DISTRIBUTED POWER FLOW CONTROLLER - AN IMPROVEMENT OF UNIFIED POWER FLOW CONTROLLER

Rashmi Raghav[1], Ashraf Raza[2],Mohammad Asim[3]

[1]*Department of Electrical Engineering, Integral University,*
[2]*Department of Electrical Engineering, Integral University,*
[3] *Department of Electrical Engineering, Integral University,*

Abstract — *A new component within the FACTS family(flexible ac-transmission system), called distributed power-flow controller (DPFC) which is modification of the unified power-flow controller (UPFC) is presented in this paper .The DPFC have the same control capability as the UPFC (unified power-flow controller) i.e the adjustment of the line impedance, the transmission angle, and the bus voltage. Two modifications are made i.e the common dc link through which active power is exchanged between the shunt and series converters in UPFC is now through the transmission lines at the third-harmonic frequency in DPFC and three-phase series converter is divided to several single-phase series distributed converters which provides redundancy, thereby makes the system more reliable. D-FACTS converters are single-phase and floating with respect to the ground, high-voltage isolation is no longer required between the phases. Comparatively, the cost of the DPFC system is less than the UPFC. DPFC has advantages like improved voltage profile and reduced power loss. In this paper performance analysis of UPFC and DPFC are compared and corresponding experimental results are carried out by simulink model.*

Keywords- Facts, D-facts, ac–dc power conversion, load flow control, power electronics, power semiconductor devices, power system control , unified power flow controller.

I. INTRODUCTION

Power systems over the worldwide becoming complex day to day and there is great demand for secured, controlled, stable economic and better quality power. The flexible ac transmission system (FACTS) technology is used to fulfill the given objective which is the application of power electronics in transmission systems [1]. Flexible AC transmission system (FACTS) is use for power flow control. The main purpose of this technology is to improve voltage and transient stability limit of line, to minimize the short circuit currents ,to control and regulate the electric variables in the power system thereby controllability of transmission networks is increased which maximize power transfer capability. Among all FACT devices, the Unified Power Flow Controller (UPFC) is the most versatile device. The main reason behind the wide spread of the UPFC are its ability to pass the real power flow bidirectionally, maintaining well regulated DC voltage, work ability in the wide range of operating condition etc.

II. UNIFIED POWER FLOW CONTROLLER

A) UPFC CONFIGURATION

A shunt converter (STATCOM) is connected to a series converter (SSSC) converter with a common DC link provided by a storage capacitor to allow bi-directional flow of active power between the series output terminals and the shunt output terminals [2].
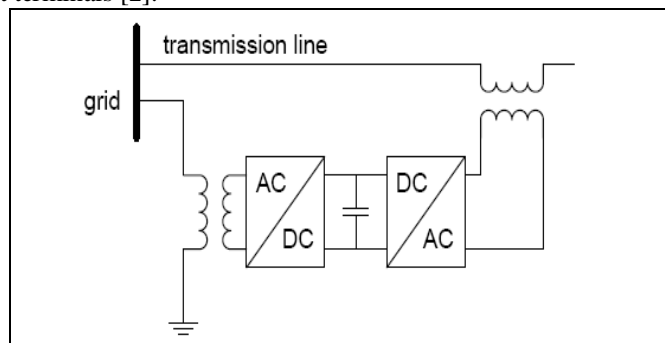
"Figure 1: Simplified representation of UPFC"

The function of series converter is to inject an ac voltage with controllable phase angle and magnitude at power frequency in series with line .Without an external energy source concurrent active and reactive series compensation is provided by means of which the UPFC is able to control the transmission angle, impedance and line voltage or,

alternatively, active and reactive power flow through the line. This voltage injection by the series converter results in active and reactive power exchange between the series converter and the transmission line. Series compensator maintains voltage profile.

The Shunt converter is used to absorb or supply the real power demanded by series converter at common d.c. link .It can also absorb or generate controllable reactive power if it is required to control the voltage of DC capacitor and thereby independent shunt reactive compensation for the line is provided. Shunt compensation increases the power transfer capability & neutralize Ferranti effect.

Drawbacks of the UPFC

LESS RELIABLE: However, the UPFC is not widely used in utility grids because it fails if there are any disturbances or faults in the source side. It is less reliable. In order to achieve the required reliability for power systems, bypass circuit or redundant back ups are needed.

HIGH COST: .The components of the UPFC handle the voltages and currents with high rating. Therefore cost is increased.

III.   DISTRIBUTED POWER FLOW CONTROLLER

The limitations of UPFC has been overcome in Distributed Power Flow Controller (DPFC) having the same capability of simultaneously adjusting all the parameters of power system like line impedances, transmission angle and bus voltage magnitude as UPFC. It has much lower cost and high reliability than the conventional FACTS devices. Two modifications are made:

REMOVAL OF COMMON DC LINK: A common DC-Link between the shunt and the series converters is eliminated. Instead of which transmission line is there in DPFC which make it possible to exchange the active power through the ac terminals of the converters.

D-FACT CONCEPT i.e. the series converter is distributed. A single shunt converter and multiple independent series converters in place of one three phase converter are used to balance the line parameters in DPFC. The shunt converter is same as a STATCOM, while the series converters utilize the DSSC concept. Each converter in the DPFC is independent and has its own DC capacitor to provide the required DC voltage.
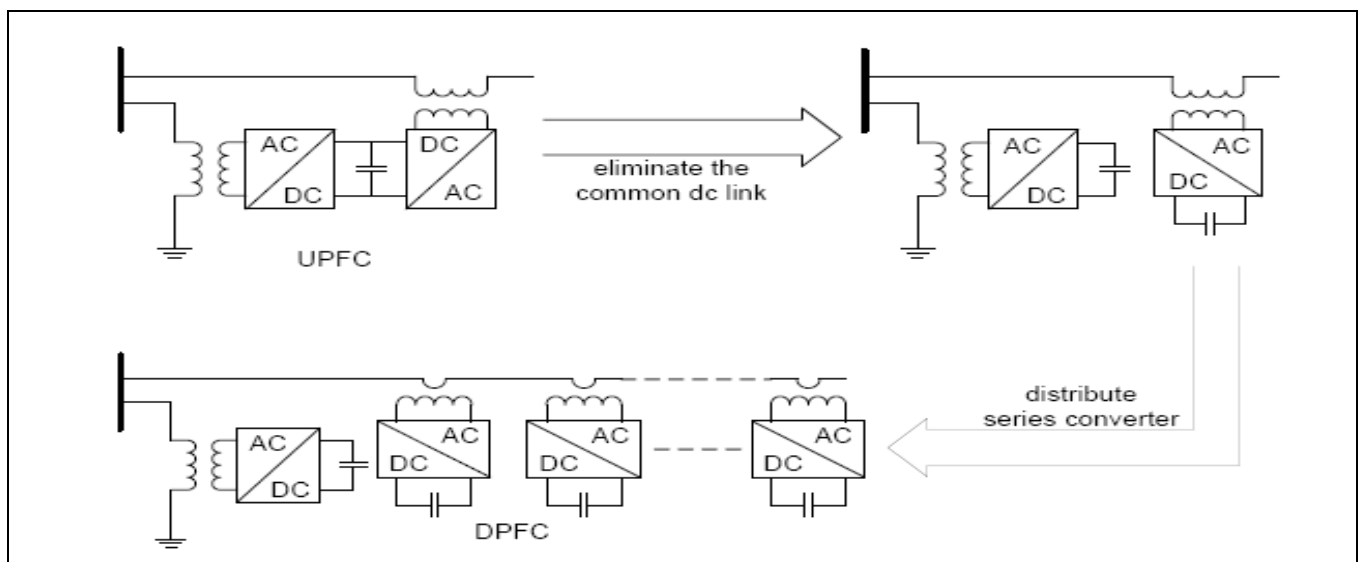

"**Figure-2: Flowchart from UPFC to DPFC**"

A.   DPFC CONFIGURATION

   The configuration of the DPFC is shown in Figure 3.A high pass filter that is shunt connected to the other side of the transmission line and a Y-Δ transformer on each side of the line is there which blocks the fundamental frequency

components and allows the harmonic components to pass, thereby a return path for the harmonic components is provided. Thus shunt and series converters, the high pass filter and the ground form a closed loop for the harmonic current.
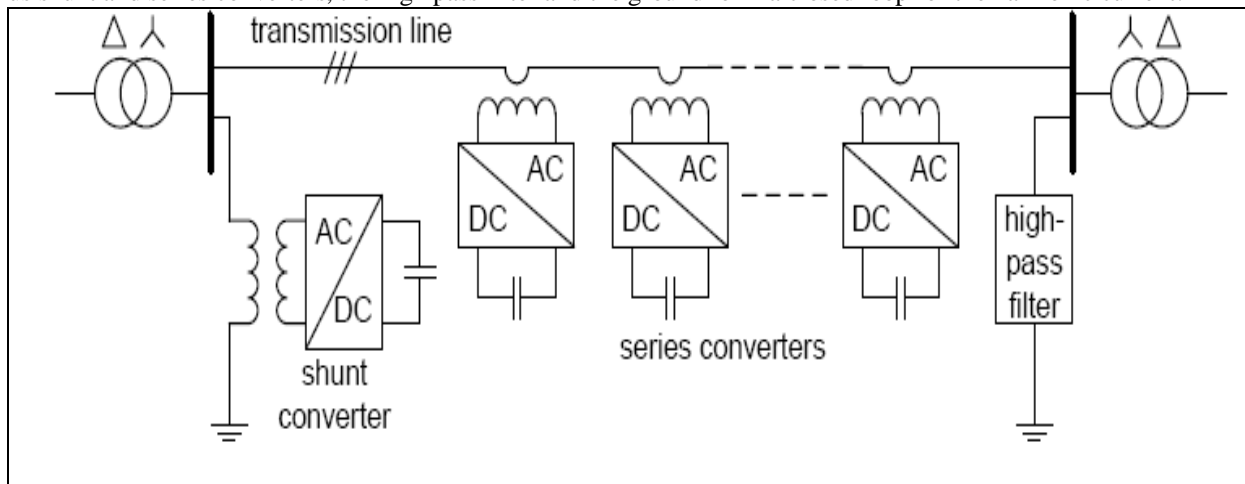

"**Figure-3: Block diagram of DPFC**"

B. DPFC OPERATING PRINCIPLE

Non-sinusoidal voltage and current be represented as the sum of sinusoidal functions in different frequencies with different amplitudes.This method of power theory of non-sinusoidal components is used to exchange active power through the AC ports.

$$P= \sum_{n=1}^{\infty} V_n I_n \cos \theta n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(i)$$

V_n and I_n are the voltage and current at the nth harmonic frequency respectively & θ_n is the angle between the voltage and current.Equation (i) is the representation of power theory of non-sinusoidal component which shows that the active powers at different frequencies are independent from each other and there is no influence of voltage or current at one frequency on the active power at other frequencies. Due to which a converter without a power source can generate active power at one frequency and absorb this power from other frequencies. By the application of this method to the DPFC, the shunt converter can absorb active power from the grid at the fundamental frequency and inject the power back at a 3rd harmonic frequency. This harmonic active power flows through a transmission line through which series converters are connected. According to the amount of required active power at the fundamental frequency, the DPFC series converters absorb the active power from harmonic components. The active power generated at the fundamental frequency is same as the power absorbed at the harmonic frequency if the losses are neglected. Figure 3-3 indicates how the active power is exchanged between the shunt and the series converters in the DPFC system.
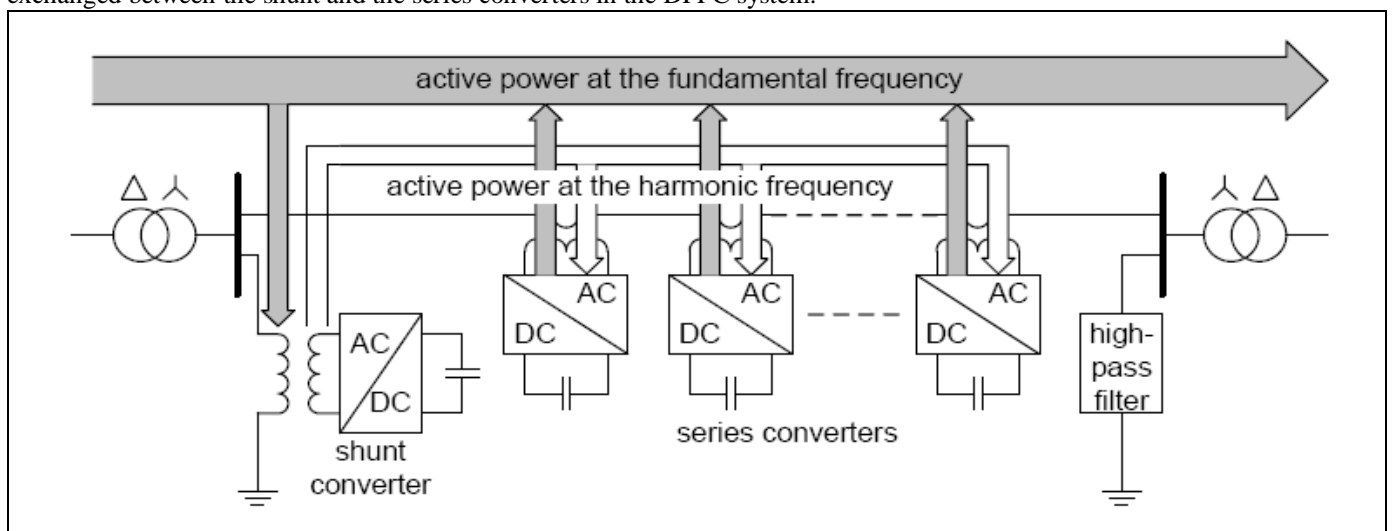
"**Figure-4: Exchange of active power between DPFC converters**"

The 3rd harmonic is selected for active power exchange in the DPFC due to its unique feature. In a three-phase system, the 3rd harmonic in each phase is identical means they are 'zero-sequence' components. As they can be naturally blocked by Y-Δ transformers and these are widely incorporated in power systems.
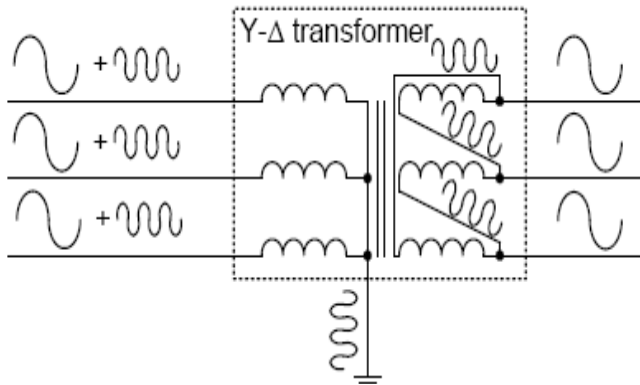

"Figure-5: To filter zero-sequence harmonic grounded Y-Δ transformer is used"

C. SIMPLIFIED CKT OF DPFC

In order to simplify the DPFC circuit, each converter can be replaced by a controllable voltage source in series with impedance. Hence each converter can be represented by two series connected controllable voltage sources at two different frequencies, one at fundamental frequency and the other at 3rd harmonic frequency. The total active power generated by the two frequency voltage source will be zero, if the converter is lossless. The conceptual representation of DPFC is shown in Fig.5, where the addition of the voltages at fundamental frequency for all series converters are represented by Vse,1 and the addition of the voltages at 3rd harmonic frequency by Vse,3. Voltage at 3rd harmonic frequency is generated by shunt generator due to which a third harmonic current will flow in the section of the transmission line to feed the active power to series converters. The capacitor dc voltage of shunt converter is compensated by the absorbing active power at fundamental frequency. The series converters inject a fundamental voltage which is controllable in both magnitude and phase by absorbing the 3rd harmonic voltage from transmission line.
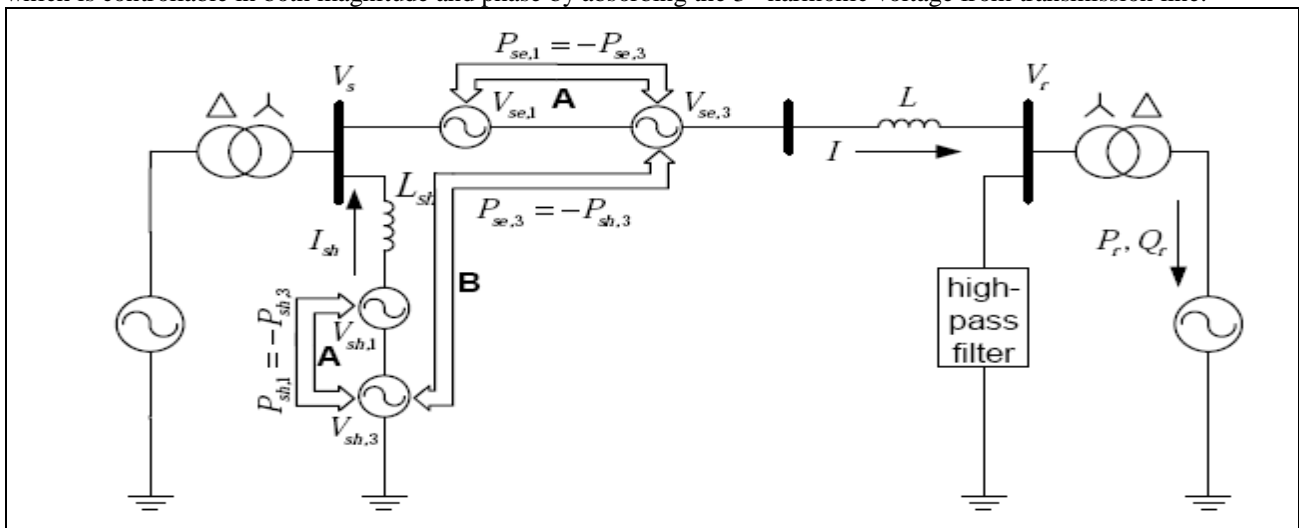
"Fig-6: Simplified representation of DPFC"
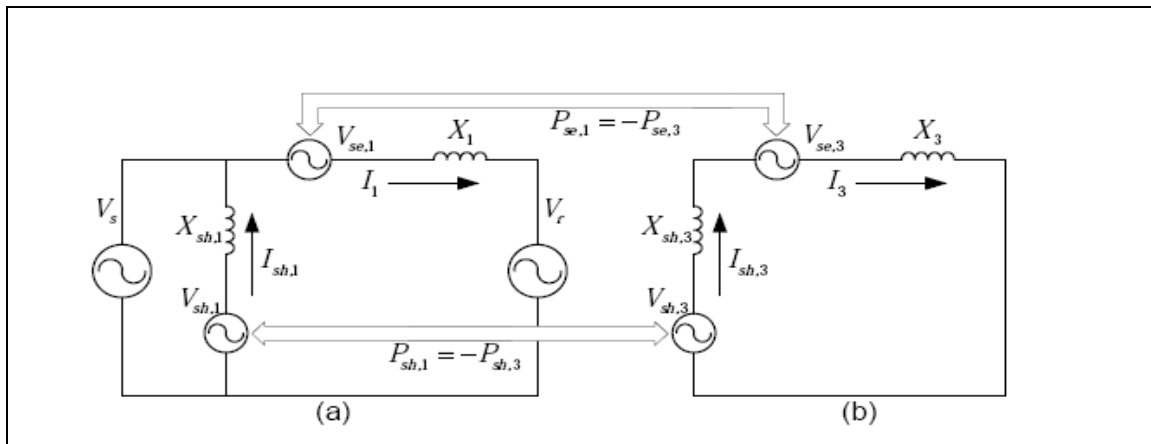
"Fig-7: Equivalent circuit of DPFC :(a) the fundamental frequency; (b) the 3rd harmonic frequency"

The circuit can be divided into two circuits at different frequencies according to superposition theorem. The two circuits are isolated from each other, and the link between two circuits is the active power balance of each converter, As shown in Fig.6, the circuit of a DPFC is the same as a UPFC at fundamental frequency, therefore the DPFC have the similar characteristic as UPFC.

VI   CONTROLLING OF DPFC

A) DPFC CONTROL PRINCIPAL: The power flow control function is controlled by an outer control loop, the power flow control block. This block receives its reference signals from the system operator, and the control signals for DPFC series converters are sent remotely via wireless or PLC communication method.
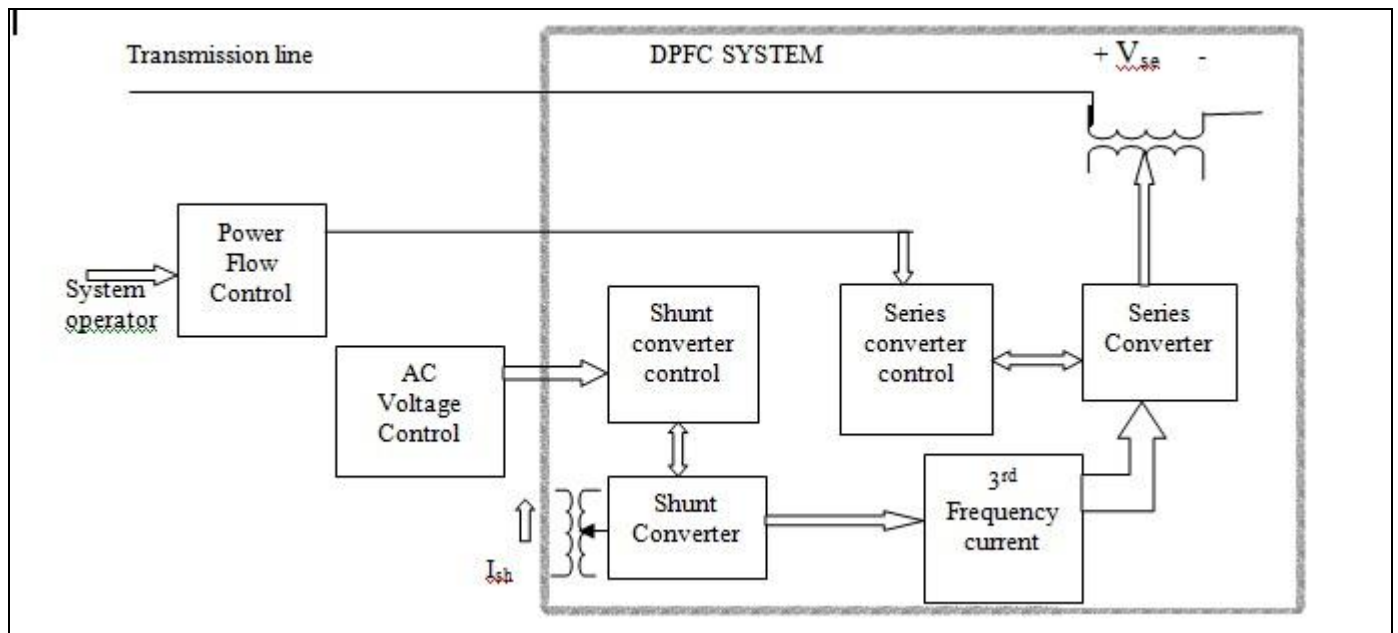
Figure 8: Block diagram of DPFC control

B)   CONTROLLERS IN DPFC: The DPFC has central controller, shunt controller, series controllers. The series and shunt controller are controlled by controlling their own converter parameters and the total power system level is controlled by the central controller.
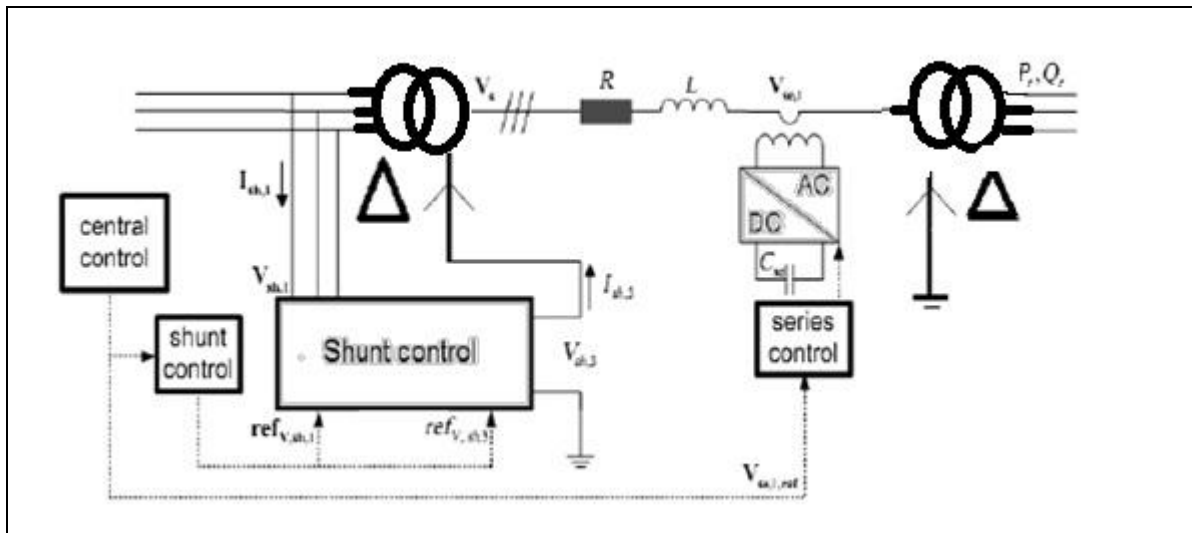
"Figure 9: Control structure of DPFC"

- **CENTRAL CONTROL**

    Reference signal for both shunt and series converters are generated by central control. It gives reactive current signal for shunt converter and voltage reference signals for series converters according to the requirement of system. Central control generates all the reference signals concerning the fundamental frequency.

- **SERIES CONTROL**

    Each series converter possesses its own series control. This control is used to maintain capacitor DC voltage by utilizing 3rd harmonic frequency components of its own converter in order to generate series voltage at fundamental frequency as per requirement of central control.
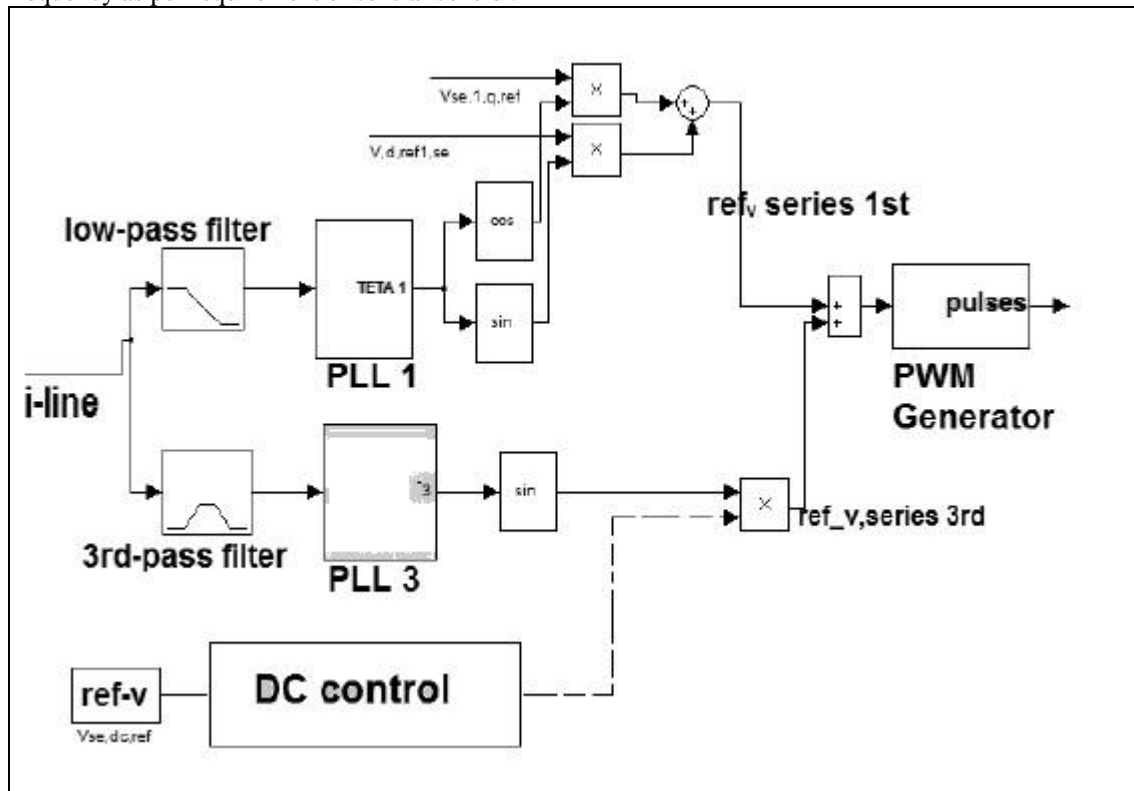
"Figure 10: Series control configuration"

- **SHUNT CONTROL**

    The shunt control is used to inject a constant 3rd harmonic current into the transmission line to supply active power for series converters. It also maintains the capacitor DC voltage of shunt converter at a constant value by injection of the required reactive current into the grid and absorption of active power from the grid at fundamental frequency.
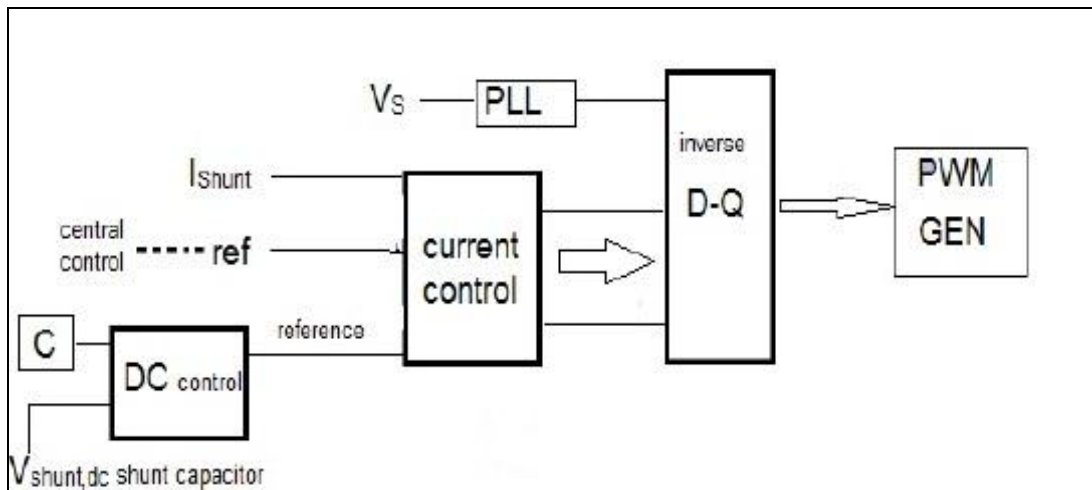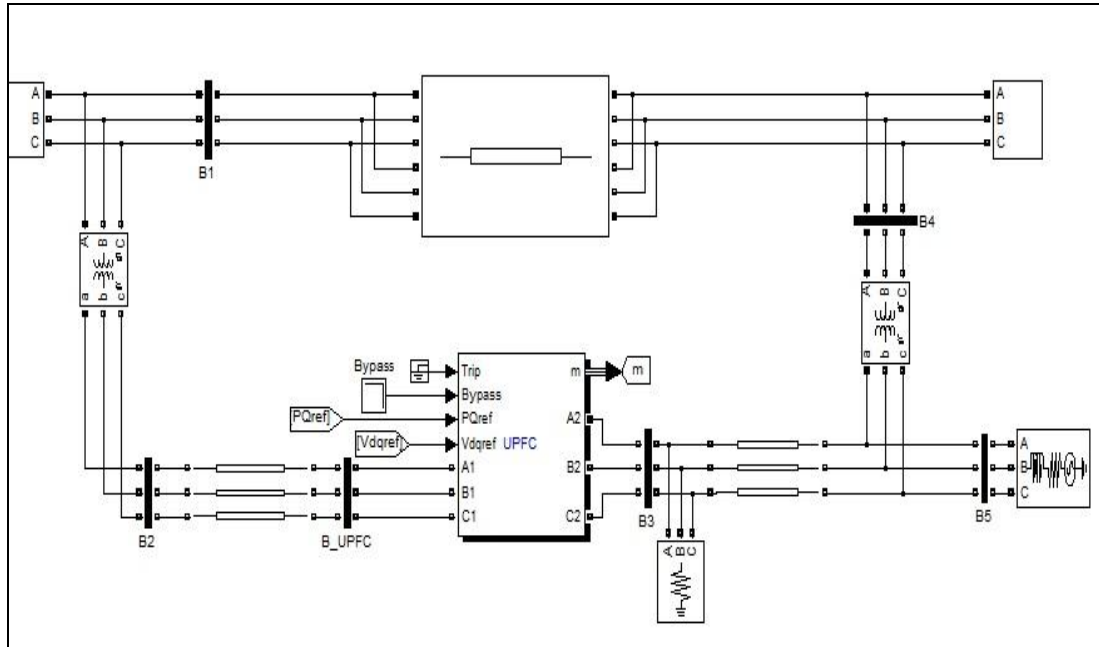
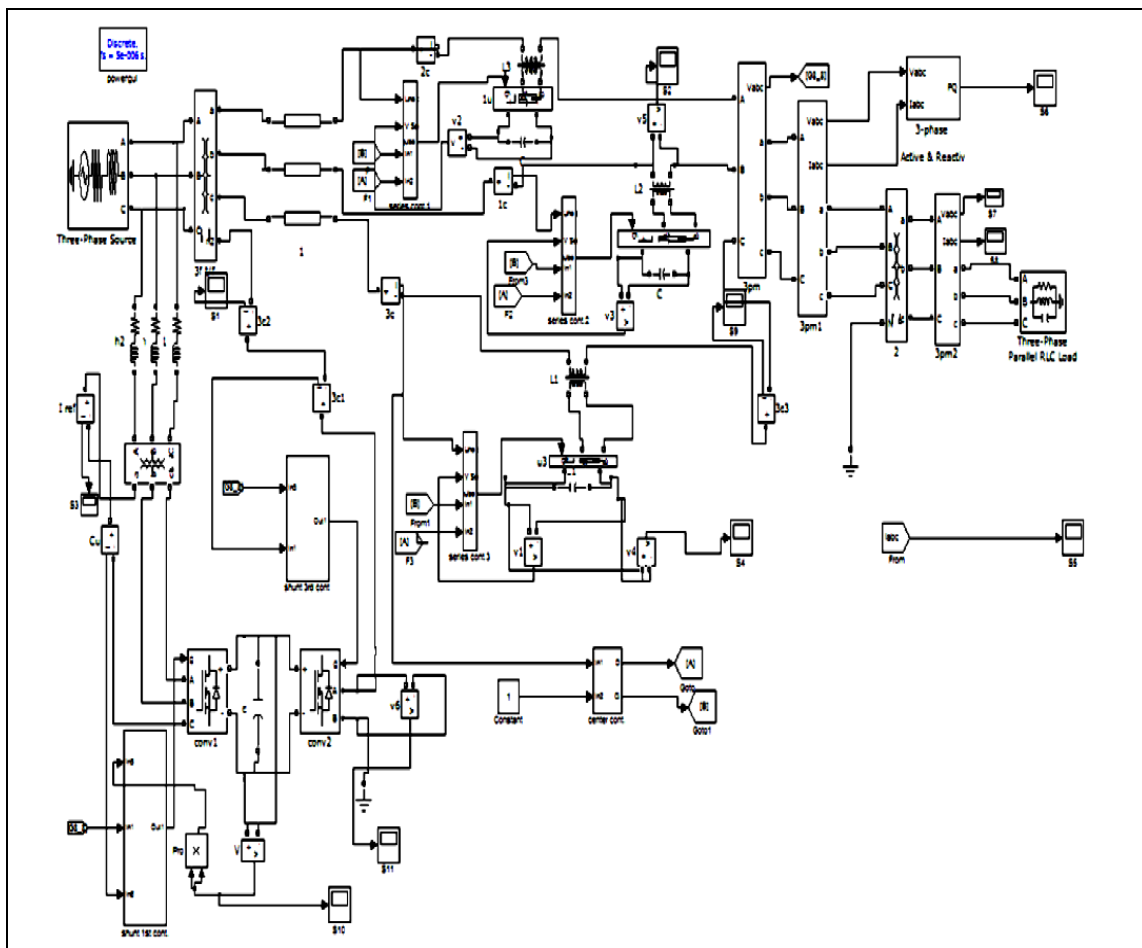**"Figure 11: Configuration for shunt control a) For fundamental frequency"**
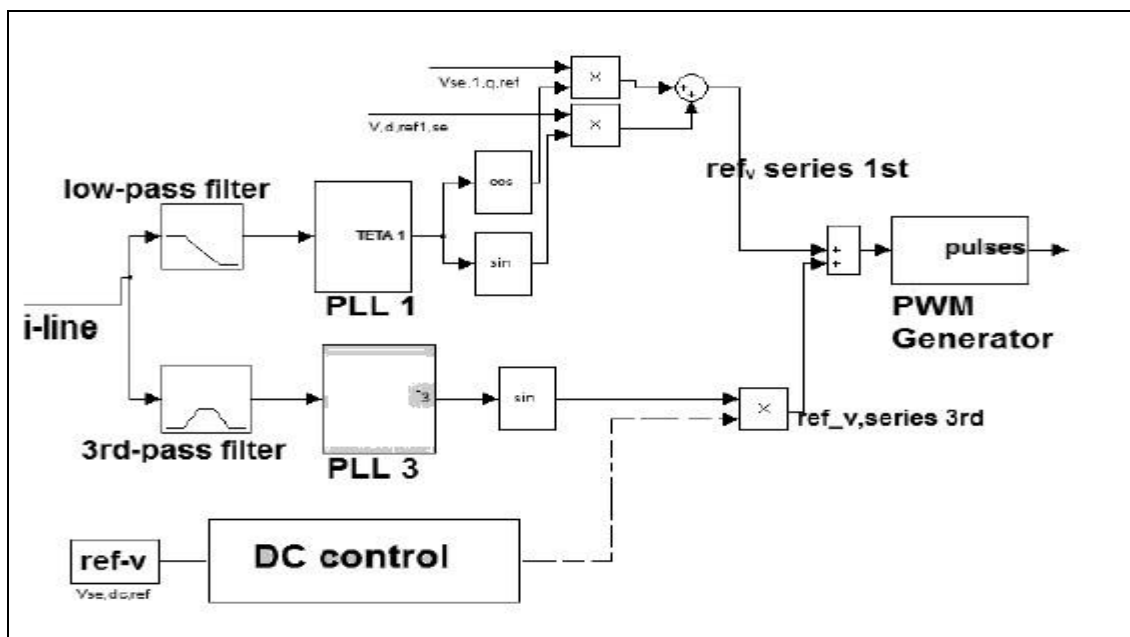
"b) For third harmonic frequency"
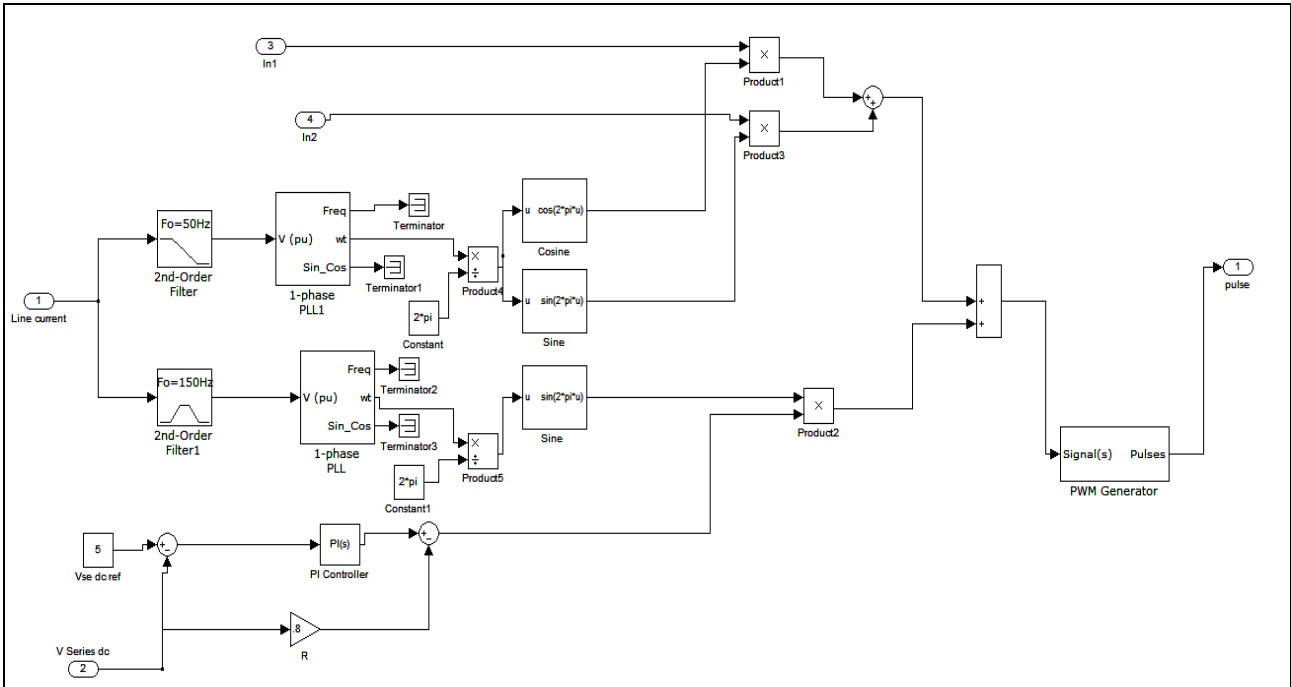
VII. SIMULATION MODEL

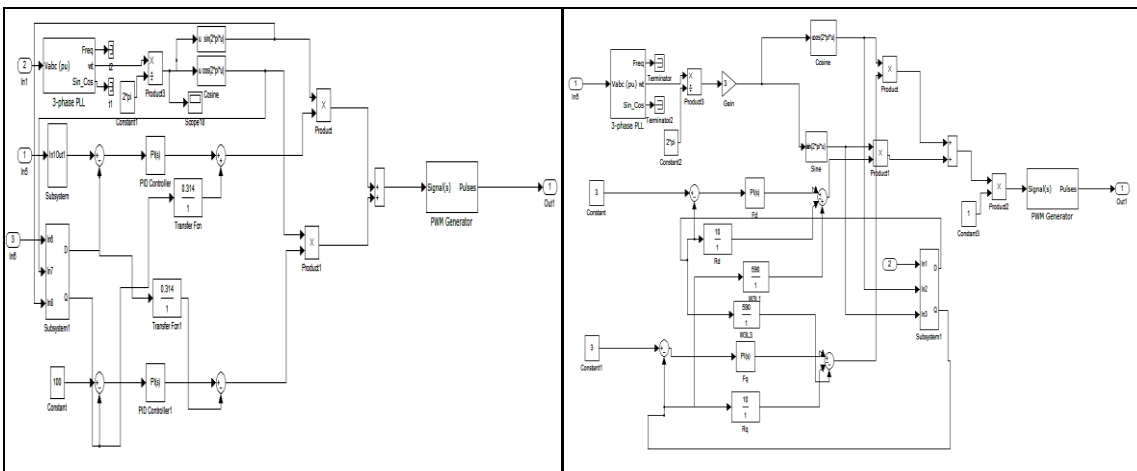**"Figure 12: Simulation setup of UPFC"**

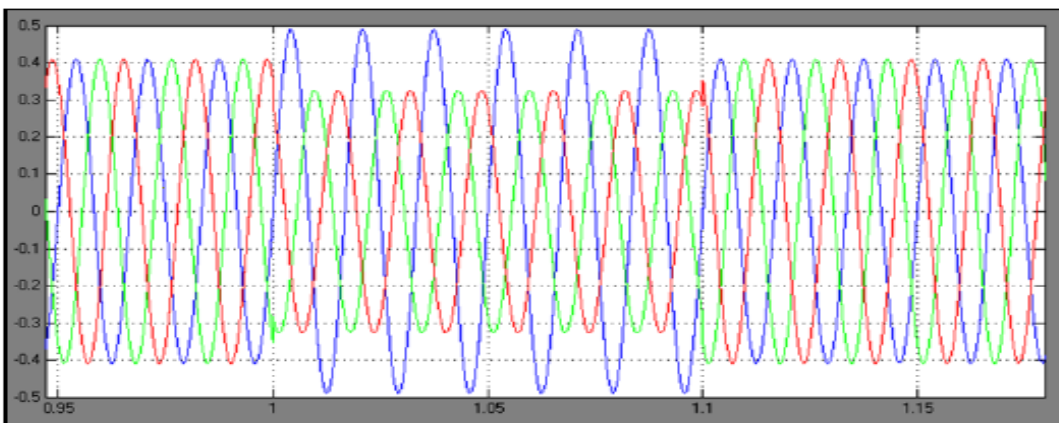**"Figure 13. Simulation setup of DPFC"**

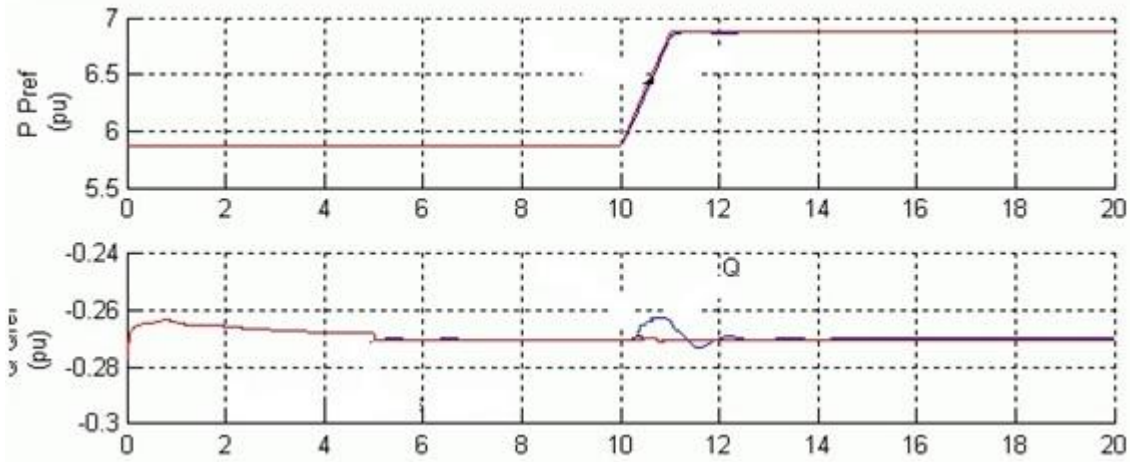**"Figure 14. Simulation setup of control of Series converter"**

"Figure 15.Simulation setup of shunt control"
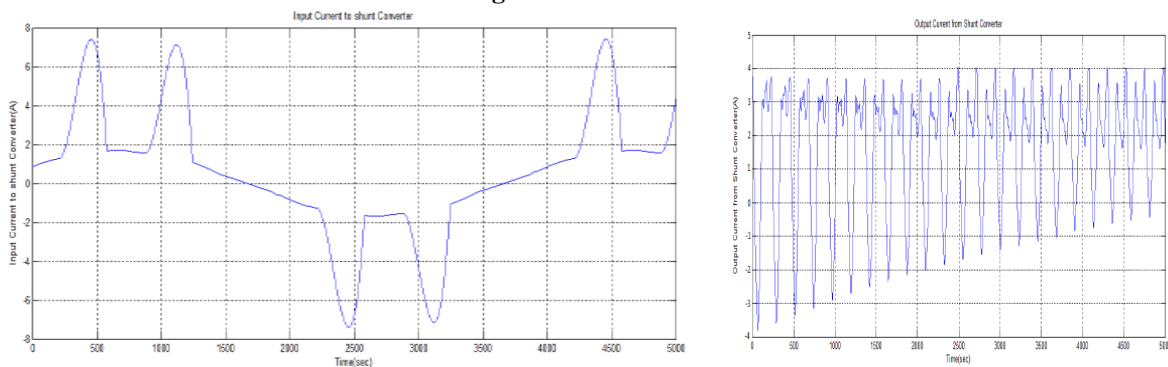**a) Third Harmonic Frequency Control b) Fundamental Current Control**
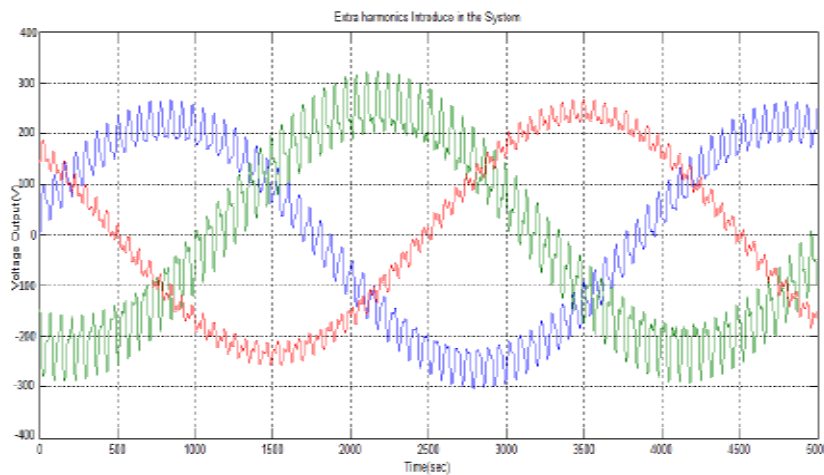
VIII   SIMULATION RESULTS

"Figure 16. Three phase current at delta side of transformer"

"Figure 17. UPFC Waveforms"

"Figure 18. Input & output Current to Shunt Converter"

"Figure 19. output voltage of Shunt converter"

VI.CONCLUSION

This paper has presented the comparison between UPFC and DPFC and controlling of DPFC. Modeling and simulation analysis of UPFC and DPFC has been presented. The limitations of UPFC have been overcome in DPFC. It has the same control capability as UPFC with improved reliability and reduced cost. DFACT concept which is to use multiple single phase converter in place of large size converter is employed which improves its reliability. There is no requirement of high voltage isolation at series counterpart and rating of component is also low in DPFC which reduce its cost.

VII. REFRENCES

[1] N. Hingorani, "Flexible AC Transmission," IEEE Spectrum, v. 30, No. 4, Apr. 1993, pp 40-45.

[2] L.Gyqyi, "the unified power flow controller: a new approach to power transmission control,''IEEE Spectrum Vol. 10, No. 2, April 1995.

[3] S. Bhattacharya, B. Fardanesh. B. Shperling and S. Zelingher, "Convertible Static Compensator: Voltage Source converter Based FACTS Application in the New York 345 KV Transmission System," in International Power Electronics Conference Records, Apr. 2005, pp. 2286-2294.

[4] Zhihui Yuan Sjoerd W.H. de Haan Braham Ferreira"A New FACTS Component — Distributed Power Flow Controller (DPFC)"

[5] Narain G. Hingorani and Laszlo GyugyiUnderstanding FACTS concept and technology of flexible AC transmission systems

[6] R.H.Miller&J.H.MalinowskiPower System OperationZhihui Yuan Sjoerd W.H. de Haan Braham Ferreira"A New FACTS Component — Distributed Power Flow Controller (DPFC)"

[7] Nagabhushan, "Distributed power flow controller,''SSRG-IJEEE– volume1 issue 5 July 2014

[8] Ferreira and Dalibor Cvoric "A FACTS Device: Distributed Power Flow Controller *(DPFC)*'', IEEETransactions Power Electronics, vol. 25, no.10,October 2010