International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in

Vol.3., Issue.3, 2015

RESEARCH ARTICLE

ISSN: 2321-7758

FUZZY LOGIC CONTROLLER BASED DISTRIBUTED POWER FLOW CONTROLLER (DPFC) FOR MITIGATING VOLTAGE SAG AND CURRENT SWELL IN THE TRANSMISSION LINE

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Article Received:13/05/2015 | Article Revised on:21/05/2015 | Article Accepted on:31/05/2015

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ABSTRACT

The growing demand and the aging of networks make it desirable to control the power flow in power-transmission systems fast and reliably. The load variation causes fluctuation in voltage in transmission lines and it must be limited, otherwise the consumer's equipment are damaged at distributed side. For reducing these types of fluctuation DPFC is used. The DPFC (Distribute Power-Flow Controller) is modified from UPFC for increasing system reliability and reducing costs. This paper consists of both voltage sag and current swell mitigation problems, using MATLAB/SIMULINK and it is simulated and its effects on the transmission lines is observed. In this paper DPFC is controlled with the help of Fuzzy logic based controller to get the minimized total harmonic distortion, mitigate voltage sag and current swell.

Keywords— Distributed Power Flow Controller, FACTS, Fuzzy logic, Power Quality, Sag and Swell Mitigation

INTRODUCTION

Power Quality is becoming an important issue for both electric utilities and end users [1] .It is defined as the index which both the delivery and consumption of electric power affect on the performance of electrical apparatus [2]. From a customer point of view, a power quality problem can be defined as any problem is manifested on voltage, current, or frequency deviation that results in power failure [3]. The power electronics progressive, especially in flexible alternating-current transmission system (FACTS) and custom power devices,affects power quality improvement [4], [5]. Generally, custom power devices, e.g., dynamic voltage restorer (DVR), are used in medium-to-low voltage levels to improve customer power quality [6]. Most serious threats for sensitive equipment in electrical grids are voltage sags (voltage dip) and swells (over voltage) [1]. These disturbances occur due to some events, *e.g.,* short circuit in the grid, inrush currents involved with the starting of large machines, or switching operations in the grid. The FACTS devices, such as unified power flow controller (UPFC) and synchronous static compensator (STAT-COM), are used to alleviate the disturbance and improve the power system quality and reliability [7], [8].. In this paper, a distributed power flow controller, introduced in [9] as a new FACTS device, is used to mitigate voltage and current waveform deviation and improve power quality in a matter of seconds. The DPFC structure is derived from the UPFC structure that is included one shunt converter and several small independent series converters, as shown in Fig. 1 [9]. The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude [10]. The paper is organized in following sections. In section II, the DPFC principle is discussed. The DPFC control is described in section III.. Simulation results are presented in section V.

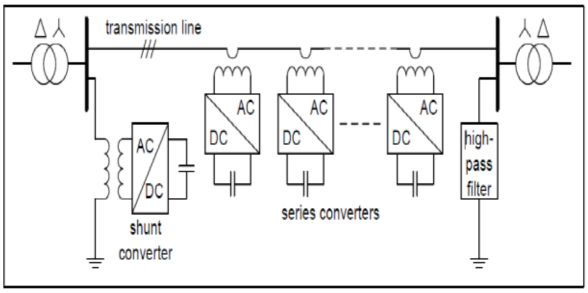


Fig.1 The DPFC structure

II. PRINCIPLE OF THE DPFC

Multiple individual converters cooperate together and compose the DPFC.The converters connected in series to the transmission lines are the series converters. They can inject a controllable voltage at the fundamental frequency; consequently they control the power flow through the line. The converter connected between the line and ground is the shunt converter. The function of the shunt converter is to compensate reactive power to the grid, and to supply the active power required by the series converter. In a normal UPFC, there is active power exchange through the DC link that connects the series converter with the shunt converter. In comparison with UPFC, the main advantage offered by DPFC is eliminating the huge DC-link and instate using 3rdharmonic current to active power exchange [9]. In the following subsections, the DPFC basic concepts are explained.

Eliminate DC Link and Power Exchange

Within the DPFC, the transmission line is used as a connection between the DC terminal of shunt converter and the AC terminal of series converters, instead of direct connection using DC-link for power exchange between converters. The method of power exchange in DPFC is based on power theory of non-sinusoidal components [9]. Based on Fourier series, a non-sinusoidal voltage or current can be presented as the sum of sinusoidal components at different frequencies. The product of voltage and current components provides the active power. Since the integral of some terms with different frequencies are zero, so the active power equation is as follow:

$$p = \sum_{i=1}^{\infty} V_i I_i \cos \varphi_i \qquad \text{..........(1)}$$

Where V_i and I_i are the voltage and current at the i^{th} harmonic, respectively, and φ_i is the angle between the voltage and current at the same frequency. Equation (1) expresses the active power at different frequency components are independent. Based on this fact, a shunt converter in DPFC can absorb the active power in one frequency and generates output power in another frequency. Assume a DPFC is placed in a transmission line of a two-bus system, as shown in Fig.2.

While the power supply generates the active power, the shunt converter has the capability to absorb power in fundamental frequency of current. Meanwhile, the third harmonic component is trapped in Y-Δ transformer. Output terminal of the shunt converter injects the third harmonic current into the neutral of Δ-Y transformer (Fig. 2). Consequently, the harmonic current flows through the transmission line. This harmonic current controls the DC voltage of series capacitors.The third harmonic is selected to exchange the active power in the DPFC and a high-pass filter is required to make a closed loopfor the harmonic current. The third-harmonic current is trapped in Δ-winding of transformer. Hence, no need to use the high-pass filter at the receiving-end of the system. In other words, by using the third-harmonic, the high-pass filter can be replaced with a cable connected between Δ-winding of transformer and ground. This cable routes the harmonic current to ground.

III. DPFC CONTROL

The DPFC has three control strategies: central controller, series control, and shunt control, as shown in Fig.2.

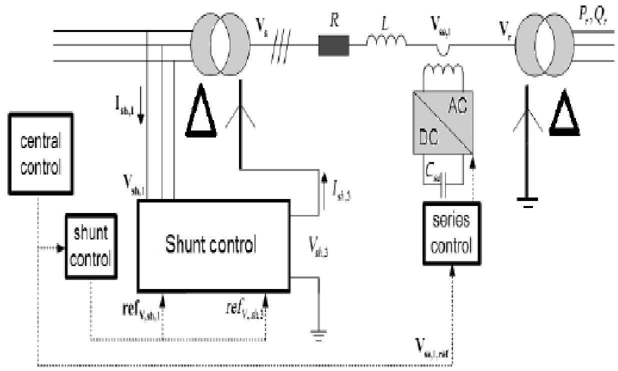


Fig.2 DPFC control structure

A. Central Control

This controller manages all the series and shunt controllers and sends reference signals to both of them.

B. Series Control

Each single-phase converter has its own series control through the line. The controller inputs are series capacitor voltages, line current, and series voltage reference in the d-q frame. Any series controller has a low-pass and a 3rd-pass filter to create fundamental and third harmonic current, respectively. Two single-phase phase lock loop (PLL) are used to take frequency and phase information from network. The block diagram of series controller in Matlab/Simulink is shown in Fig.6. The PWM-Generator block manages switching processes.

C. Shunt Control

The shunt converter includes a three-phase converter connected back-to-back to a single-phase converter. The three-phase converter absorbs active power from grid at fundamental frequency and controls the dc voltage of capacitor between this converter and single-phase one. Other task of the shunt converter is to inject constant third-harmonic current into lines through the neutral cable of Δ-Y transformer.

D. Fuzzy logic control

Fuzzy logic controller is becoming an increasing area of research in power electronics, this controller is based on the fuzzy set theory which takes its fundamentals from human thinking A fuzzy controller consists of stages: fuzzification, knowledge base, inference mechanisms, and defuzzification. The knowledge base is composed of a data base and a rule base, and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbances.The data base, consisting of input and output membership functions, provides information for the appropriate fuzzification operations, the inference mechanism,and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert the fuzzy outputs into control signals [7, 8].

Basic fuzzy algorithm

The fuzzy controller is characterized as follows:

1- Seven fuzzy sets for each input and outputs: NB (negative big) NM(negative medium), NS (negative small), ZE (zero), PS (positive small), PM(positive medium), PB (positive big).

2- Triangular membership functions for simplicity.

3-Fuzzification using continuous universe of discourse.

4- Implication using Mamdani's operator.

5-Defuzzification using the 'height' method.

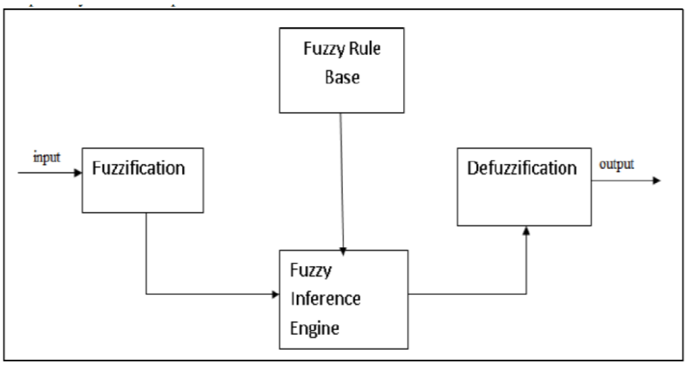


Fig.3 Internal structure of fuzzy logic controller

Design of control rules

The fuzzy control rule design involves defining rules that relate the input variables to the output model properties. For better control performance finer fuzzy partitioned subspaces are used and summarized in table no1:

V_{dcref} / V_{dc}	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Table 1 Rule base

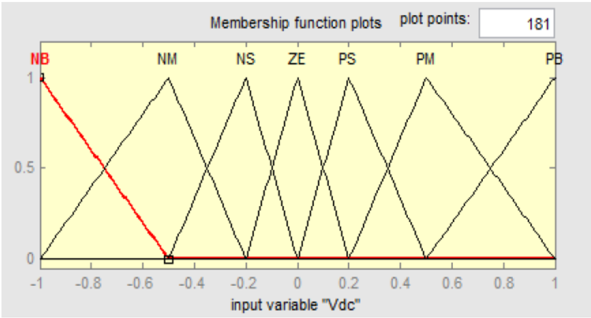


Fig4. Normalized trapezoidal membership functions used in Fuzzification(V_{dc})

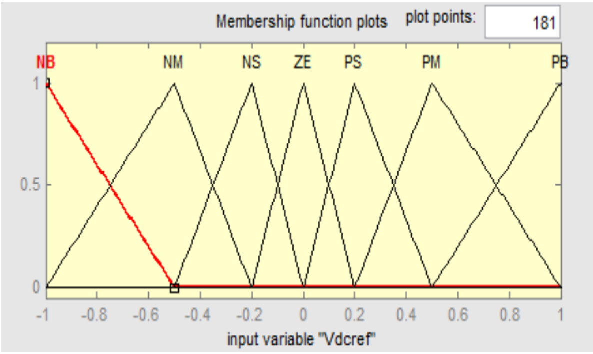


Fig.5 Normalized triangular membership functions used in Fuzzification(V_{dcref})

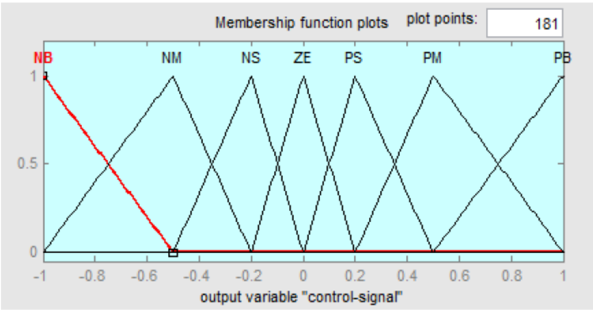


Fig.6 Normalized triangular membership functions used in Fuzzification(Output)

Simulink model of DPFC connected to the transmission line

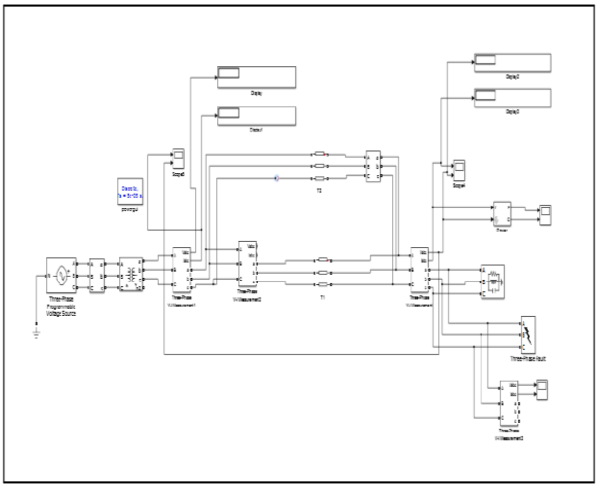


Fig.7 Simulink model of two bus system connected with single machine without DPFC

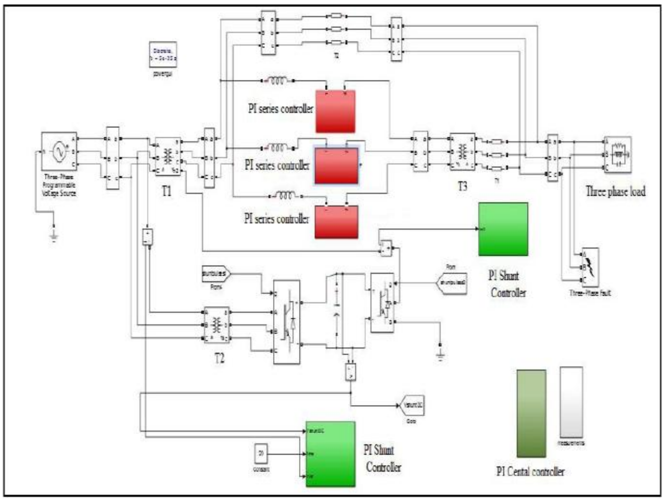


Fig 8 Simulink model of two bus system connected with single machine with fuzzy based DPFC

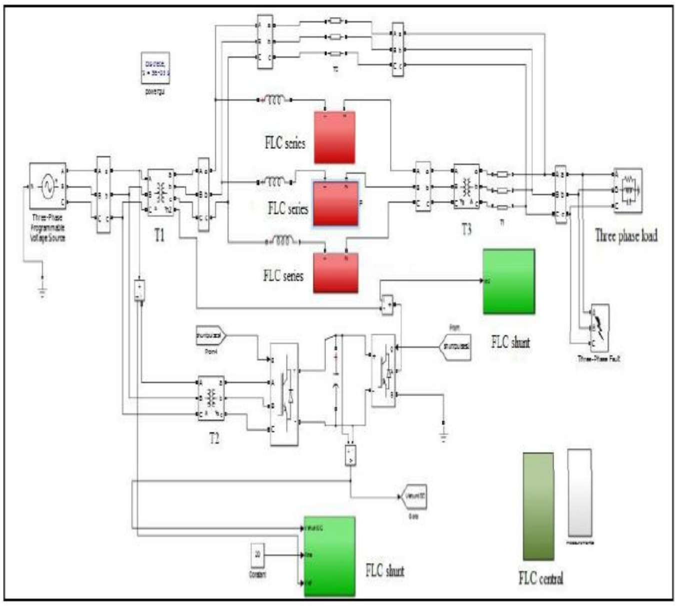


Fig .9 simulink model of two bus system connected with single machine with fuzzy based DPFC

V. SIMULATION RESULTS

In this paper we have considered the two bus system with single machine connected with DPFC. We have compared the simulation results of system without controllers, with PI based controllers and at last with Fuzzy based controllers The whole model of system under study is shown in Fig. 9. The system contains a three-phase source connected to a nonlinear RLC load through parallel transmission lines (Line 1 and Line 2) with the same lengths. The DPFC is placed in transmission line, which the shunt converter is connected to the transmission line 2 in parallel through a Y-Δ three- phase transformer, and series converters is distributed through this line.To simulate the dynamic performance, a three-phase fault is considered near the load. The time duration of the fault is 0.5 seconds (500-1000 millisecond). The voltage sag value is about 0.5 per unit. After adding a DPFC, load voltage sag can be mitigated effectively, as shown in Fig. 14 and 15.

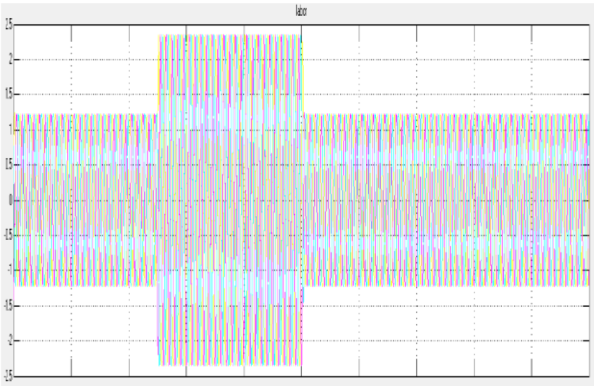


Fig.10 waveform of three phase load current swell without DPFC

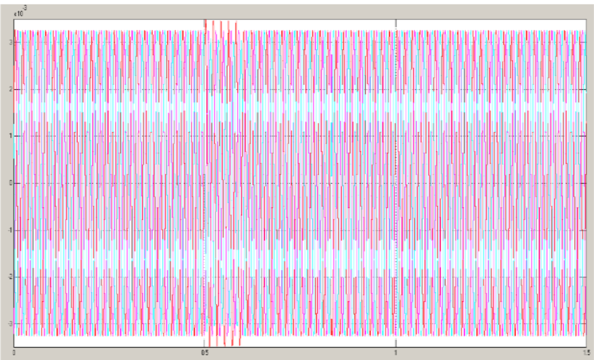


Fig.11 mitigation of three phase load current swell with PI based DPFC

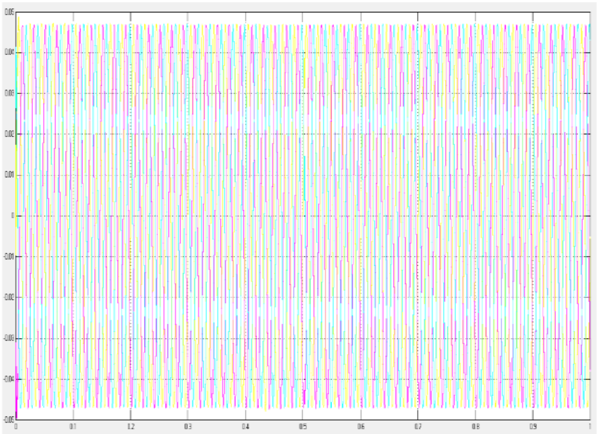
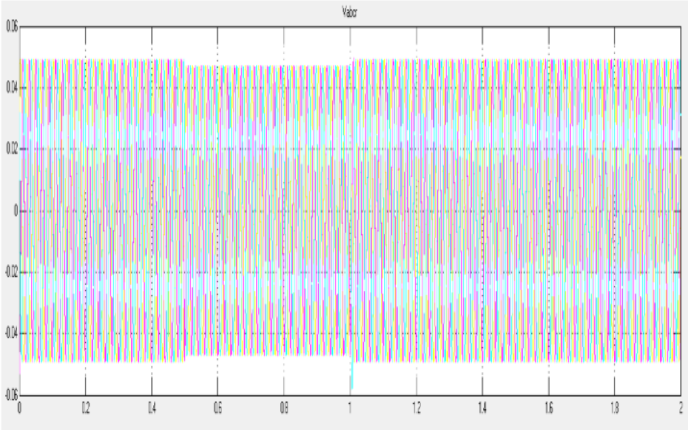


Fig12.mitigation of three phase load current with fuzzy based DPFC



Fig,13 waveform of three phase load voltage sag withou DPFC

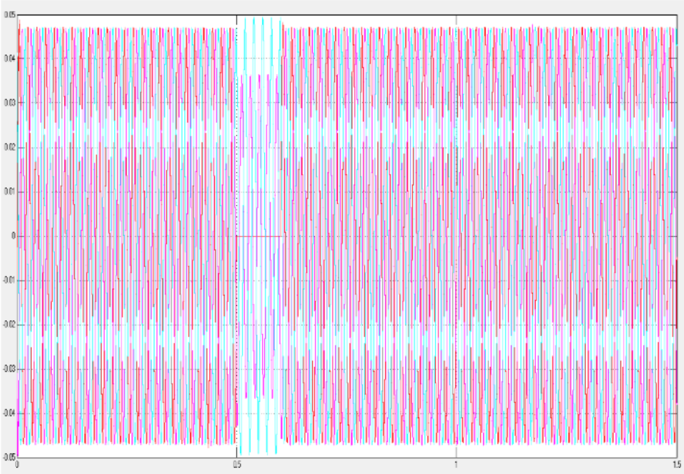


Fig.14 mitigation of three phase load voltage sag with PI based DPFC

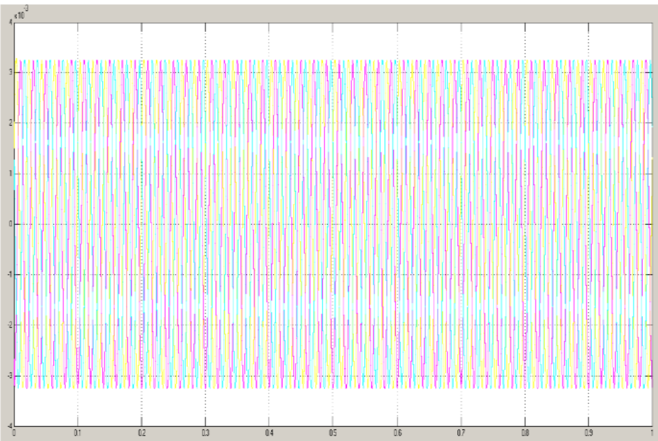


Fig.15 Mitigation of three-phase load voltage sag with DPFC (With Fuzzy)

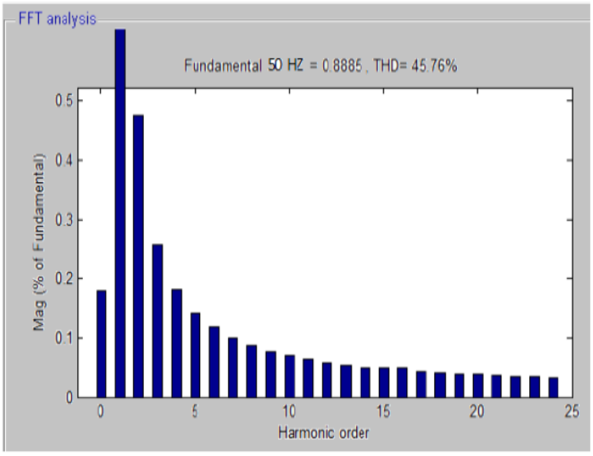


Fig.16 Total harmonic distortion of load voltage without DPFC

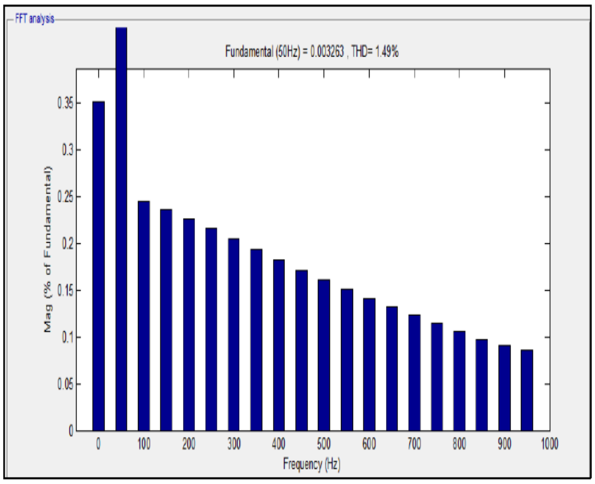


Fig.17 Total harmonic distortion of load voltage with DPFC (with PI)

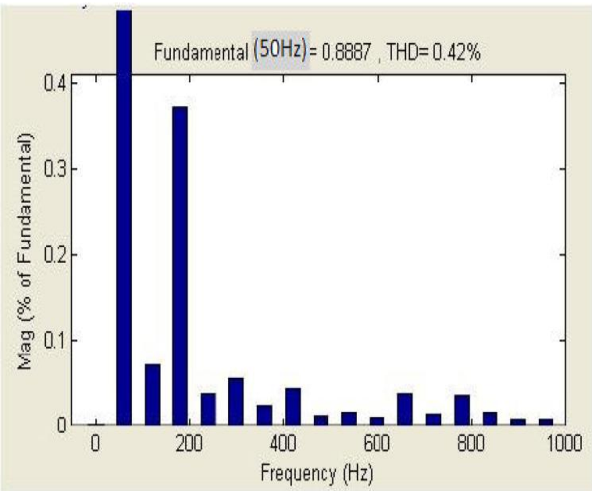


Fig.18 Total harmonic distortion of load voltage with DPFC (with fuzzy)

After implementation of the DPFC, the load current swell is removed effectively. The current swell mitigation for this case can be observed from The load voltage harmonic analysis with PI controller presence of DPFC is illustrated in Fig. 17. It can be seen, after DPFC implementation in system, the even harmonics is eliminated ,the odd harmonics are reduced within acceptable limits, and total harmonic distortion (THD) of load voltage is minimized to 1.49% (with PI) and to 0.42% (with Fuzzy), i.e., the standard THD is less than 5 percent in IEEE standards .From all the above simulate results, it is proved that fuzzy controller gives the better performance compared to conventional one i.e., PI controller

VI. CONCLUSION

In this paper, the voltage and current sag and swell mitigation, using a new FACTS device called distributed power flow controller (DPFC) is presented. However, the DPFC offers some advantages, in comparison with UPFC, such as high control capability, high reliability, and low cost. The DPFC is modelled and three control loops, i.e. central controller, series control, and shunt control are design. The system under study is a single machine infinite-bus system, with and without DPFC. To simulate the dynamic performance, a three-phase fault is considered near the load. It is shown that the DPFC gives an acceptable performance in power quality mitigation and power flow control. As the simulation results shown it gives the comparison of PI and fuzzy, from that result we can say fuzzy logic controller gives the improved power quality compared than PI controller.

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