

Comparison of Performance of Distributed Power Flow Controller (DPFC) and Unified Power Flow Controller (UPFC)

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Abstract —Increasing demand of power has lead to enhancement of transmission capabilities. The work carried out in this paper is related to development of a new Power flow controlling device that provides same control capability as the UPFC with decreased cost and increased reliability. This FACTS device named “The Distributed Power Flow Controller” (DPFC) is a further development of the UPFC with an eliminated common d.c link. The transmission lines at 3rd harmonic frequency are used for active power exchange between shunt and series converters. The DPFC consists of one shunt and several series-connected converters. The shunt converter is similar as a STATCOM, while the series converter employs the D-FACTS concept, which is to use multiple single-phase converters instead of one large rated converter. Each converter within the DPFC is independent and has its own dc capacitor to provide the required dc voltage. 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 reduced power loss and voltage profile. In this paper performance analysis of UPFC and DPFC are compared and corresponding experimental results are carried out by Simulink model.

Keywords- Power Flow Control, Flexible AC Transmission System, Current Control, symmetrical component, Voltage Source Converter, Transmission, Distributed Power Flow Controller, Unified Power Flow Controller.

I. INTRODUCTION

In present scenario, drastic increase in consumption as well as generation of electricity results in growing rate of the requirement of fast and reliable control power flow in power system. An electrical power system deals with electrical generation, transmission, distribution and consumption.



“Figure 1. Power System”

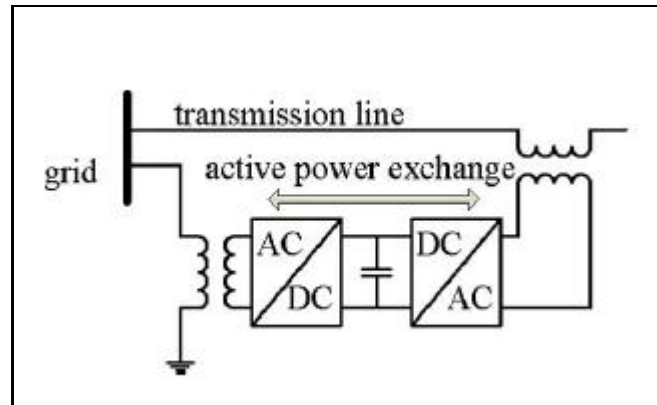
A.C. transmission systems incorporating power electronics-based and other static controllers to enhance controllability and increase power transfer capability. FACTS devices provide control of one or more A.C-transmission system parameters to enhance controllability and power transfer capability with the use of **UPFC (Unified Power Flow Controller)** till now [1]. FACTS technology gives us a new opportunity of controlling and enhancing power. The possibility that current through a line can be controlled at a desirable cost enables a large potential of increasing the capacity of existing lines with larger conductors, and use of one of the FACTS Controllers in order to allow corresponding power to flow through such lines under normal and abnormal conditions.

II. UPFC VERSUS DPFC

The UPFC was composed for the real-time control and dynamic compensation of ac transmission systems. UPFC is able to control all the parameters affecting power flow in the transmission line i.e. voltage, impedance, and phase angle and this unique feature is signified by the adjective "unified" in its name [2]. It can independently control both the real and reactive power flow in the transmission line. The UPFC is has two parts such as static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC). STATCOM is a shunt connected device and SSSC is a series connected device, both are coupled through a common dc link [1]. UPFC has some Capabilities

- Increase transmission line capacity
- Direct power flow along selected lines

- Powerful system oscillation damping
- Voltage support and regulation
- Control of active and reactive power flow at both sending- and receiving-end



“Figure 2. UPFC Configuration”

It allows bidirectional flow of active power between the series and shunt converters. In UPFC, the series connected converter injects four-quadrant voltage with controllable magnitude and phase. The injected voltage works as a synchronous ac-voltage source and is used to vary the line impedance and transmission angle, thereby independently controlling the active and reactive power flow through the line. The series voltage results in active and reactive power injection or absorption between the series converter and the transmission line. Series converter generates reactive power internally, and shunt converter supplies the active power[3]. The shunt converter can provide reactive compensation for the bus. By absorbing or generating active power from the bus, the shunt converter controls the voltage of the dc capacitor, so it works as a synchronous source in parallel with the system. But UPFC has some **limitations** :

A. High cost

Due to the common dc-link, any failure in one converter will influence the whole system. To achieve the required reliability for power systems, bypass circuits and backup transformer, etc. are needed, which also increases the cost. The components of the UPFC handle the voltages and currents with high rating so the total cost of the system is high.

B. Low Reliability

The UPFC is not widely used in utility grids because it fails if there is any disturbances or faults in the source side. It is less reliable.

To rule out the limitations of UPFC we design a new device Distributed Power Flow Controller (DPFC). It provides higher flexibility and reliability at lower cost. The DPFC is an improvement of UPFC that employs the D-FACTS concept and the concept of exchanging power through the 3rd harmonic. It has following **advantages** that make it more efficient than UPFC:

C. High controllability

The DPFC can simultaneously control all the parameters of the transmission network: line impedance, transmission angle and bus voltage.

D. High reliability

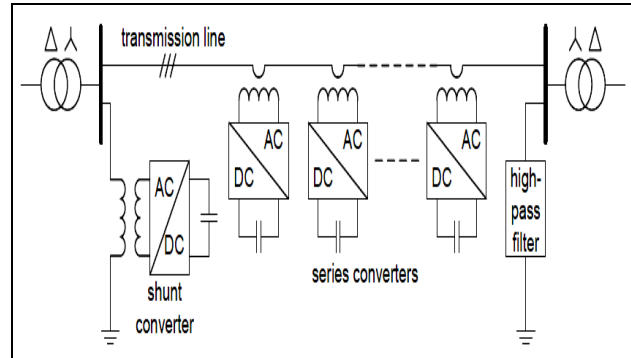
Without increasing cost, the redundancy of the series converter gives high reliability. In addition, the shunt and series converters are independent and failure of one will not influence the other converter.

E. Low cost

In DPFC we use low power rating converters which lowers its cost. There is no phase-to-phase voltage isolation required between the series converters of different phases. Because of the large number of the series converters, they can be manufactured in series production.

DPFC is extracted from the UPFC and has the same control capabilities of UPFC. It simultaneously adjusts all the parameters of the power system i.e. line impedance, transmission angle, and bus voltage magnitude. Within the DPFC, the common dc

link between the shunt and series converters is eliminated, which provides flexibility to transmission system. In this the transmission lines at 3rd harmonic frequency is used for active power exchange between both converters. Instead of using one high rating three-phase converter we use multiple single-phase converters based on D-FACTS concept used in DPFC. This concept increases reliability and reduces the rating of the components. The scheme of the DPFC in a simple two-bus system is illustrated in Fig. 3.

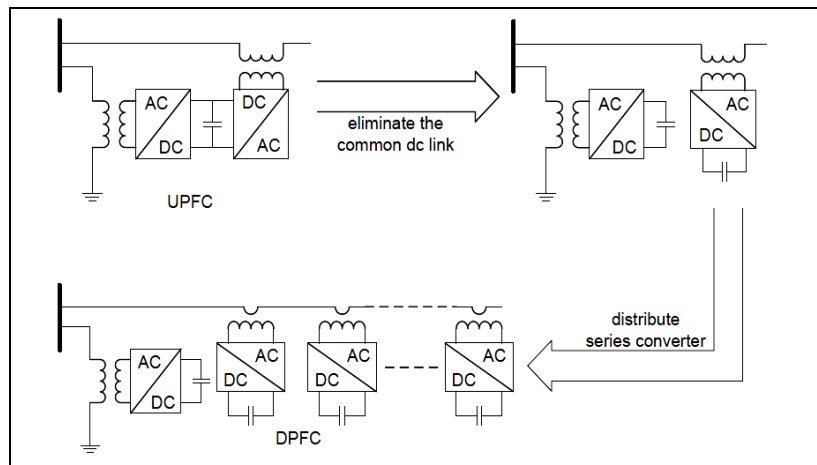


“Figure 3. DPFC Configuration”

The high reliability of the DPFC is provided by the redundancy of the converters. If one converter fails, the others will continue operation. However, the failed converter will stop providing the desired voltage, thereby causing asymmetry of the series converters and reducing the performance of the DPFC.

III BASIC PRINCIPLE OF DPFC

In order to increase flexibility and reliability of system, two methodologies are used to design DPFC from UPFC are as follows:

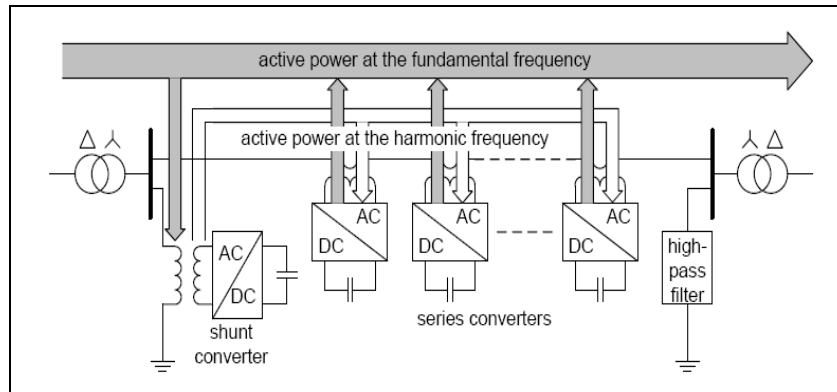


“Figure 4 . DPFC derived from UPFC”

A. Active power exchange with eliminated dc link

In the DPFC, the transmission line is a common connection between the AC ports of the shunt and the series converters. Therefore, it is possible to exchange active power through the AC ports. The method is based on power theory of non-sinusoidal components. According to the Fourier analysis.

$$P = \sum_{i=1}^{\infty} V_i I_i \cos \phi \quad \dots\dots\dots (1)$$



“Figure 5 . DPFC derived from UPFC

Equation (1) shows that the active powers at different frequencies are independent from each other and the voltage or current at one frequency has no influence on the active power at other frequencies. By applying 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 harmonic frequency. This harmonic current will flow through the transmission line. DPFC series converters generate a voltage at the harmonic frequency, thereby absorbing the active power from harmonic components as per requirement of active power at the fundamental frequency. The high-pass filter is used to block the fundamental frequency components and allows the harmonic components to pass, thereby providing a return path for the harmonic components. The third harmonic is used to exchange the active power in the DPFC. In a three-phase system, the third harmonic in each phase is identical, which is referred to as “zero-sequence.” Y- Δ transformers are used in power system to change voltage level and the zero-sequence harmonic can be naturally blocked by it.

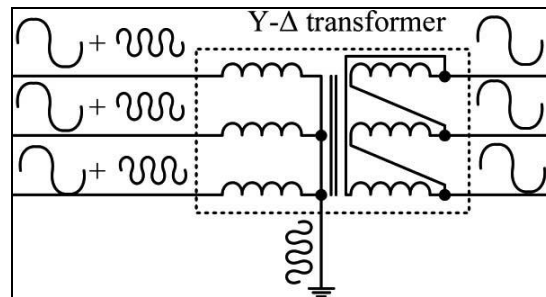


Figure 6. “Grounded Y- Δ transformer to provide the path for the zero- sequence third harmonic”

B. Distributed Series Converters

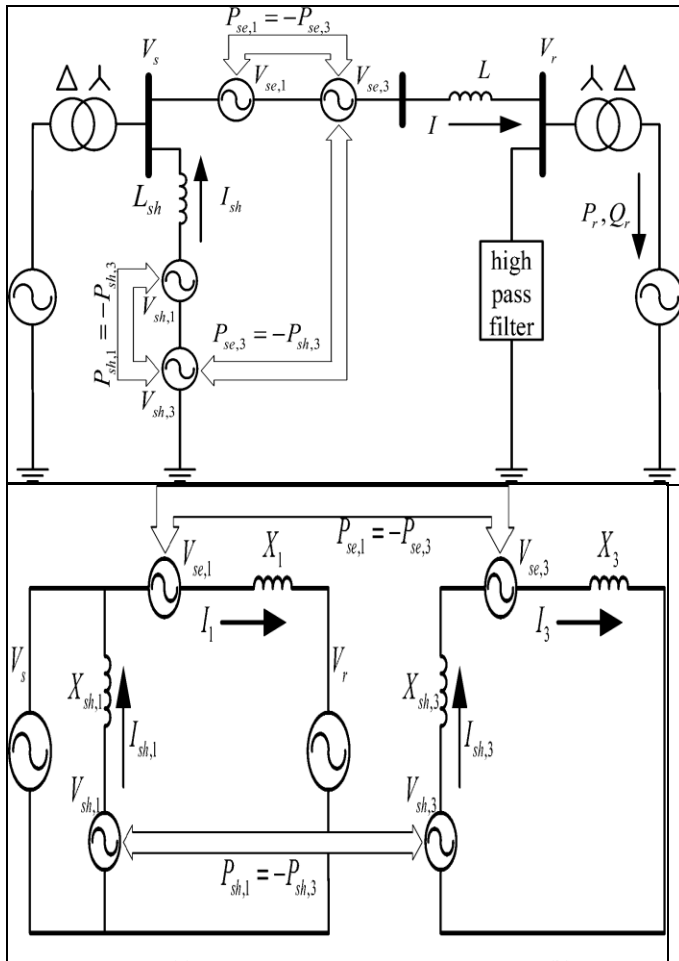
In order to reduce cost and increase reliability, the D-FACTS (distributed FACTS) concept is used. In which multiple small-size single-phase converters are used instead of the one large-size three-phase series converter as in UPFC. The converters are hanging on the line in order to reduce cost of high-voltage isolation.

IV ANALYSIS OF DPFC WITH EQUIVALENT CIRCUIT

Since each converter generates voltages at two different frequencies, they are represented by two series connected controllable voltage sources, one at the fundamental frequency and the other at the 3rd harmonic frequency. For an easier analysis based on the superposition theorem the circuit can be further simplified by splitting it into two circuits at different frequencies. The two circuits are isolated from each other, and the link between these circuits is the active power balance of each converter.

For simplification the converters in DPFC are replaced by controllable voltage sources in series with impedance. Since each converter generates its voltage at two different frequencies, one at the fundamental frequency and the other at the third-harmonic frequency. Assuming lossless transmission line and converter, the total active power generated by the two voltage sources will be zero at different frequencies. The multiple series converters are simplified as one large converter with the voltage, which is equal to the sum of the voltages for all series converter, as shown in **Figure 7**. In this the DPFC is placed in a two-bus system with the sending-end and the receiving-end voltages V_s and V_r , respectively. The transmission line is

represented by an inductance L with the line current I . The voltage injected by all the DPFC series converters is $V_{se,1}$ and $V_{se,3}$ at the fundamental and the third-harmonic frequency, respectively. The shunt converter is connected to the sending bus through the inductor L_{sh} and generates the voltage $V_{sh,1}$ and $V_{sh,3}$; the current. Based on the superposition theorem, the circuit can be further divided into two circuits at different frequencies. The two circuits are isolated from each other, and the link between these circuits is the active power balance of each converter, as shown in **Figure 8**.



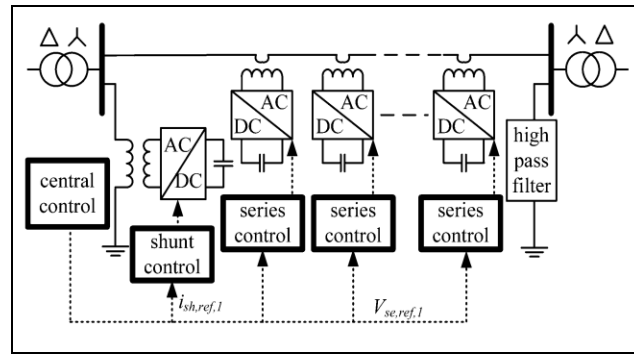
“Figure 7. DPFC simplified circuit”

8.1. Fundamental frequency 8.2. Third harmonics
“Figure 8. Equivalent circuits of

DPFC “

V DPFC CONTROL METHODS

To control the operation of converters in DPFC, three types of controllers are as follows-



“ Figure 9. Control scheme ”

A. Central control

According to the requirements of system the central control gives corresponding voltage reference signals for the series converters and reactive current signal for the shunt converter. Its control function depends on the needs of the DPFC application at the power system level, such as power flow control, low frequency power oscillation damping and balancing of asymmetrical components. All the reference signals generated by the central control at fundamental frequency components.

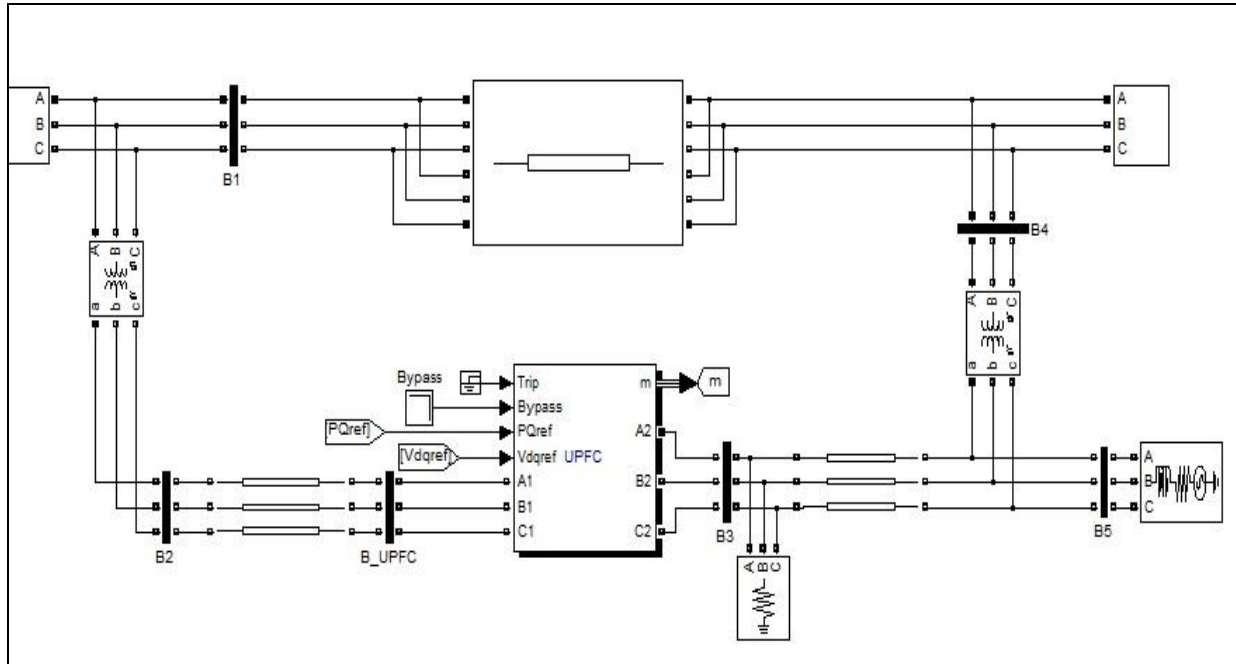
B. Series control

The third-harmonic frequency control is the major control loop with the DPFC series converter control. Each series converter needs its own series control. The controller maintains the capacitor dc voltage of its own converter by using the third harmonic frequency components and series voltage is generated at the fundamental frequency that is prescribed by the central control.

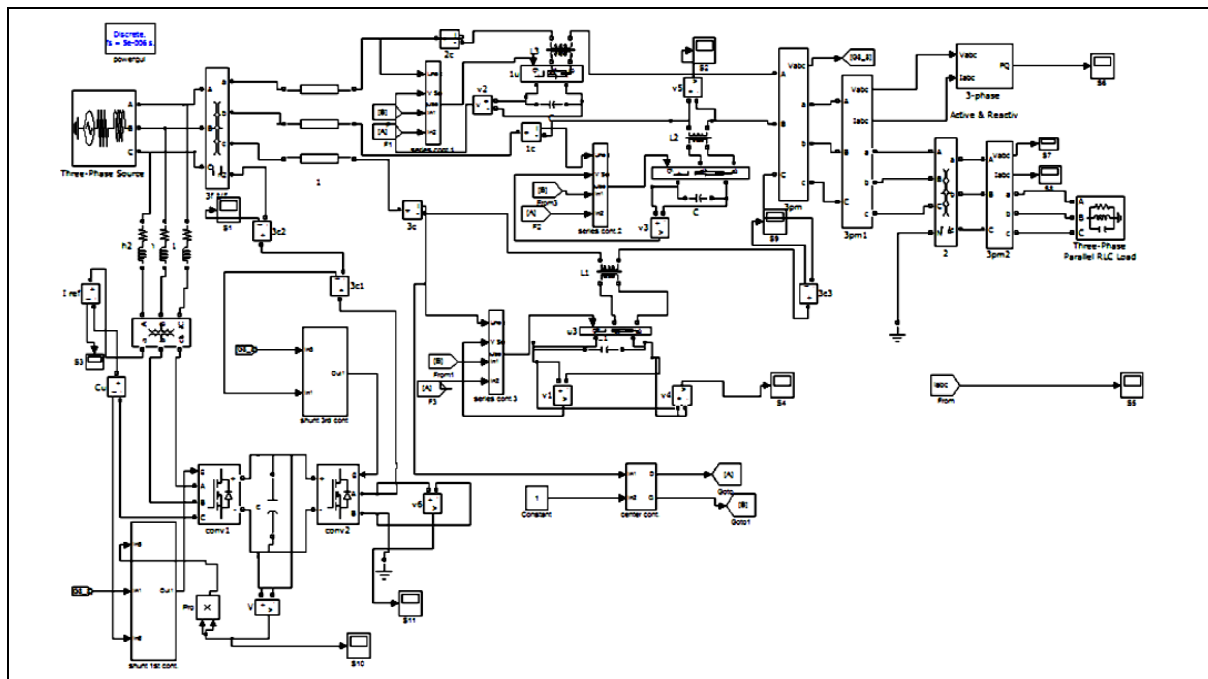
C. Shunt control

In Shunt control a constant 3rd harmonic current is injected in the line to supply active power for the series converters . At the same time, the capacitor DC voltage of the shunt converter at a constant value is maintained by absorbing active power from the grid at the fundamental frequency and injecting the required reactive current at the fundamental frequency into the grid.

VI SIMULATION SETUP

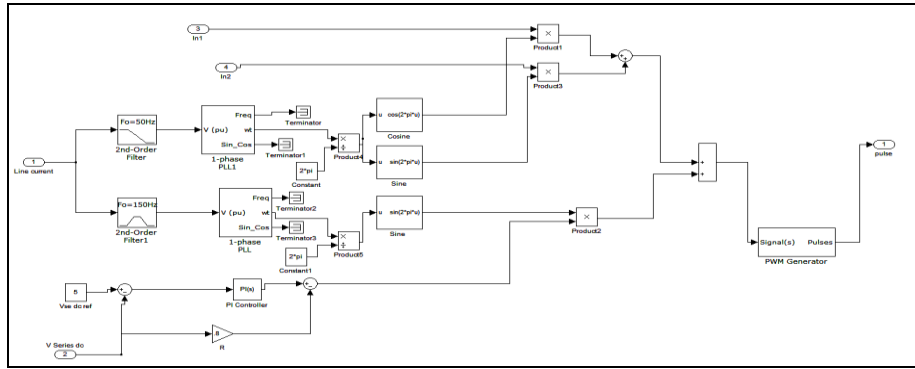


“Figure 10. Simulation setup of UPFC”



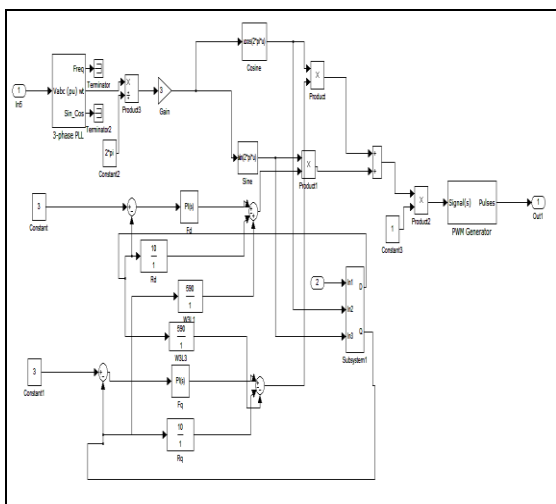
“Figure 11. Simulation setup of DPFC”

A. Series Control

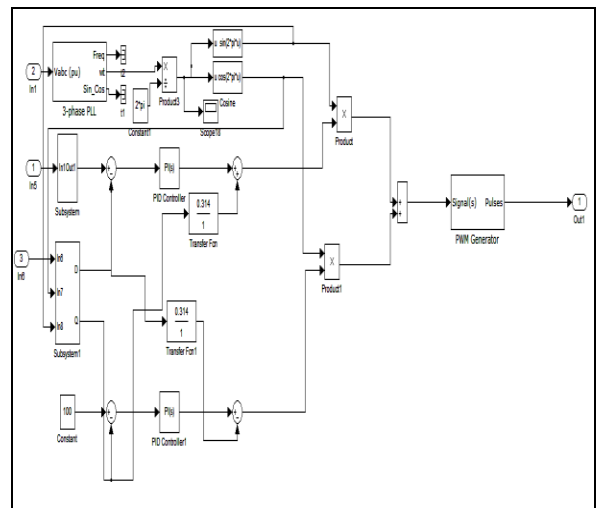


“Figure 12. Simulation setup of control of Series converter”

B. Shunt Control

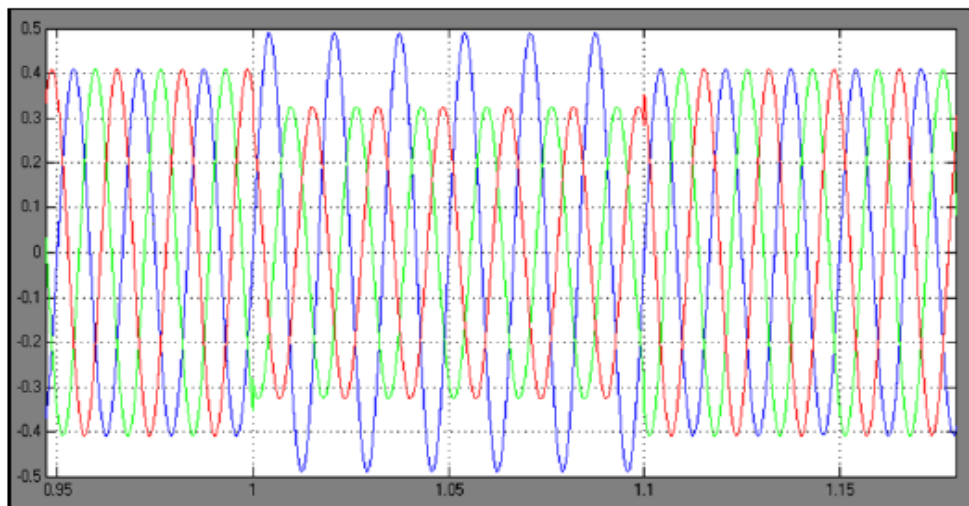


“Figure 13. Third Harmonic Frequency Control ”



“Figure 14. Fundamental Current Control ”

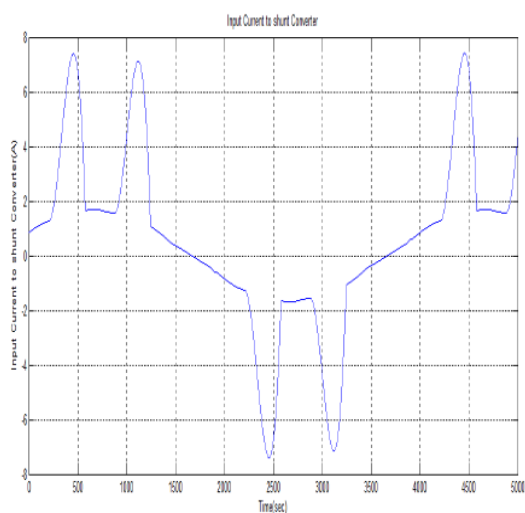
VII SIMULATION RESULTS



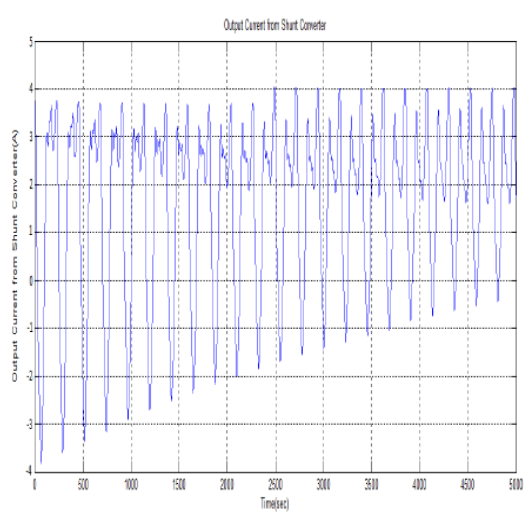
“Figure 15. Three phase current at delta side of transformer”



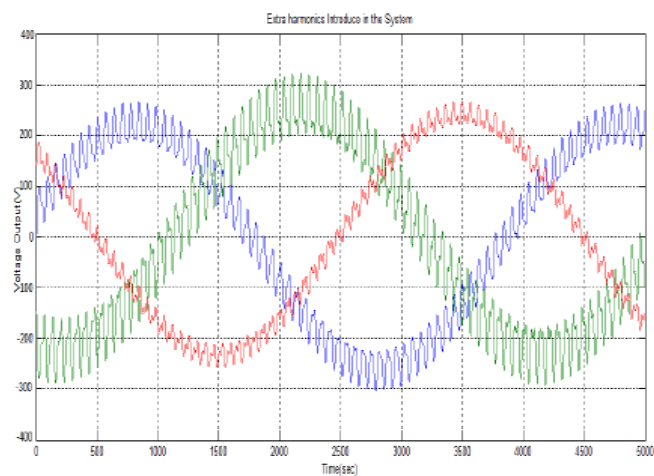
“Figure 16. Simulation results for step-like changes in P and Q demands.”



“Figure 17. Input Current to Shunt Converter ”

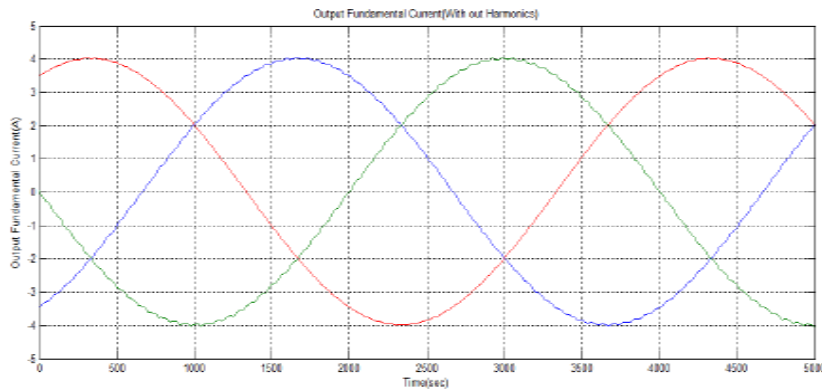


“Figure 18. Output Current to Shunt Converter ”



“Figure 19. Fundamental + 3rd Harmonic Current (output

voltage of Shunt converter)”



“Figure 20. Output Fundamental Current (Series converter output)”

VIII CONCLUSION

The DPFC is derived from the UPFC and inherits same the control capability of the UPFC. The common dc link between the shunt and series converters that is used for transferring active power in the UPFC, is now eliminated. This power is now transmitted through the transmission line at the third-harmonic frequency. So 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 is low. The simulation results, obtained by MATLAB shows the efficiency of DPFC, in controlling line both active and reactive power flow is much higher than UPFC , which increases reliability of system with reduced cost.

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