rapidly and recover under fault condition accordingly the controlled real and reactive power were analyzed.

VI. REFERENCES

[1] P. Kaymaz, J. Valenzuela, and C. S. Park, “Transmission congestion and competition on power generation expansion,” IEEE Trans. Power Syst., vol. 22, no. 1, pp. 156–163, Feb. 2007.

[2] N. G. Hingorani, L. Gyugyi, "Understanding FACTS; Concepts and Technology of Flexible AC Transmission Systems," IEEE Press book, 2000.

[3] B. T. Ooi, M. Kazerani, R. Marceau, Z. Wolanki, F. D. Galiana, D. McGillis and G. Joos, “Mid-Point Sitting of FACTS Devices in Transmission Lines,” IEEE Transactions on Power Delivery, vol. 12, No. 4, October 1997, pp. 1717-1722.

[4] A. Claudio, T.F. Zeno, "Analysis of SVC and TCSC Controllers in Voltage Collapse", IEEE Transacions on Power Systems, Vol. 14, No. 1, pp. 158-165, 1999.

[5] Kannan Sreenivasachar, Unified Power Flow Controller: Modeling, Stability analysis, Control Strategy and Control System Design, Thesis of PhD, Electrical and computer Engineering, University of Waterloo, Canada, 2001.

[6] B.C. Pal, "Robust damping of interarea oscillations with unified powerflow controller"Power Engineering Society General Meeting, 2003, IEEE, 03 March 2004.

[7] www.coretronix.org

[8] L-Gyugyi, " Unified power-flow concept for flexible ac transmission systems," IEE Proceedings-C, Vol. 139, No.4, July 1992, pp. 323-331.

[9] Kang Mingcai Bo Zhiqian," Reducing of power system low frequency oscillations by UPFC ", International Conference on IEEE, pp.1-6, 21 August 2009.

[10] Dash, P.K.Morris, S.Mishra, S.” Design of a nonlinear variable-gain fuzzy controller for FACTS devices ” Control Systems Technology, IEEE Transactions on , vol.12, pp: 428 – 438, 2004.

[11] A.Jayalaxmi, Tulasi Ram Das, K. Uma Rao” Design, Control And Simulation Of Unified Power Flow Controller Using Matlab” International Conference.

[12] Kedar Patil1PG Student [EPS], M&V Patel Department of Electrical Engineering, CHARUSAT, Changa, India 1” Harmonic Analysis of Sine PWM and hysteresis current controller” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering *(An ISO* 3297: 2007 Certified Organization) Vol. 2, Issue 11, November 2013.

[13] A hybrid of fuzzy and proportional-integral derivative controller for electro-hydraulic position servo system. Energy Res. J., 1: 62-67. DOI: 10.3844/erjsp.2010.62.67Saha, S.K., 2010.

[14] “Simulation and Analysis of a Static Synchronous Series Compensator for Power System Stability Enhancement with Fuzzy Controller” journal of electrical and electronics engineering ISSN-4567-7860.

[15] ” Total Harmonic Distortion and Effects in Electrical Power Systems” by Associated Power Technologies.