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RESEARCH ARTICLE

A NOVEL IMPLEMENTATION OF FUZZY PI BASED DISTRIBUTED POWER FLOW CONTROLLER FOR POWER QUALITY IMPROVEMENT AND MITIGATION

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ABSTRACT

The new inventions in technology lead to more power consumption by more number of nonlinear loads, which in turn effecting 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. Nonlinear loads create harmonic currents which in turn creates system resonance, capacitor overloading, decrease in efficiency, voltage magnitude changes. 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 in the UPFC. The large number of series converters provides redundancy, thereby increasing the system reliability. 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.

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INTRODUCTION

In the past years, the maintenance of quality of electrical power issue has been the significant concern for most of the power companies. Power quality is defined as the index which focuses both on delivery and utility of electric power affect on the performance of electrical appliances from customer end. A problem related to power quality can be defined as any problem manifested on voltage, current, or frequency deviation that results in power failure. The progressiveness of power electronics, especially in flexible alternating-current transmission system (FACTS) and custom power devices, affects improvement of power quality. Generally, custom power devices, e.g., dynamic voltage restorer (DVR), are used in medium-to-low voltage levels to improve customer power quality. Serious problems for delicate equipment in electrical grids are voltage sags (voltage dip) and swells (over voltage). 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 eliminate the disturbance and improve the power system quality and reliability. In this paper, a distributed power flow controller, introduced 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 obtained from the UPFC structure that is included one shunt converter and several small independent series converters, as shown in Fig.1. Capability of DPFC is same as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude.

Objective of paper: In this paper a distributed power flow controller, introduced as a new FACTS device, is used to mitigate voltage, deviation of current waveform and enhance power quality in a matter of seconds. The receiving end voltage fluctuations were studied for different loads, in order to maintain the receiving end voltage, current constant.

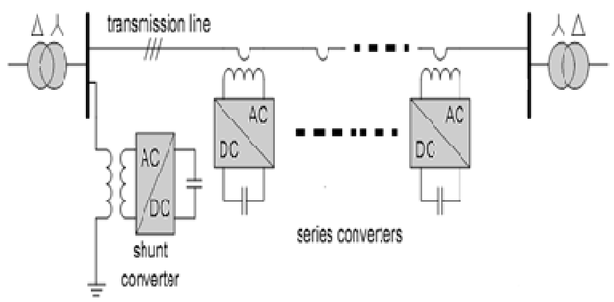

Fig.1. The DPFC Structure

Fuzzy logic controller has been designed to achieve the constant load voltage, load current such that a flat voltage profile is maintained. All the results thus obtained, were verified and were utilized in framing of fuzzy rule base in order to achieve exact compensation of reactive power.

Literature Survey

J.R.Enslin (1998) said, Voltage sag and swell of the power quality issue and Unified power flow controller (UPFC) is used for mitigation. The switching level model is constructed using three phase six pulse shunt and series converters. Both the converters are modeled as back to back voltage source inverters connected with the D.C link are controlled by sinusoidal pulse width modulation scheme. This model is implemented in single machine infinite parallel transmission line system. The result shows that UPFC controller is capable of mitigating the voltage sag and swell in the proposed system. K.Al-Haddad (1999) said, Active filtering of electric power has now become a mature technology for harmonic and reactive power compensation in two-wire (single phase), three-wire (three phase without neutral), and four-wire (three phase with neutral) ac power networks with nonlinear loads. This paper presents a comprehensive review of active filter (AF) configurations, control strategies, selection of components, other related economic and technical considerations, and their selection for specific applications. It is aimed at providing a broad perspective on the status of AF technology to researchers and application engineers dealing with power quality issues. A list of more than 200 research publications on the subject is also appended for a quick reference.

P.Pohjanheimo (2000) said, Utilities have traditionally carried out power flow and fault current calculations in their distribution network for monitoring and planning purposes. The network iscontrolled and operated as a complete system. Network information systems (AMEM-GIS) and different distribution management systems (DMS, SCADA) are the most common software platforms used for completing the task. The calculations are performed in steady state. Solid-state and energy storage based power conditioners, i.e. custom power devices introduce a new generation of active components in the network. To be able to control and operate the network also the new components have to be modeled for steady state simulation and furthermore implemented in the established applications. The models provide the utility software with proper tools for the network power flow, harmonic power flow and energy flow calculations. Also new tools for power quality management can be developed. A.L.Olimpo (2002) said, The timely issue of modeling and analysis of custom power controllers, a new generation of power electronics-based equipment aimed at enhancing the reliability and quality of power flows in low-voltage distribution networks. The modeling approach adopted in the paper is graphical in nature, as opposed to mathematical models embedded in code using a high-level computer language. The well-developed graphic facilities available in an industry standard power system package, namely PSCAD/EMTDC, are used to conduct all aspects of model implementation and to carry out extensive simulation studies. Graphics based models suitable for electromagnetic transient studies are presented for the following three custom power controllers: the distribution static compensator (D-STATCOM), the dynamic voltage restorer (DVR), and the solid-state transfer switch (SSTS). Comprehensive results are presented to assess the performance of each device as a potential custom power solution.

M.A.Hannan (2005) said, the simulation of a unified series shunt compensator (USSC) aimed at examining its capability in improving power quality in a power distribution system. The USSC simulation model comprises of two 12-pulse inverters which are connected in series and in shunt to the system. A generalized sinusoidal pulse width modulation switching technique is developed in the proposed controller design for fast control action of the USSC. Simulations were carried out using the PSCAD/EMTDC electromagnetic transient program to validate the performance of the USSC model. Simulation results verify the capabilities of the USSC in performing voltage sag compensation, flicker reduction, voltage unbalance mitigation, UPS mode, power-flow control and harmonics elimination. A comparison of the USSC with other custom power devices shows that the USSC gives a better performance in power-quality mitigation.

I.Nita (2008) said, power system faults are typical causes for the occurrence of power quality problem, voltage sag in the system. Because of increasing utilization of sensitive and sophisticated control in almost all modern devices in the industries and residences, the Voltage sag which is the reason for severe problems to such devices needs to be analyzed. Factors which affect the characteristics of voltage sag as a type of fault in the system, location of fault in the system, *X*/*R* ratio of transmission lines, type of transmission as single or double circuit transmission, Point on wave of sag. ZhihuiYuan(2009) said, Distributed Power Flow Controller (DPFC) is a new device within the family of FACTS. The DPFC has the same control capability as the UPFC, however at much lower cost and with a higher reliability. The reliability of the DPFC is given by the redundancy of multiple series converters. The shunt converter is the bottleneck for remaining reliability, because there is only one shunt converter in a DPFC system. During the shunt converter failure, the DPFC continues to work as controlled impedance, and only control the active power flow through the line. This paper presents a control of the DPFC, which keeps the DPFC system stable during the shunt converter failure. Adapted control schemes are employed to every series converters, which can automatically switch the series converter between the full control mode and limited-control mode. With the adapted control, the reliability of the whole DFPC system is further improved.

Sjoerd W.H. de Haan (2010) said, a new component within the flexible ac transmission system (FACTS) family, called distributed power-flow controller (DPFC). The DPFC is derived from the unified power-flow controller (UPFC). The DPFC can be considered as a UPFC with an eliminated common dc link. The active power exchange between the shunt and series converters, which is through the common dc link in the UPFC, is now through the transmission lines at the third-harmonic frequency. The DPFC 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 in the UPFC. The large number of series converters provides redundancy, thereby increasing the system reliability. As the D-FACTS converters are single-phase and floating with respect to the ground, there is no high voltage isolation required between the phases. Accordingly, the cost of the DPFC system is lower than 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.

S.MasoudBarakati (2011) said, a dynamic voltage restorer (DVR) as a solution to compensate the voltage sags and swells and to protect sensitive loads. In order to apply the DVR in the distribution systems with voltage in range of kilovolts, series converter as one of the important components of DVR should be implemented based on the multilevel converters which have the capability to handle voltage in the range of kilovolts and power of several megawatts. A configuration of DVR based on asymmetrical cascade multi cell converter is proposed. The main property of this asymmetrical CM converter is increase in the number of output voltage levels with reduced number of switches. Also, the pre-sag compensation strategy and the proposed voltage sag/swell detection and DVR reference voltages determination methods based on synchronous reference frame (SRF) are adopted as the control system.

Ahmad Jamshidi (2012) said, According to growth of electricity demand and the increased number of non-linear loads in power grids, providing a high quality electrical power should be considered. And he said, voltage sag and swell of the power quality issues are studied and distributed power flow controller (DPFC) is used to mitigate the voltage deviation and improve power quality. The DPFC is a new FACTS device, which its structure is similar to unified power flow controller (UPFC). In spite of UPFC, in DPFC the common dc-link between the shunt and series converters is eliminated and three-phase series converter is divided to several single-phase series distributed converters through the line. The case study contains a DPFC sited in a single-machine infinite bus power system including two parallel transmission lines.

DPFC Methodology: 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

Eliminate DC Link and Power Exchange: Within the DPFC, the transmission line is utilized as an interconnection between the DC terminal of shunt converter and the AC terminal of series converters, instead of directly connecting using DC-link for power exchange between converters. The power exchange method in DPFC is based on power theory of non-sinusoidal components. With the Fourier series analysis, 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 results in active power. Since the integral of some terms with different frequencies are zero, so the active power equation is as follow:

$$p = \sum_{i=1}^{\infty} V_i I_i \cos \varphi_i$$

Where *Vi* and *Ii* are the voltage and current at the i^{th} harmonic, respectively, and *φi* is the angle between the voltage and current at the same frequency. Equation (4.1) shows that the active power at different frequency components is 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 4.1 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 consequently, the harmonic current flows through the transmission line. This harmonic current controls the DC voltage of series capacitors. Fig. 4.1 illustrates how the active power is exchanged between the shunt and series converters in the DPFC. The third harmonic is selected to exchange the active power in the DPFC and a high-pass filter is required to make a closed loop for 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.

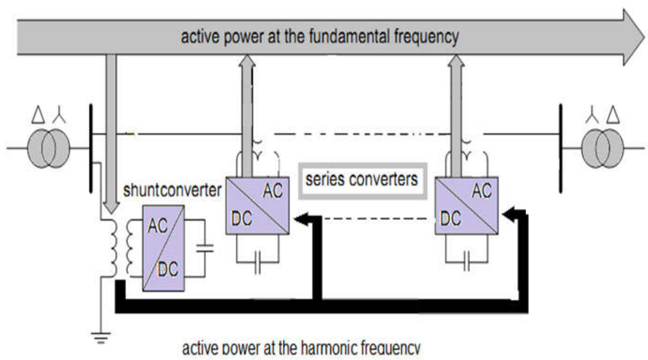

Fig.4.1. Active power exchange between DPFC converters

Performance Analysis of Fuzzy Logic Based On DPFC: FACTS devices are utilized mainly to control the flow of power, to enhance the transmission capacity and to optimize the power system stability. One among the extensively used FACTS devices is Distributed Power Flow Controller (DPFC). The controller used in this control mechanism has a significantly effects on controlling of the power flow and enhancing the system stability of DPFC. According to this, the capability of DPFC is observed by using variety of control mechanisms based on P, PI, PID and fuzzy logic controllers (FLC) in this study. FLC was developed by taking consideration of Takagi- Sugeno inference system in the decision process and Sugeno's weighted average method in the defuzzification process. To prove the ability of DPFC on controlling the power flow and its effectiveness of controllers on the performance of DPFC, case studies with various different operating conditions are applied.

In view of environmental and economical constraints, the future growth of the power systems will depend on increasing the capability of present transmission systems rather than building the new transmission lines and the power stations. The requirement of the new power flow controllers, which increases the transmission capability and controlling flow of power through the predefined corridors, will increase due to the deregulation of the electricity markets. Also, these new controllers must control the voltage levels and the real/reactive power flow in the transmission line to use maximum capability of the system in rare cases where no reduction in the system stability and security margins is observed. A new technology concept known as Flexible Alternating Current Transmission Systems (FACTS) technology was presented in the late of 1980s. FACTS devices, with its fast control characteristics and continuous compensating capability, enhance the stability of the power system. To control the power flow and increase the transmission capacity of the prevailing transmission lines are the two main objectives of FACTS technology.

Hence, with the above objectives the optimal condition for utilization existing power system can be achieved and controllability of power system can be increased. Gyugyi proposed the Distributed Power Flow Controller which is the new type generation of FACTS devices in 1991. Distributed Power Flow Controller (DPFC) is the member of FACTS device which has emerged for the controlling and the optimizing of power flow in the electrical power transmission systems. This device is formed by the combination of two other FACTS devices namely as Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). A common DC link connects these devices, which is a l storage capacitor. All the parameters of the power transmission line (impedance, voltage and phase angle) can be controlled in parallel by DPFC. In addition, it can be used to perform the control function of the transmission line real/reactive power flow, DPFC bus voltage and the shunt-reactive-power flow control. The capability of DPFC in the controlling of the power flow and its effectiveness on performance of DPFC in the power transmission line are examined in two case studies, using different control mechanisms based on PI and fuzzy controllers in this paper. In the modeling of fuzzy controller, "Takagi-Sugeno Inference System" is used for the process of decision making and "Weighted Average" method which is the special case of "Mamdani" model is used in the defuzzification process. The desired signals are subtracted from the reference signals and the results are transformed into three phase balanced system to use in the sinusoidal-pulse-width modulation (SPWM). Thus, SPWM technique is used to produce the firing angles of IGBTs (insulated gate bipolar transistors).

Simulation work and Results

Simulation Diagram without DPFC

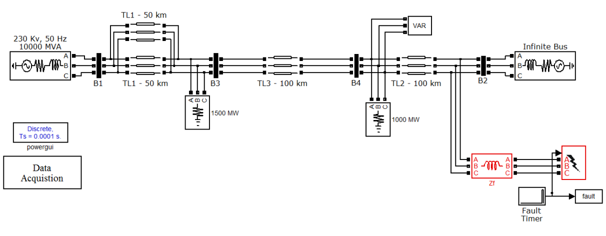

Fig.5.1. Simulation design in matlab without DPFC

Simulation model Diagram with DPFC: The complete model of system under study is shown in Fig. 5.2.

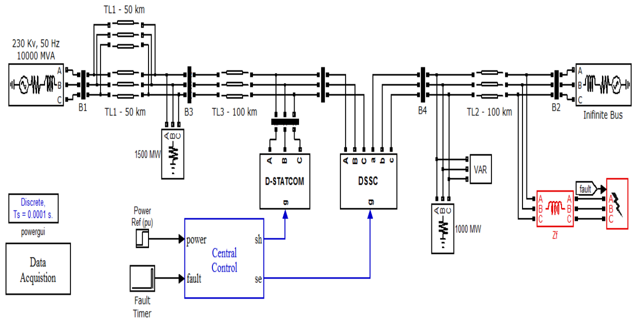

Fig: 5.2. Simulation model Diagram with DPFC

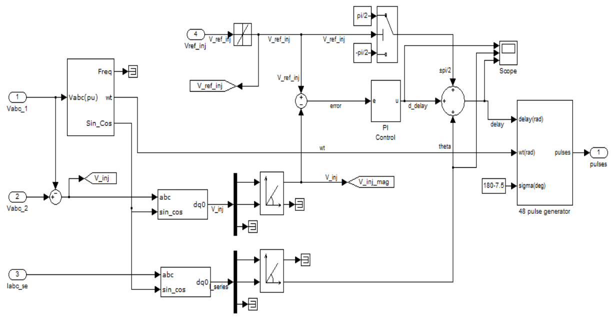

Fig.5.3. Representation of series control circuit

It consists of a three phase source connected to a nonlinear RLC load through transmission lines (Line 1 and Line 2) with the same lengths, in parallel.

The DPFC is placed in transmission line, such that 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. The operational mode to "SSSC (Voltage injection)". Make sure that the SSSC references values (3rd line of parameters) [Vinj_InitialVinj_FinalStepTime] are set to [0.0 0.08 0.3].

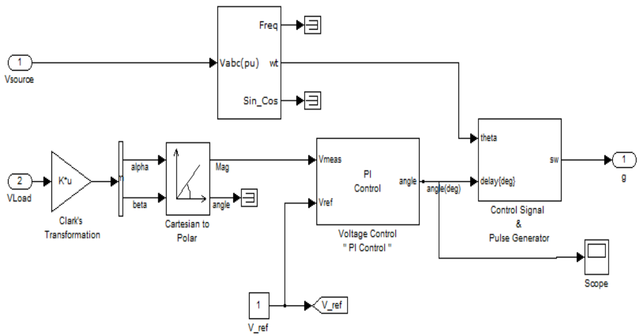

Fig.5.4. Representation of shunt control circuit

Simulation results: At time t = 0 sec a power command of 400 MW is initiated to DPFC and the results is shown in Fig 5.5. below plot show that DPFC with PI Control takes 0.8 sec to reach to the reference value and DPFC with Fuzzy Logic control takes 0.6 sec. The corresponding voltage at the bus connect at DPFC is show in Fig.5.6

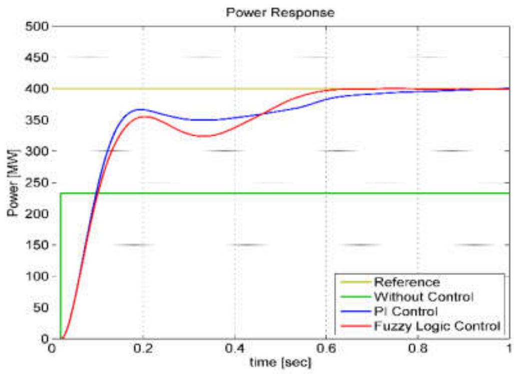

Fig.5.5 Power flow from single machine to infinite bus

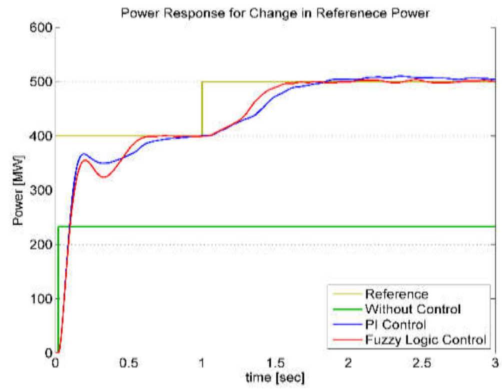

Fig.5.7. Power for Change in power command from

Table 1. Comparison of their settling time of DPFC with PI Control & Fuzzy Logic controller

	Initially		Change in Power Command		Voltage Sag		Voltage Swell	
	PI	Fuzzy	PI	Fuzzy	PI	Fuzzy	PI	Fuzzy
Load Voltage			2.05	1.16	2.067	1.45	1.55	1.17
Power	0.8	0.6	2.37	1.504	1.75	1.56	2.83	1.91

Table 2. Simulated system parameters

Parameters	Values
Three phase source	
Rated voltage	230 kV
Rated power/Frequency	100MW/60HZ
X/R	3
Short circuit capacity	11000MW
Transmission line	
Resistance	0.012 pu/km
Inductance/ Capacitance reactance	0.12/0.12pu/km
Length of transmission line	100 km
Shunt Converter 3-phase	
Nominal power	60 MVAR
DC link capacitor	600 µF
Continue of Table I :	
Coupling transformer (shunt)	
Nominal power	100 MVA
Rated voltage	230/15 kV
Series Converters	
Rated voltage	6 Kv
Nominal power	6 MVAR
Three-phase fault	
Type	ABC-G
Ground resistance	0.01ohm

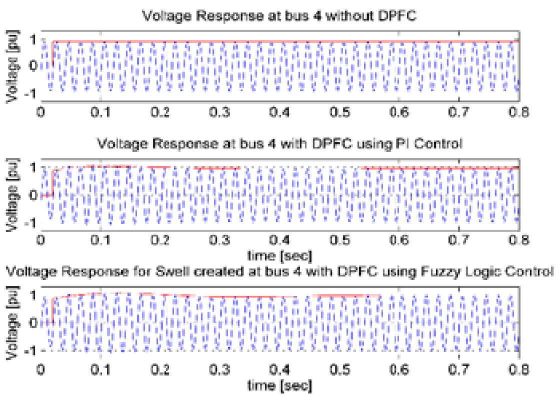

Fig.5.6 Voltage Response for power command 400 MW

400MW to 500MW

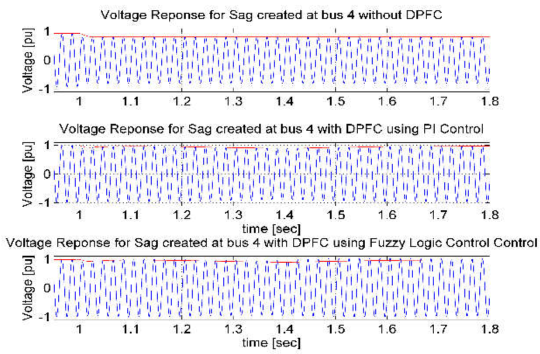

Fig.5.7. Show the power response for increase in the power from 400 to 500MW. It show that PI Control takes 2.37 sec to settle to its reference value whereas Fuzzy control takes 1.5 sec

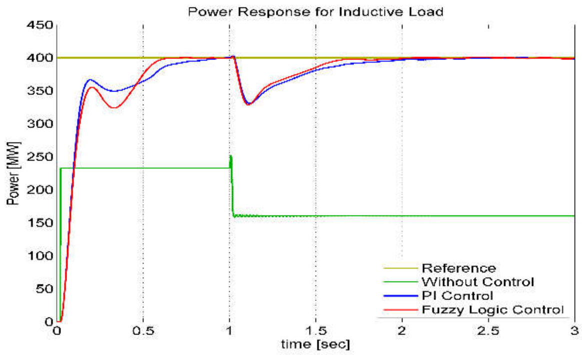

Fig.5.8. Mitigation of load voltage sag with DPFC

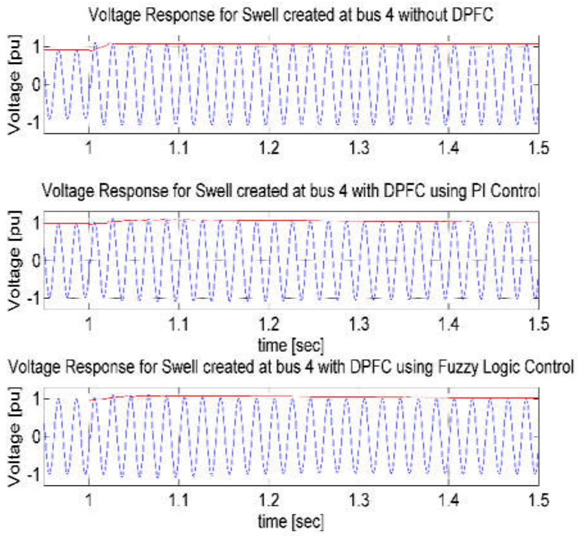

Fig.5.9. Power response for Mitigation of sag with DPFC

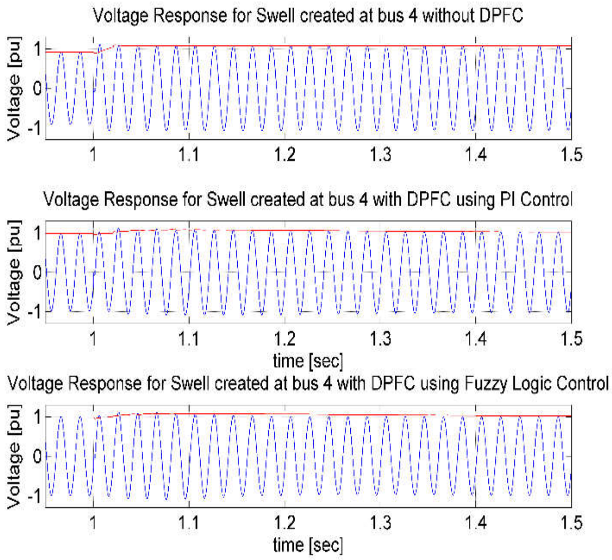

Fig.5.10 Mitigation of load voltage swell with DPFC

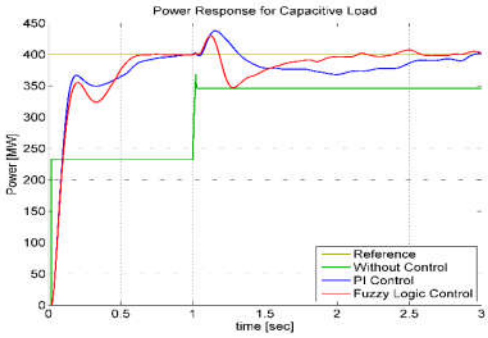

Fig.5.11 Power response for Mitigation of sag with DPFC

Conclusion

In order to improve power quality in the power transmission system, some of the effective methods are presented. In this paper, the voltage sag and swell mitigation, using a novel FACTS device called distributed power flow controller (DPFC) is presented. Its structure is similar to unified power flow controller (UPFC) and has a same control capability to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude. However, the DPFC offers some additional advantages such as high control capability, high reliability, and low cost. The DPFC is modeled with three different control loops, i.e., central controller, series control, and shunt control. The system under study is a single machine infinite-bus system, with and without DPFC. Over all DPFC shown improved performance than conventional controller in terms of settling time.

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