ISSN 2278-3083

International Journal of Science and Applied Information Technology (IJSAIT), Vol. 3 , No.4, Pages : 22 - 28 (2014)

Special Issue of ICECT 2014 - Held during September 01, 2014 in The Golkonda Hotel, Hyderabad, India

Mitigation of Voltage Sag and Swell in Transmission Line using DPFC with PI and Fuzzy Logic Control

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Abstract**—** The Power Quality problems during the last two decades has been the major concern of the power companies. The operation of power systems has become complex due to growing consumption and increased number of non-linear loads because of which compensation of multiple power quality issues has become an compulsion. A new component within the flexible AC-transmission system (FACTS) family, called Distributed Power-flow controller (DPFC) is presented in this paper. DPFC is derived from the unified power-flow controller (UPFC). 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. Power quality issues are studied and DPFC is used to mitigate the voltage deviation and improve power quality. In this paper, the capability of DPFC is observed for the transmission line based on PI and fuzzy logic controllers (FLC). On comparing the two controllers performance, we can say that Fuzzy Logic Controller based DPFC gives better compensation than PI Controller based DPFC. Simulink models are developed with and without the controllers. The three phase fault is created near the load. Simulation results show the effectiveness between the two controllers.

Keywords**—Power Quality,D-FACTS,DPFC,Voltage Sag, Swell, PI Controller,Fuzzy Logic Controller**

INTRODUCTION

This paper discusses the concept of a distributed approach for realizing FACTS devices in particular series FACTS devices. The future power system will be a meshed network and the power flow within this network, both the direction and quantity, will be controlled. To keep the system stable during faults or weather variations, the response time of the power flow control should be within several cycles to minutes. Without proper controls, the power cannot flow as required, because it follows the path determined by the parameters of generation, consumption and transmission .To fulfill the power flow requirements for the future network, power flow controlling devices are needed. The device that attempts to vary system parameters to control the power flow can be described as a Power Flow Controlling Device(PFCD). Depending on how devices are connected in systems, PFCDs can be divided into shunt devices, series devices, and combined devices(both in shunt and series with the system). Based on the implemented technology, PFCDs can be categorized into mechanical-based devices and power electronics(PE)-based devices. Mechanical PFCDs consist of fixed or mechanical interchangeable passive components, such as inductors or capacitors, together with transformers. PE PFCDs also contain passive components, but include additional PE switches to achieve smaller steps and faster adjustments. There is another term- Flexible AC Transmission System(FACTS) - that overlaps with the PE PFCDs. According to the IEEE, FACTS is defined as an alternating current transmission system incorporating power electronic based and other static controllers to enhance controllability and increase power transfer capability'. Normally, the High Voltage DC transmission(HVDC) and PE devices that are applied at the distribution network, such as a Dynamic Voltage Restorer (DVR), are also considered as FACTS controllers. Most of the FACTS controllers can be used for power flow control. However, the HVDC and the DVR are out of the scope of the PFCD. PE combined PFCDs (also referred to as combined FACTS) have the best control capability among all PFCDs. They inherit the advantages of PE PFCDs and combined PFCDs, which is the fast adjustment of multiple system parameters. The FACTS devices, such as unified power flow controller(UPFC) is currently the most used PFCD's and synchronous static compensator (STAT-COM), are used to alleviate the disturbance and improve the power system quality and reliability.

The same as the UPFC, DPFC 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 derived from the UPFC structure with one shunt converter and several small independent series converters, as shown in Fig. 1. The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude.

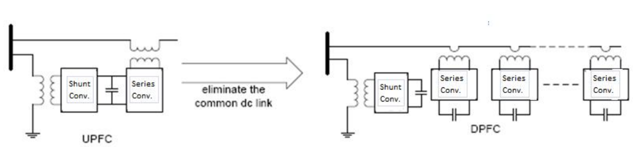

Fig 1: Flow Chart from UPFC to DPFC

ISSN 2278-3083

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DPFC TOPOLOGY

By introducing the two approaches (elimination of the common DC link and distribution of the series converter) into the UPFC, the DPFC is achieved. Similar as the UPFC, the DPFC consists of shunt and series connected converters. The shunt converter is similar as a STATCOM, while the series converter employs the DSSC concept, which is to use multiple single-phase converters instead of one three-phase converter. Each converter within the DPFC is independent and has its own DC capacitor to provide the required DC voltage. The configuration of the DPFC is shown in figure 2.

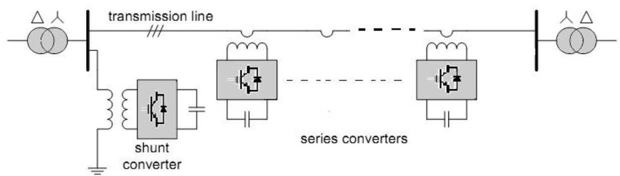

Fig 2: The DPFC Structure

DPFC Operating principle

Within the DPFC, the transmission line is used as a connection between shunt converter output and AC port of series converters, instead of using DC-link for power exchange between converters. The method of power exchange in DPFC is based on power theory of non-sinusoidal components. Non-sinusoidal voltage and current can be presented as the sum of sinusoidal components at different frequencies. It is the main result of Fourier analysis. 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:

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

where V_i and I_i are the voltage and current at the i_{th} harmonic frequency, respectively, and φi is the angle between the voltage and current at the same frequency. Equation. 1 expresses the active powers at different frequencies are independent from each others. Thus, the converter can absorb the active power in one frequency and generates output power in another frequency.

Active Power exchange between DPFC Converters

Assume the DPFC is located in transmission line of a two-bus system; therefore, the power supply generates the active power and the shunt converter absorbs it 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. 3 illustrates how the active power is exchanged between the shunt and series converters in the DPFC using third harmonic components.

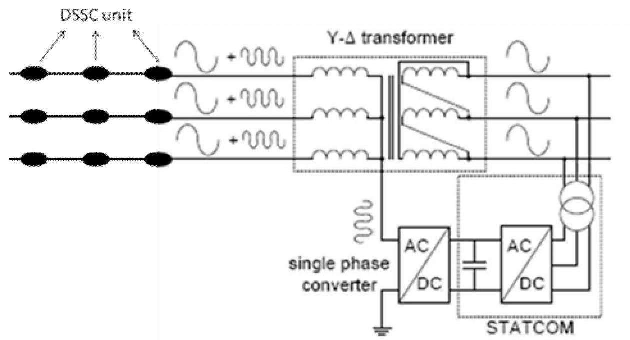

Fig 3: Active Power exchange between DPFC Converters in the transmission line at the third harmonic frequency

Advantages and Limitation of the DPFC

The DPFC in comparison with UPFC has some advantages, as follows:

1) High control capability.
The DPFC can control all parameters of transmission network: line impedance, transmission angle and bus voltage magnitude.
2) High reliability.
The series converters redundancy increases the DPFC reliability during converters operation [10]. It means, if one of series converters fails, the others can continue to work.
3) Low cost.
The single-phase converters rating, in comparison with three-phase converters is very low. Furthermore, the series converters, in this configuration, no need to any voltage isolation to connect in line. We can use the single turn transformers for series converters hanging.

However, there is a limitation using the DPFC:

Extra currents: Because the exchange of power between the converters takes place through the same transmission line as the main power, extra currents at the 3rd harmonic frequency are introduced. These currents reduce the capacity of the transmission line and result in extra losses within the line and the two Y-Δ transformers. However, because this extra current is at the 3rd harmonic frequency, the increase in the RMS value of the line current is not large and through the design process can be limited to less than 5% of the nominal current.

DPFC CONTROL AND MODELLING

The DPFC has three control strategies: central controller, series control, and shunt control, as shown in Fig. 4

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Central Control

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

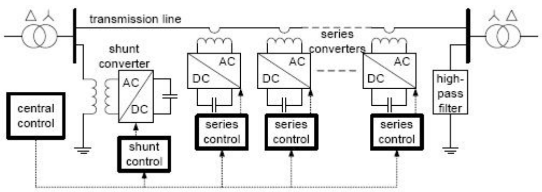

Fig 4: DPFC Control Structure

PI Controller based Series Control

Each single-phase converter has its own series control through the line. This controller inputs are series capacitor voltages, line current and series voltage reference in dq-frame. Any series controller has one low-pass and one 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 control scheme of series converter is shown in figure 5 and the simulated diagram of the series controller is shown in figure 6.

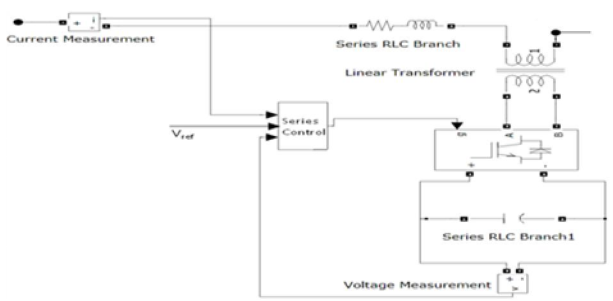

Fig 5: Simplified Diagram of Series Converter in Matlab/Simulink

PI Controller based Shunt Control

The shunt converter includes a three-phase converter which is back-to-back connected 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. The shunt control structure block diagram is shown in Fig. 6

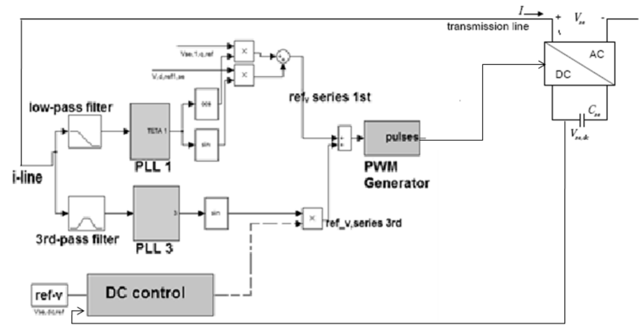

Fig 6: Control Scheme of Series Converter

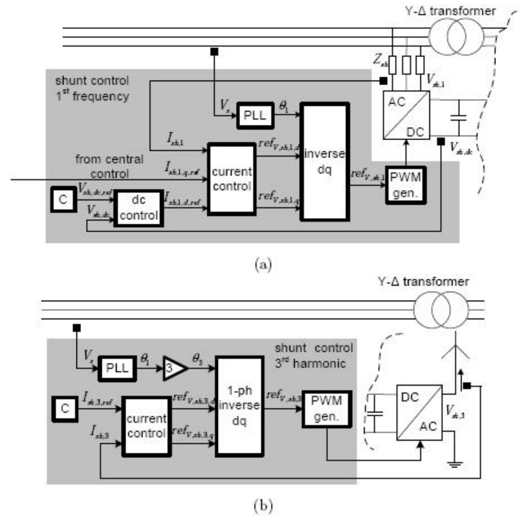

Fig 7: Control scheme of the shunt converter (a)for the fundamental frequency components; (b) for the 3rd harmonic frequency components

FUZZY LOGIC BASED DISTRIBUTED POWER FLOW CONTROLLER

Design of Fuzzy Logic Controller

Fuzzy logic (FL) controller is one of the most successful operations of fuzzy set theory; its major features are the use of linguistic variables rather than numerical variables. This control technique relies on human capability to understand the systems behavior and is based on quality control rules. Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information.

A fuzzy logic controller is based on set of rules called as fuzzy rules among the linguistic variables. These rules are expressed in the form of conditional statements. Our basic structure of the fuzzy logic coordination controller to damp out the oscillations in the power system consists of 3 important parts, viz. fuzzification, knowledge base-decision making logic (inference system) and the defuzzification, which are

ISSN 2278-3083

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explained in brief as follows. Fig.8 shows the Fuzzy Editor with inputs and output.

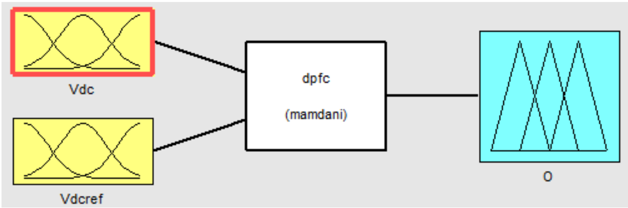

Fig 8: FIS Fuzzy Editor with 2 inputs and 1 output

Memembership Functions used in Fuzzification process are shown in Fig. 9

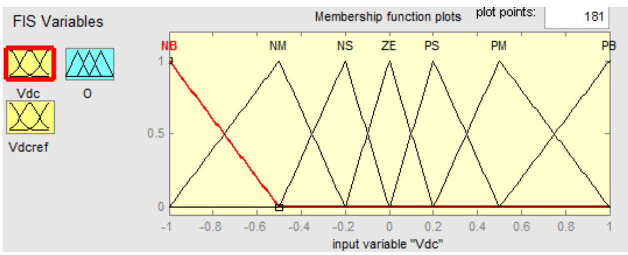

Fig 9(a) : The membership function for input in this model

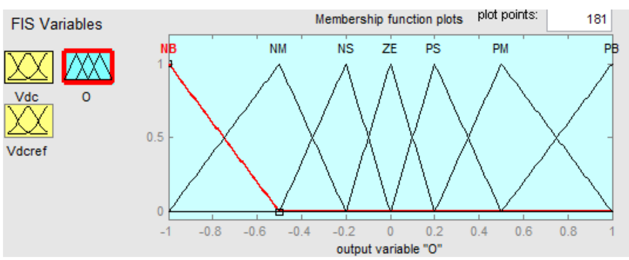

Fig 9(b): The membership function for output in this model

In this controller 49 rules have been used.

A simulink block of the shunt converter control for fundamental components using a Fuzzy Logic Controller in DPFC is shown in the Fig. 10.

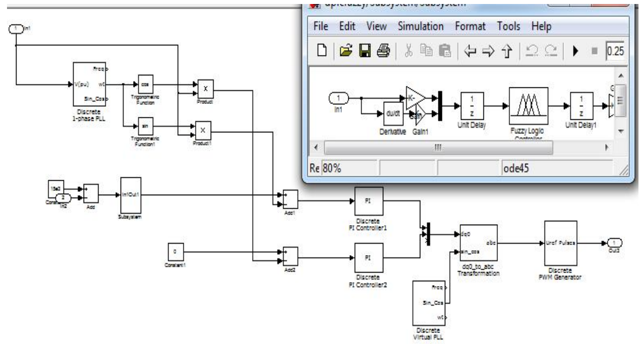

Fig 10: Simulink Model of a Shunt Controller with Fuzzy Logic Control

SIMULATION SET UP OF DPFC

System model under study is shown in Fig. 11 Simulation studies are carried out to analyze the performance of DPFC for voltage sag and swell conditions in a transmission system with a voltage of 230kV and 60Hz. A three phase fault with fault resistance of 50Ω near the load is said to be introduced into the system. Due to this voltage sag is created with a value 0.5 per unit. The voltage sag and swell are said to be compensated in the transmission line using DPFC with PI controller and Fuzzy Logic controller

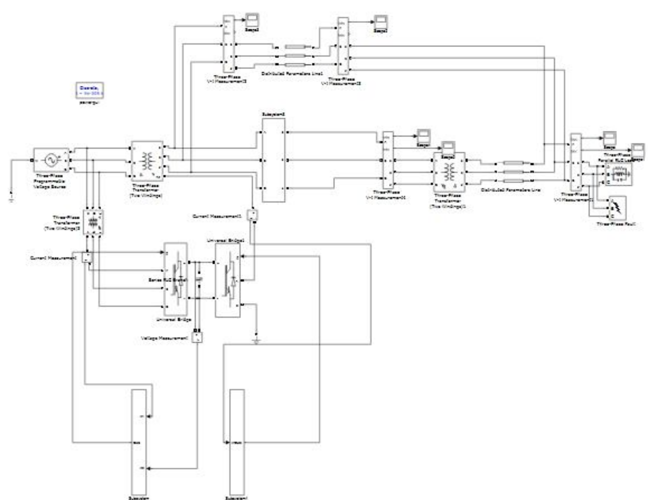

Fig 11: Simulation Model of DPFC

EXAMINING SIMULATION RESULTS

Simulation results for three types of connections are taken considering sag/swell condition using two types of controllers
1. DPFC with PI controller.
2. DPFC with Fuzzy Logic controller
Results showing the load voltage harmonic analysis using fast fourier transform (FFT) of power GUI window by simulink are as follows.

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Simulation results without DPFC

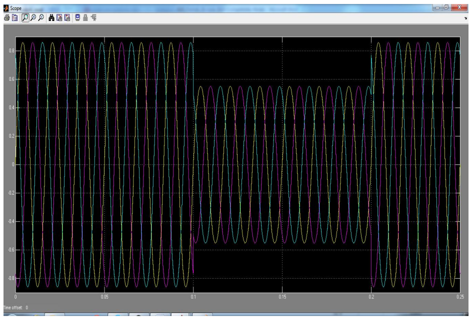

Fig 12: Voltage Sag without DPFC

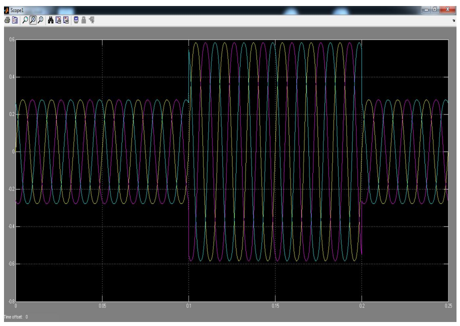

Fig 13: Current Swell without DPFC

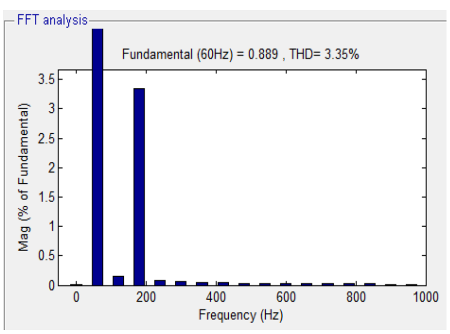

Fig 14: THD without DPFC

Simulation Results with DPFC using PI Controller

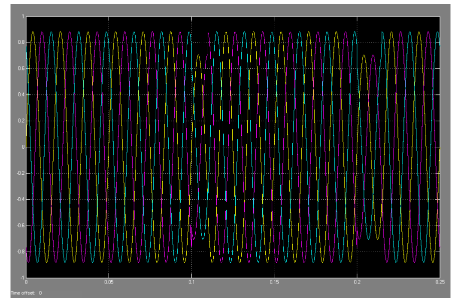

Fig 15: Voltage sag Compensation with DPFC using PI Controller

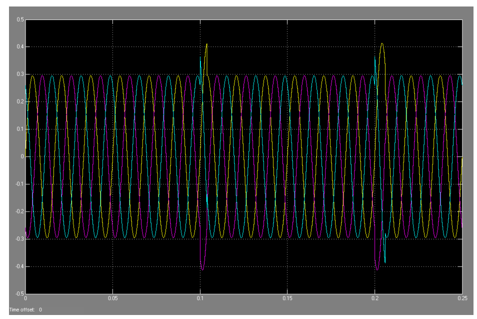

Fig 16: Current Swell Compensation with DPFC using PI Controller

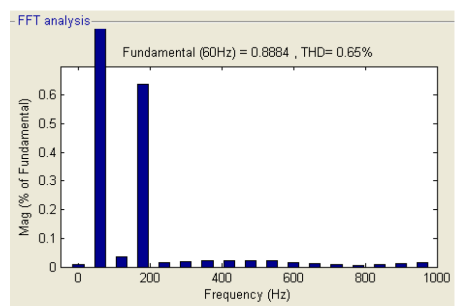

Fig 17: THD with DPFC using PI Controller

ISSN 2278-3083

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Simulation Results with DPFC using Fuzzy Logic Controller

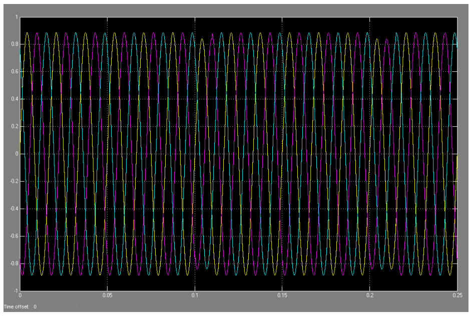

Fig 18: Voltage Sag Compensation with DPFC using Fuzzy Logic Controller

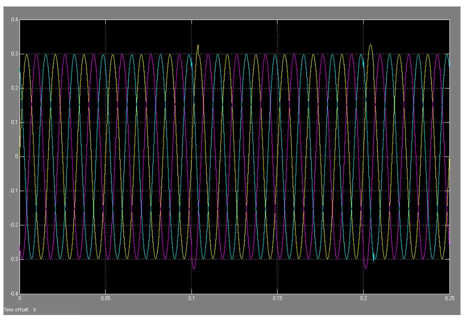

Fig l9: Current Swell Compensation with DPFC using Fuzzy Logic Controller

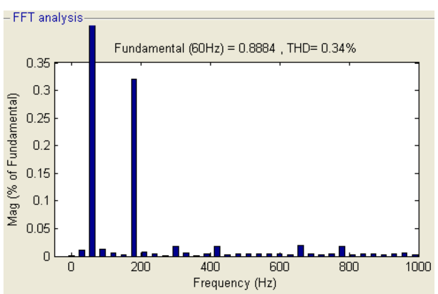

Fig 20: THD with DPFC using Fuzzy Logic Controller

APPENDIX

Table1 shows Simulation System Parameters

Parameters	**Values**
Three Phase Source	
Rated Voltage	230 kV
Rated Power/Frequency	100 MW/60 Hz
X/R	3
Short Circuit Capacity	11000 MW
Transmission Line	
Resistance	0.012 pu/km
Inductance/Capacitive Reactance	0.12/0.12 pu/km
Length of Transmission Line	100 km
Shunt Converter 3-Phase	
Nominal Power	60 MVAR
DC link Capacitor	600 µF
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	0.01 Ω

CONCLUSION

In this study mitigation of power quality issues like voltage sag and swell are simulated in Matlab/Simulink environment employing a new FACTS device called Distributed Power Flow Controller(DPFC). The DPFC is emerged from the UPFC and inherits the control capability of the UPFC, which is the simultaneous adjustment of the line impedance, the transmission angle, and the bus voltage magnitude. The common dc link between the shunt and series converters, which is used for exchanging active power in the UPFC, is eliminated. This power is now transmitted through the transmission line at the third harmonic frequency. The series converter of the DPFC employs the D FACTS concept, which uses multiple small single phase converters instead of one large size converter. The reliability of the DPFC is greatly increased because of the redundancy of the series converters. The total cost of the DPFC is also much lower than the

UPFC, because no high voltage isolation is required at the series converter part and the rating of the components of is low. It is proved that the shunt and series converters in the DPFC can exchange active power at the third harmonic frequency, and the series converters are able to inject controllable active and reactive power at the fundamental frequency .Also the performance of DPFC is simulated using two mechanisms i.e., with PI and Fuzzy Logic controllers.The results prove that the DPFC with Fuzzy controller gives better voltage compensation than DPFC with PI controller.

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