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RESEARCH ARTICLE

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ENHANCEMENT OF POWER QUALITY OF A DISTRIBUTION SYSTEM USING DPFC WITH FUZZY CONTROLLER

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ABSTRACT

The new inventions in technology lead to more power consumption by more number of nonlinear loads, which in turn affecting the quality of power transmitted. The power transmitted in a line is needed to be of high quality. The flow of power basically depends on the line impedance, sending end and receiving end voltage magnitudes. The DPFC is a new FACTS device, employs the distributed FACTS (D-FACTS) concept, which is to use multiple small-size single-phase converters instead of the one large-size three-phase series converter as in the UPFC. The DPFC has the same control capability as the UPFC, which comprises the adjustment of the line impedance, the transmission angle, and the bus voltage. The principle and analysis of the DPFC are presented in this research and the corresponding experimental results are shown. The proposed method introduces low cost low power rating DPFC in Single Machine connected to Infinite Bus system which improves the power quality. In this project to address power quality issues such as swell, sag a fuzzy controller based DPFC is proposed. The performance of proposed DPFC with fuzzy controller is compared to DPFC with PI controller.

Key Words—Power quality, D-FACTS, UPFC, DPFC, SMIB, PI controller and fuzzy controller.

I INTRODUCTION

In the last few decades, the main concern for many electrical power supplying companies is that the power quality. It is defined as the index in which both the delivery and consumption of electric power affect on the performance of electrical apparatus from a customer point of view. It mainly occurs due to the deviations in voltage, current, or frequency and which leads to power failure. In order to enhance the power quality, it is necessary to attach the transmission line with some special equipment like Flexible AC Transmission system (FACTS) devices [1] and custom power devices. A dynamic voltage restorer (DVR) is a custom device used to improve power quality [3] of a customer and which is applied at medium-to-low voltage cases. Voltage sag is a serious problem for the devices connected in the grid and is defined as a dip in the voltage level less than1pu and the other problem is voltage swell and is represented as a rise of voltage level in the power system greater than 1pu. The main causes for voltage sags and swells are grid short circuits, operation of switches in a grid and also due to development of high currents during starting. The important FACTS device are Unified Power Flow Controller (UPFC), Static Synchronous Compensator (STAT-COM), Static Synchronous Series Compensators (SSSC) etc, reduce the disturbances that occur in the transmission system and then improves reliability of a system and also enhances power quality.

II Introduction of DPFC

A Distributed Power Flow Controller (DPFC) decreases waveform deviations of a current and voltage in a distribution system which occurs during faults and hence power quality will be improved in few seconds [1].The DPFC model is based on the structure of UPFC, which has shunt converter and so many small series converters acting independently, which is shown in Fig.1.The DPFC can balance the line parameters as UPFC with more reliability and less effective cost than that of UPFC.

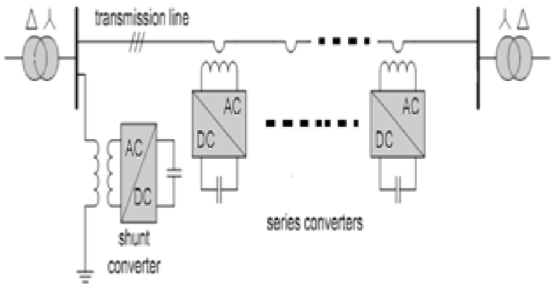

Fig.1: The DPFC Structure

DPFC device is proposed to decrease waveform deviations in current and voltage in a system, and hence power quality will be improved in few seconds. In general, during fault conditions voltage fluctuations occur for different loads at the receiving end. The constant voltage and current are maintained by designing a Fuzzy Logic Controller (FLC) [7], which maintains a flat voltage profile. Variations in the voltage occurs due to different load resistance, capacitance and inductance values, for this purpose a FLC is designed, that controls the firing angle of both the shunt converter and series converter and which automatically maintains the receiving end voltage constant.

III Power Quality and its importance

In the recent years, researchers are facing huge number of power quality disturbance, in order to overcome this problem many of the researchers came out with good results. Maintaining better power quality is a significant point for domestic, commercial and industrial users now-a-days. Another main problem in the power system is voltage sag (also known as under-voltage condition), during which high current will enter in to the transmission system by any means of fault or a short circuit. In customer opinion a power problem is deviation in voltage, high or low current flow and change in frequency causes equipments to be failed.To overcome the voltage sag and swell problems fast acting power electronics based FACTS devices are introduced [6]. IEEE defined FACTS as 'FACTS is a power electronic systemand consists of static devices which offer command over one (or) more system parameters to raise power transfer capacity and improve controllability and used to control the power flow'.

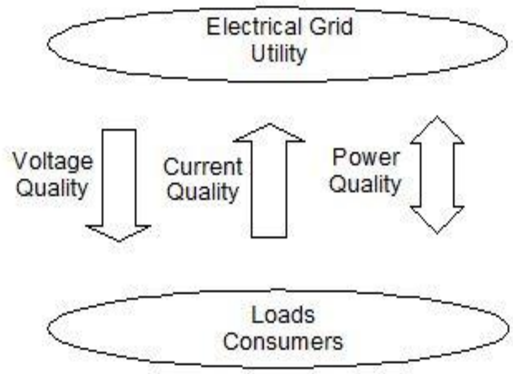

Fig 2:Power Quality Diagram

The above diagram shows power flow of a general power system from electrical grid to consumers by maintaining better power quality which is possible only when voltage and current fluctuations are mitigated whenever faults occur in the system. The Electric Power Research Institute(EPRI) had given a harsh evaluation of 15% - 20% of the mass electric loads were non-linear in the year 1992 and which is still continuing and reached to 50% -70% of the total loads in the year 2000.In this work a new device of FACTS family known as DPFC is introduced with low cost compared to UPFC which mitigates voltage sags and swells during fault by employing PI controller and Fuzzy logic controller.

A) Causes for degradation of power quality:

The main reasons that affect power quality are voltage sags or swells, harmonics and their types, voltage and frequency imbalance, transients etc.

Another main cause for degradation of power quality is bulk use of non-linear loads.

Sag: It is the main problem associated with the power quality which mostly affects industrial equipments and commercial customers. Voltage sag occurs randomly and hence becomes hard to estimate. A survey revealed that 87% of voltage disturbances occurs on industries is voltage sag, [6] mostly L-G fault.

Swell: It occurs during a L-G fault with a temporary rise in the voltage on the un-faulted phase. Swells are not similar to voltage dips, which are defined by both fault magnitude and its period of occurrence.

Harmonics: It is an integral multiple of the fundamental frequency normally 50 or 60 Hz. It is one of the main cause for waveform distortion. Loads like discharge lighting, electric arc furnaces etc., creates harmonics which leads to poor power quality.

Total Harmonic Distortion,

$$(THD_i) = \left[\frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \right] \quad \text{...........(1)}$$

The maximum allowable THD is 5% above which the devices fail to operate in a convenient way. These problems can be mitigated by using FACTS devices. There are several types of them, [2] it is due to the individual static and dynamic properties.

B) Types of FACTS devices:

The FACTS technology opened up the use of power controlling in the transmission line and also enhance the capacity of transmission system. The FACTS controllers are mainly classified into SERIES, SHUNT, SERIES-SHUNT type of controllers. Some of the important Facts devices are SVC, STATCOM, TCSC, SSSC, UPFC, DPFC, etc. In this paper a new member in the family of FACTS i.e, DPFC is taken. This paper explains the advantages of DPFC over other devices. The use of DPFC is economical and reliable and hence can be adopted in power system to mitigate the disturbances that occur during the faults. Thus, it can replace UPFC in a transmission system.

IV Working Principle of DPFC

A) Active power exchange by eliminating DC-link:

The main advantage of DPFC is that active power exchange can take place between the two converters without a common DC-link [4]. It adopts power theory of non-sinusoidal components. According to Fourier analysis, non-sinusoidal voltage and current can be expressed as the sum of sinusoidal functions in different frequencies with different amplitudes. The active power resulting from it is defined as the mean value of the product of voltage and current. Since the integrals of all the cross product of terms with different frequencies are zero, the active power can be expressed by:

$$P = \sum_{i=1}^{\infty} V_i I_i \cos\phi_i \quad \text{...............(2)}$$

B) Using third harmonic frequency components:

The other main feature used in DPFC is 3^{rd} harmonic frequency component for the purpose of active power exchange. In a 3-Ø system, the 3^{rd} harmonic in each phase is identical, which means they are 'zero-sequence' components. Because the zero-sequence harmonic can be naturally blocked by YΔ transformers and these are widely incorporated in power systems, there is no extra filter required to prevent harmonic leakage.

V DPFC Control

The operation of DPFC takes place in three steps. They are Central control, Series control and Shunt control [5]. The block diagram representation of these three control systems in a DPFC is as shown below:

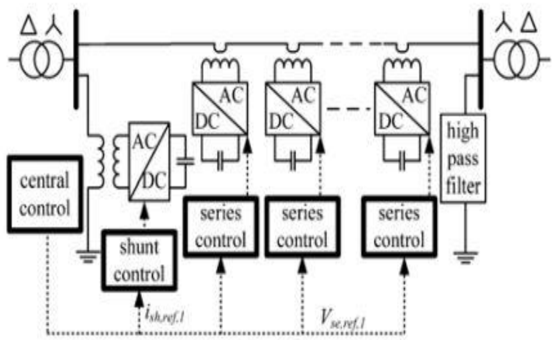

Fig 3: Block diagram of DPFC control

A) Central control:
It generates reference signals for both the shunt and series converters of the DPFC [4]. It is focused on the DPFC tasks at the power system level, such as power-flow control, low-frequency power oscillation damping, and balancing of asymmetrical components. According to the system requirement, the central control gives corresponding voltage reference signals for the series converters and reactive current signal for the shunt converter.

B) Series control:
Each DPFC series converter is locally controlled by its own controller, and the scheme for each series control is identical. To control the series converter, separate control loops are employed for the two frequency components. The 3^{rd} harmonic control loop is used for DC voltage control. The block diagram representation of DPFC series converter control is as shown below:

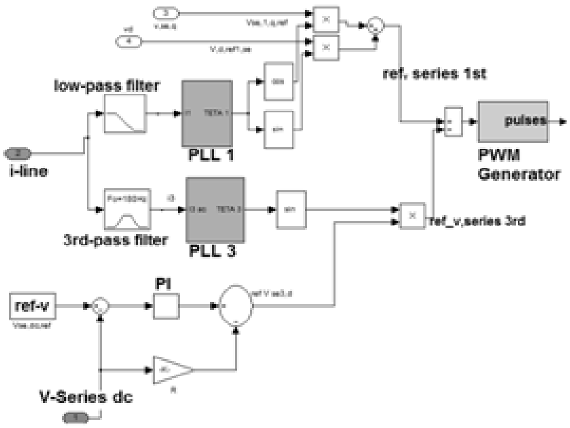

Fig 4: Block diagram of series control structure

C) Shunt control: The shunt converter contains two converters. The 1-Ø converter injects the constant 3^{rd} harmonic current into the grid. The 3-Ø converter maintains the DC voltage at a constant value and generates reactive power to the grid [5]. The control of each converter is independent.

VI Implementation of DPFC on SMIB:
In this paper three different cases are proposed [1]
1. A single machine connected to infinite bus system without DPFC.
2. A single machine connected to infinite bus system with DPFC which adopts PI controller.
3. A single machine connected to infinite bus system with DPFC which adopts Fuzzy controller.

Each case is designed separately and executed, and their simulation results are provided in the following.

1. A single machine connected to infinite bus system without DPFC:

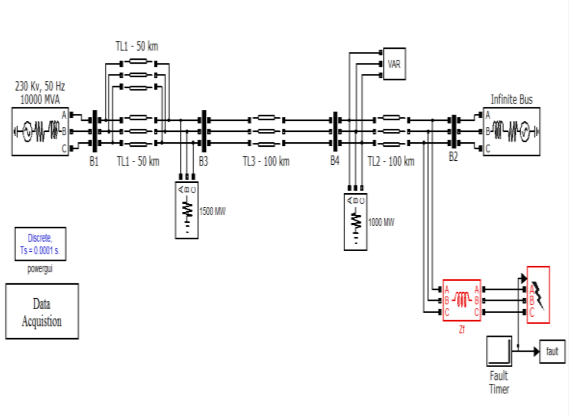

Fig 5: simulation diagram of SMIB

The Simulink model of this case does not have DPFC as shown above and which consists of a source connected to the bus which is connected with two parallel transmission lines and then proceeds to infinite bus. In between source and infinite bus a resistive load, a VAR block representing inductive or capacitive are connected to create sag or swell condition. Also a fault block is connected at the end as shown in order to create fault condition along with fault timer. In this case whenever a 3-Øfaultis created the output is disturbed and never reaches to the steady state which is shown in fig 7. Hence, there is a necessity of DPFC to mitigate faults and to reach steady state.

2. A single machine connected to infinite bus system with DPFC (PI controller):
In this case a DPFC is placed on SMIB at bus 4 which has PI controller technique employed in central control, which generates required pulse signals for shunt and series converters according to which necessary reactive power can be generated by shunt control or the required voltage can be injected by series control in order to meet the requirements of a transmission system during faults

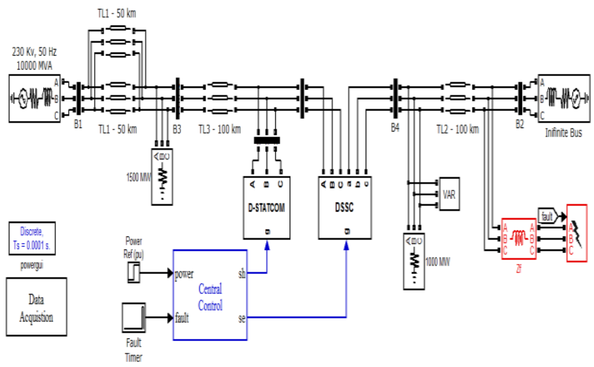

Fig 6: simulation diagram of SMIB with DPFC

The above Simulink diagram is designed and executed in MATLAB/Simulink and results are observed which definitely shows improvement of a system than the previous case and the results are shown in the next section.

3. A single machine connected to infinite bus system with DPFC (Fuzzy logic controller):

In this case PI controller is replaced with Fuzzy logic controller in central control mechanism. The simple rule for FLC formation is “If x and y then z”. It can be simply understood by the personal experience and by knowing the behavior of the system. The correct combinations of rules improve the performance of the system. In this study, five membership functions will be assigned and 25 rules to be formed by the fuzzy system [7].

Table I: Fuzzy decision table

$E\backslash\Delta E$	NB	NS	Z	PS	PB
NB	NB	NB	NS	NS	Z
NS	NB	NS	NS	Z	Z
Z	NS	NS	Z	PS	PS
PS	Z	Z	PS	PS	PB
PB	Z	PS	PS	PB	PB

A FLC is implanted on DPFC by forming the above fuzzy rules, which will optimizes than PI controller. Thus, a DPFC with fuzzy logic controller is connected to the SMIB as shown in fig 6 which has the same control blocks but with a different controller. This case can be executed in MATLAB/ Simulink and the results are provided in the next section.

VII Simulation Results and Analysis

The simulation results of DPFC are presented in this section of three different case studies. Each case is compared with another and finally reach a point such that DPFC with fuzzy logic controller provides the best results when compared to other two cases as following:

Case 1:A single machine connected to infinite bus system without DPFC:

When the Simulink diagram shown in Fig 5 following results are obtained which clearly shows that the power curve shown in fig 7 does not reach the reference power (400 MW) and in fig 8 it is clear that due to fault voltage level increased from 1 sec and it does not settled down which is not a favourable condition for a power system.

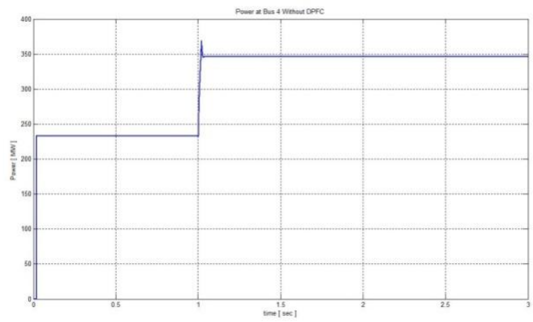

Fig 7: power flow from single machine to infinite bus

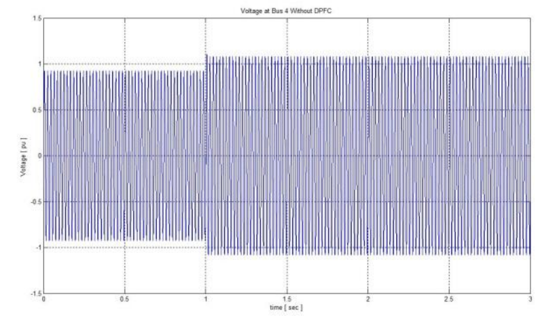

Fig 8: voltage response at bus 4 without DPFC

Case 2: A single machine connected to infinite bus system with DPFC (PI controller):

When the Simulink diagram shown in fig 6 is executed in MATLAB following results are obtained. The special cases of voltage sag and voltage swell are also shown in the following.

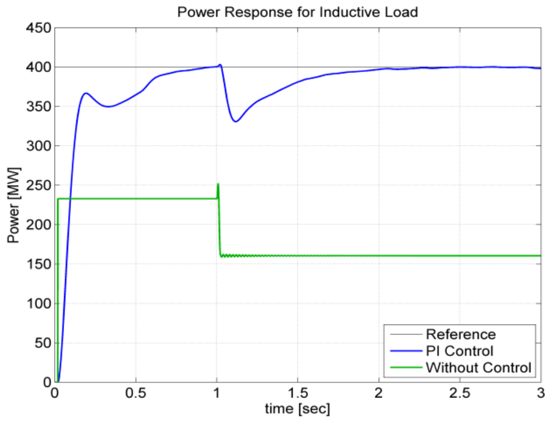

Fig 9 (i): power response of DPFC PI controller during voltage sag

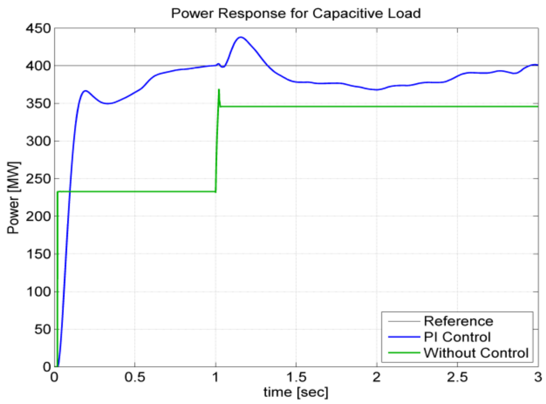

Fig 9 (ii): power response of DPFC PI controller during voltage swell

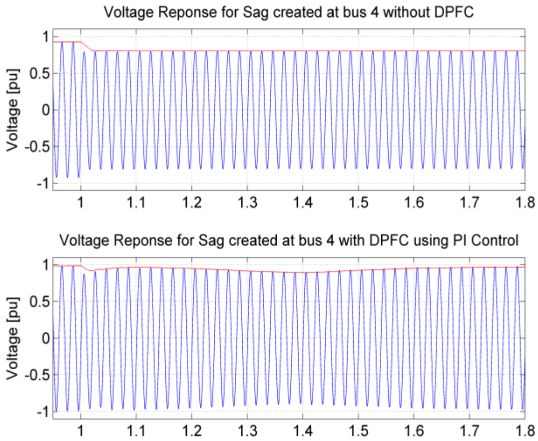

Fig 10 (i): voltage response for sag created at bus4 with and without DPFC

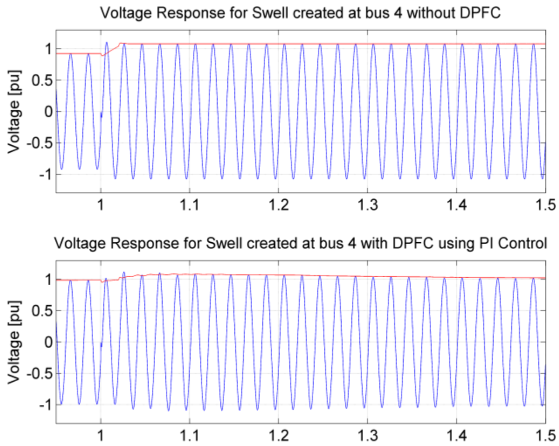

Fig 10 (ii): voltage response for swell created at bus4 with and without DPFC

The above results show that the power quality of a system is improved during sag and swell conditions by reaching to the steady state even the fault occurs. Therefore SMIB with DPFC (PI controller) is better when compared to the SMIB without DPFC.

Case 3: **A single machine connected to infinite bus system with DPFC (Fuzzy logic controller):**

Here in this case the PI controller in DPFC is replaced with fuzzy logic controller [7] and then the Simulink diagram shown in fig 6 is executed and the following results are obtained.

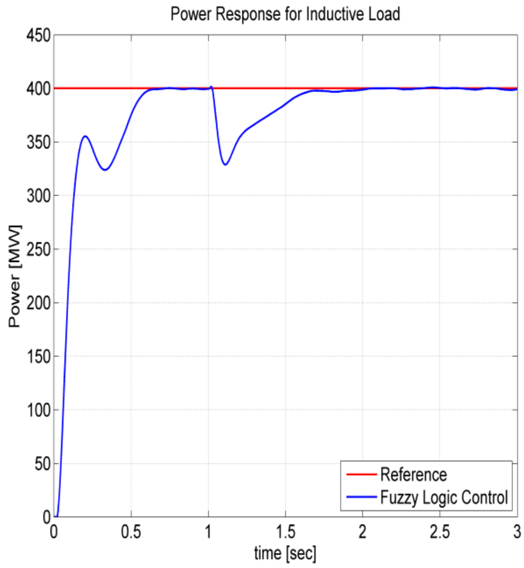

Fig 11(i): power response of DPFC FLC controller during voltage sag

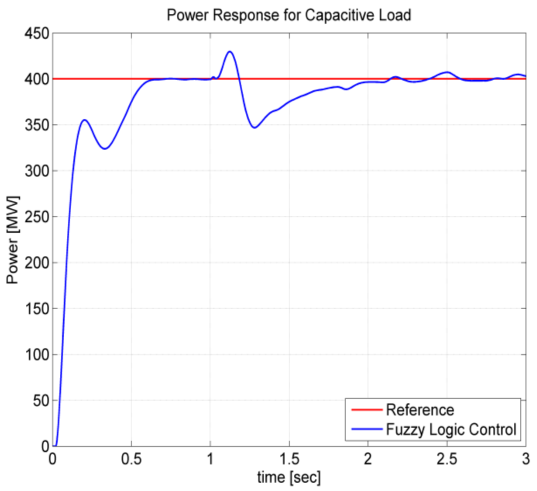

Fig 11(ii):power response of DPFC FLC controller during voltage swell

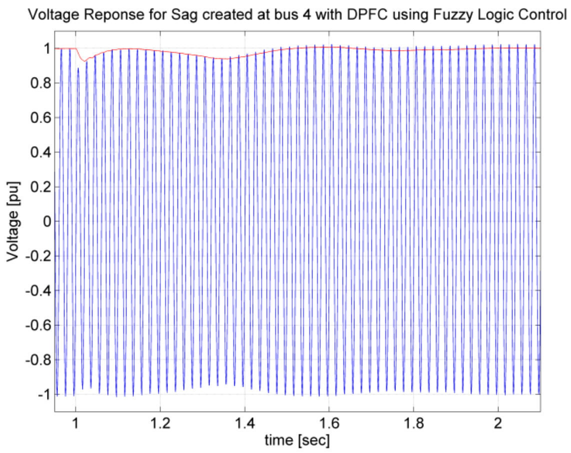

Fig 12(i): voltage response for sag created at bus4 with DPFC FLC controller

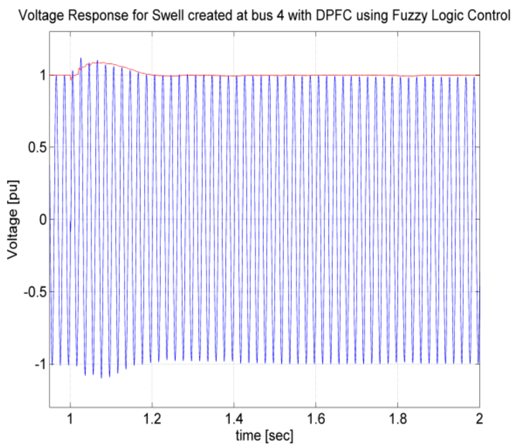

Fig 12(ii): voltage response for swell created at bus4 with DPFC FLC controller

The power responses of all the three cases i.e., without DPFC, with DPFC PI controller and with DPFC FLC controller is shown in the single graph for easy comparison as below:

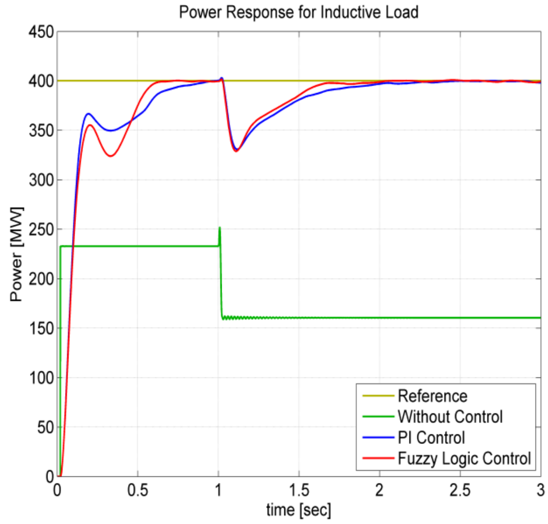

Fig 13: power responses for sag created at bus 4 without DPFC, with DPFC (PI &FLC) controllers

From the above graph it is clear that DPFC with fuzzy logic controller provides best response during fault condition.

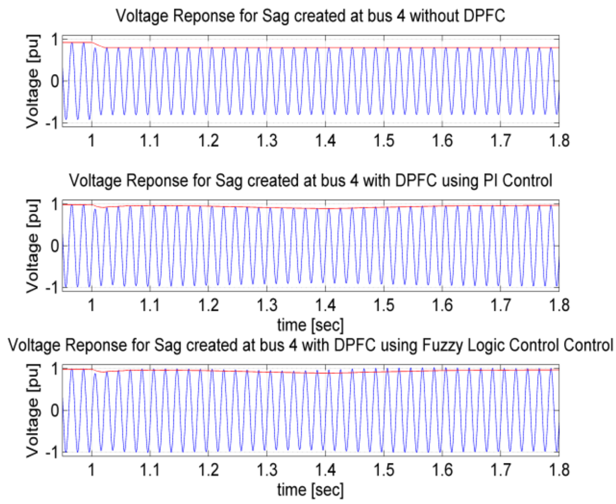

Fig 14: voltage response for sag created at bus4 without DPFC, with DPFC (PI &FLC) controllers

From the above graph a conclusion can be made such that voltage response can be improved by adopting DPFC with fuzzy logic controller than with DPFC PI controller.

Table II: Comparison of settling time of DPFC with PI and FLC controllers

	Change in power command		Voltage sag		Voltage swell	
	PI	FLC	PI	FLC	PI	FLC
Load voltage	2.05	1.16	2.067	1.45	1.55	1.17
power	2.37	1.504	1.75	1.56	2.88	1.91

VIII CONCLUSION

To enhance power quality in the transmission system, there are some effective methods. In this project, the voltage sag and swell mitigation, using a new FACTS device called distributed power flow controller (DPFC) is presented. The DPFC has the capability of balancing the line parameters, i.e., bus voltage magnitude, line impedance and transmission angle. It offers some advantages, in comparison with UPFC, such as high control capability, high reliability and low cost. In this project a single machine infinite-bus system, without DPFC, with DPFC PI controller and with DPFC fuzzy logic controller are designed and executed. A SMIB with DPFC fuzzy logic control showed enhanced performance than PI controller in terms of settling time. Hence, the power quality of a system is enhanced using DPFC fuzzy logic controller.

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