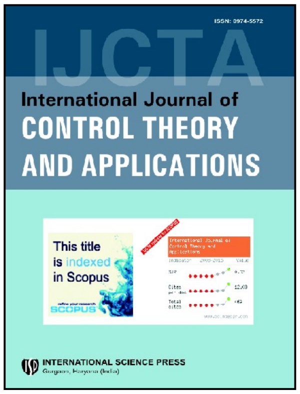

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Distributed Power-Flow Controller (DPFC)

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Abstract: This paper deals with a contemporary element available among the flexible ac-transmission system (FACTS) progeny, known as distributed power flow controller (DPFC). In DPFC the dc link is eradicated for a UPFC. In DPFC the transfer of power amidst converters happens over transmission lines for particular frequency. DPFC technology engages distributed FACTS (D-FACTS) approach, which proposes to employ numerous converters of small size converters rather than one large size converter in the UPFC. Due to employability of several converters the cost gets curtailed on comparison with UPFC as there is no need of isolation between phases.

Key Words: Power electronic devices, FACTS devices, power transmission control, load flow control

1. INTRODUCTION

Flexible AC-Transmission System (FACTS) attributes to descendants of power electronics-based devices, which are capable of boosting power transfer capacity. IEEE has defined FACTS a power-electronic based system that provides control of ac transmission system parameters to enhance power-transfer capability. Apart from increasing power transfer capability FACTS devices can be resorted for control flow of power and damping oscillations. FACTS devices can concurrently control the different criteria's of the system which are impedance, angle and voltage.

The amalgamation of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) results in a Unified Power Flow Controller (UPFC) as shown in Fig 1. Both these FACTS device are allied by virtue of intermediate DC link, for bidirectional passage of active power. A voltage is interjected in progression with the line and series converter. The voltage injected approximately operates as a concurrent voltage source, whose purpose is to alter the criteria's which are angle and impedance.

The outcome of series voltage is injection or absorption of active and reactive power. The voltage across the capacitor is controlled by shunt converter either by means of absorption or generation of active power to and fro the bus, hence this has been termed as concurrent source in shunt with the system. The disadvantage associated with this system is if the common dc-link fails, the whole system come to standby.

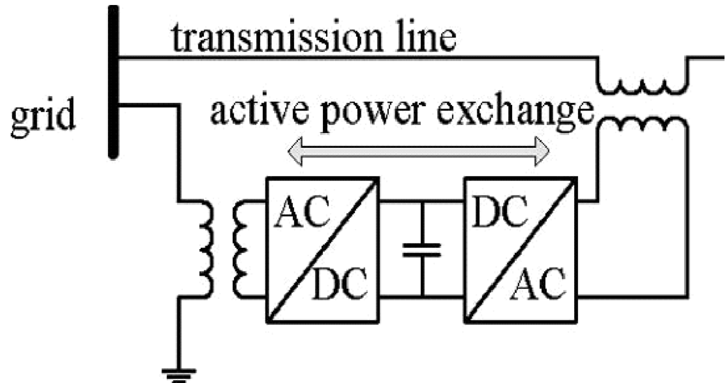

Figure 1: Block diagram of UPFC

This paper proposes a new approach, termed as distributed power-flow controller (DPFC) which has been derived from UPFC. The DPFC eradicate intermediate DC link between converters.

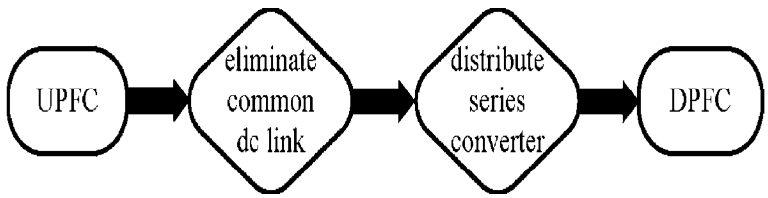

Figure 2: Power flow from UPFC to DPFC

The series converter available in UPFC uses the D-FACTS concept. The DPFC have two considerable preferences over UPFC:

1) Low cost.
2) High reliability.

The power flow can be controlled by altering the impedance or by the alteration of angle, to achieve this cost effective "series VAR" are required.

To achieve a smart and fault tolerant power grid FACTS devices have to be implemented. STATCOM, SVC, SSSC and UPFC can be banded in series, shunt or a consolidation of two to achieve voltage regulation, power system damping and power flow control.

2. DISTRIBUTED POWER FLOW CONTROLLER

2.1. Introduction

The high cost and perceptivity to failures restrict the use of UPFC and IPFC in practice. Because of the complex topology of these devices the reliability cannot be revamped by decreasing the components number. Other options available to increase the reliability are to select the different segments with above ratings in comparison to previous or applying prolixity. But the possible solutions available increase the initial investment necessary. So as to improve reliability and decrease the cost of the devices mentioned above new approaches need to be implemented. On careful observation it is observed that due to the presence of common DC link increases the risk of failure thereby diminishing the reliability of the device. To further improve the reliability of the device distributed series converter can be employed in the system. The series converter employed reduces cost as the need of high voltage isolation and high power rating components are eliminated. UPFC can be further flourished to Distributed Power Flow Controller (DPFC). DPFC is realized by excluding intermediate DC link and distribution of series converter, as represented in Fig. 3.

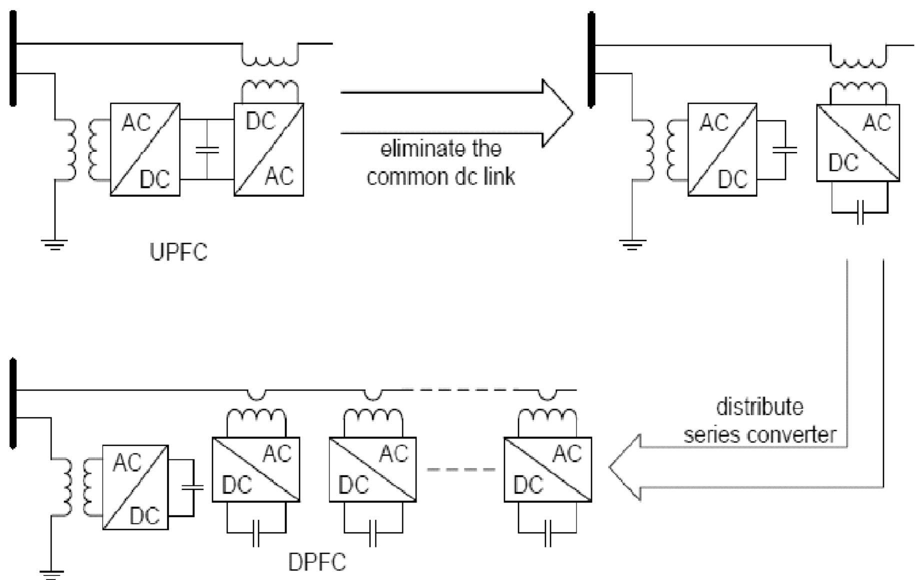

Figure 3: Inter-relation between DPFC and UPFC

2.2. DPFC Topology

The difference between DPFC and UPFC is that the series converter in DPFC adopts the DSSC concept. The converters employed in DPFC are self reliant and every converter is employed with individual capacitor to administer the desired DC voltage. The basic structure of DPFC is shown in Figure 4.

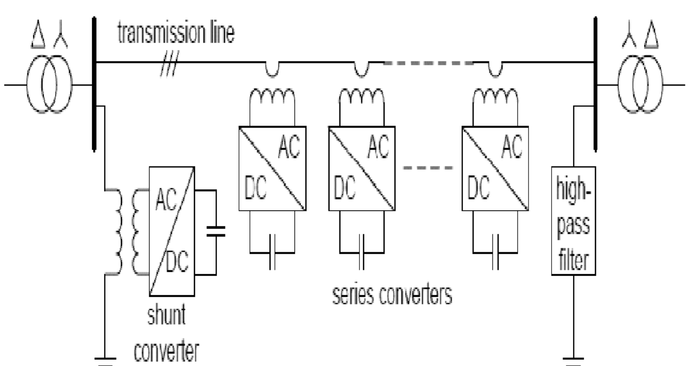

Figure 4: DPFC basic structure

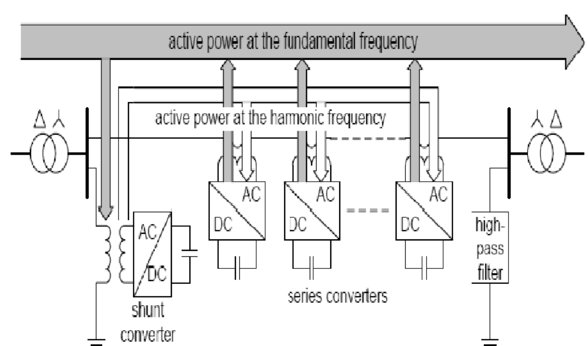

Figure 5: Exchange of active power in DPFC system

In addition to series and shunt converters, DPFC employs high pass filter which is connected in parallel with the transmission line.

2.3. DPFC Operating Principle

UPFC freely exchanges active power which is a unique control capability so as to expect the same response from DPFC a method is required for exchange of active power as the intermediate DC link is excluded. On observing the structure of DPFC it can be observed that the transmission line acts as a common relation between the series and shunt converters. DPFC utilizes the ideology of non-sinusoidal components. Bestowing upon this the average value of the product of voltage and current is the active power for non sinusoidal components. Mathematically active power can be represented as:

$$P = \Sigma_{i=1}^{\infty} V_i I_i \cos \phi_i \qquad (1)$$

In the equation (1) V_i is the voltage at i^{th} harmonic frequency and I_i is the current at the i^{th} harmonic frequency, and ϕ_i is the respective angle between the two quantities. Eq (1) represents the active power at distinct frequencies which are not related to each other. The self reliant nature of active power indicates that absence of source in converter engender active power for a specified frequency and absorb power at other than specified frequency.

On implementing above theory to DPFC, shunt converter ingests power from grid at the fundamental frequency and inject the power backward at frequencies other than fundamental frequency. Depending upon the capacity of active power required series converters generates a voltage at the harmonic frequency. Fig 5 represents the exchange of power between the converters available in DPFC system. The high-pass filter present in DPFC blocks the fundamental frequency components and grants other than fundamental components, so as to provide a return path for the harmonic components. A closed loop is formed for the harmonic current by using shunt, series, high pass filter and ground.

2.4. Using third harmonic components

As 3rd harmonic frequency components are unique it is preferred for exchange of active power in DPFC. It is unique in nature because they are zero sequence components. To eliminate the use of filter star delta transformer can be employed as zero-sequence harmonic components can be instinctively barred by star-delta transformers. To form a closed loop a filter is required. Due to the proximity of harmonic frequency to cut off frequency, need for filter arises. To sustain power the filter becomes costly. For cost optimization the objective of filter can be served by a cable. Due to the placement of star-delta transformer all the harmonic currents flow through star winding. As the filter is replaced with the cable, the harmonic currents flow through the grounding cable. Hence the need of filter is elucidated. The flow of harmonic currents is represented in Fig 6.

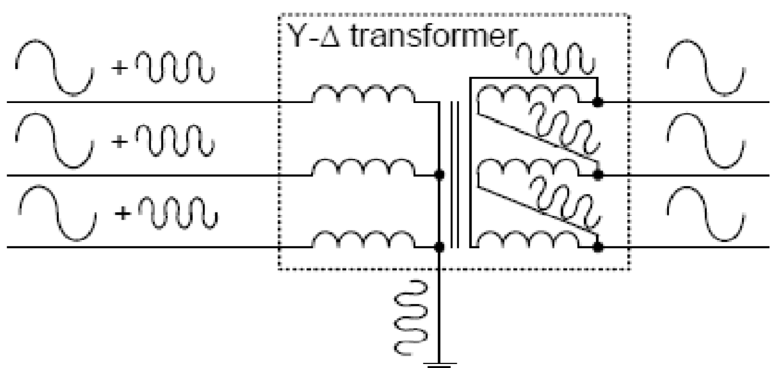

Figure 6: Arrangement to filter harmonic currents

2.5. Distributed Series converter

Another solution available to steadfast the series converter is the D-FACTS. The basic idea behind D-FACTS is to employ several controllers with low rating as a substitute to one controller. Usually low rating controller is a single phase converter.

The converters are hanged on the line to avoid high voltage isolation. Usually the transformers are hanged to the transmission line via single turn transformer. For this transformer, transmission line acts as secondary winding. Fig 7 shows the D FACTS module configuration in which it shows that it is self reliant and can be regulated by remote.

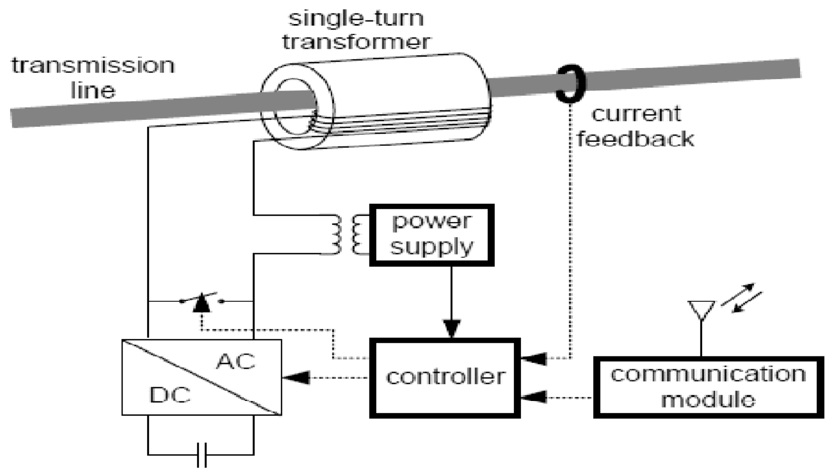

Figure 7: D-FACTS unit configuration

3. DPFC CONTROL

In order for controlling multiple converters present, DPFC requires three different types of controllers. They are a) Central control b) Shunt control and c) Series control. The schematic diagram of controllers is shown in Fig. 8.

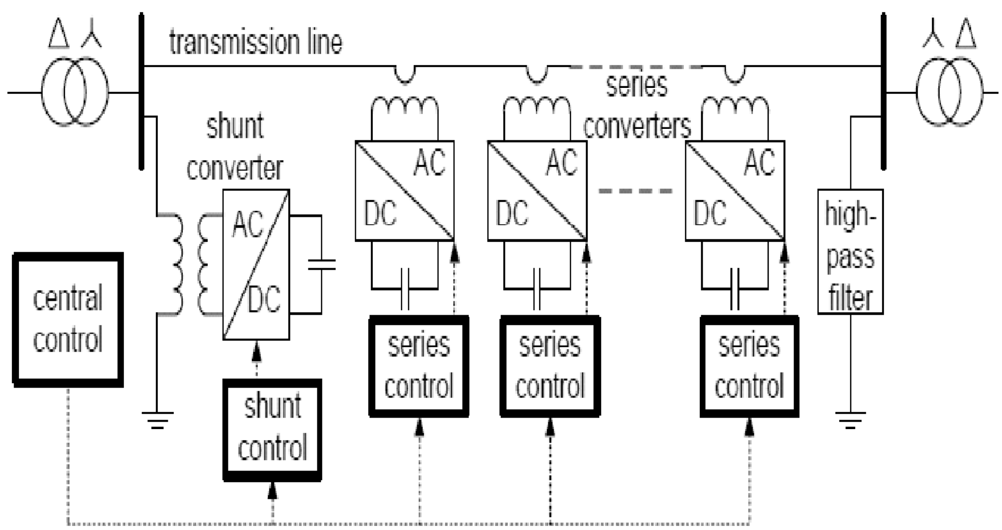

Figure 8: DPFC control diagram

3.1. Central control

This controller generates the reference signal for both shunt and series converters. The control function depends on the application of DPFC. Depending on the requirements of the system, the controller provides respective voltage reference for the series converters and reactive current signal for the shunt converter. The reference signal contains the fundamental frequency components.

3.2. Series control

As DPFC contains series converter so each converter has its own controller which in particular is series control. The controller generated the series voltage at the fundamental frequency and maintains the capacitor DC voltage of its own converter, by using 3rdharmonic frequency components. Fig 9 shows the block diagram of series converter. The major control loop is the 3rd harmonic frequency control.

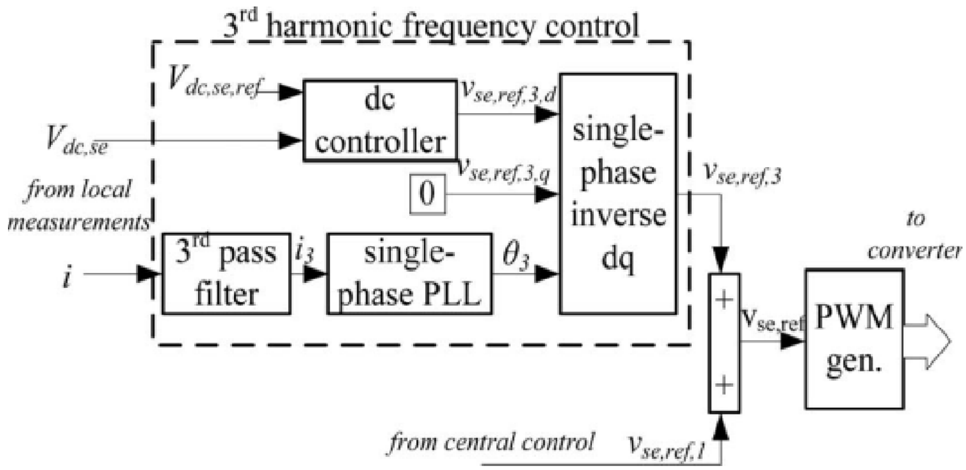

Figure 9: Block diagram of the series converter control

3.3. Shunt control

Shunt control injects a constant 3rd harmonic current into the line to provide active power for series converter. Along with the injection, the controller also maintains the voltage across the capacitor constant.

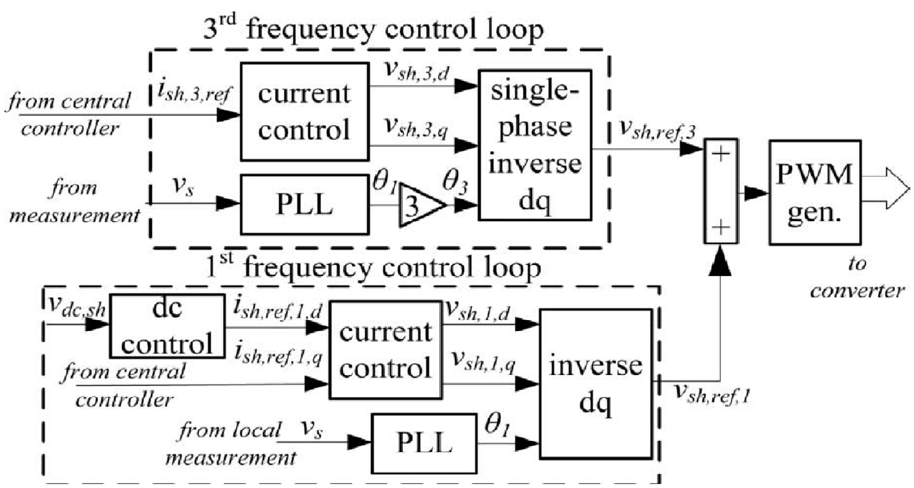

Figure 10: Block diagram of the shunt converter control

4. SIMULATION CIRCUIT

In order to verify the principle and control of DPFC simulation circuit has been developed. Fig11 shows the simulation circuit.

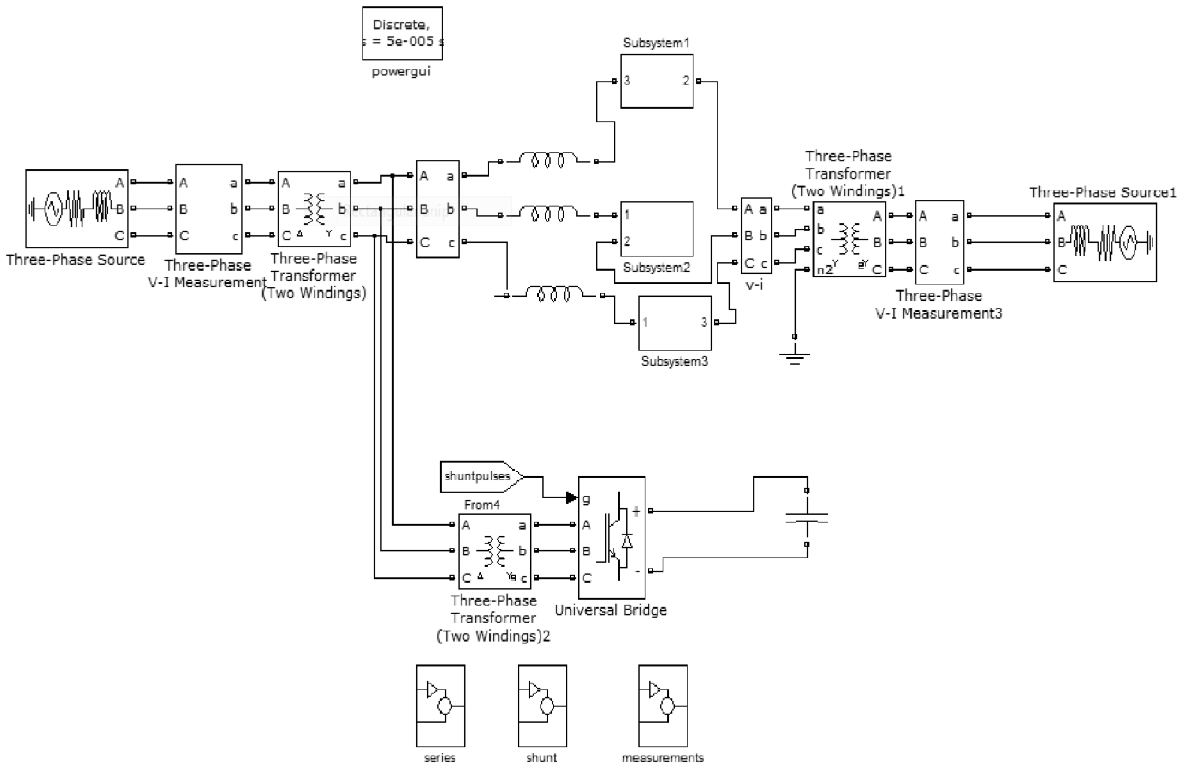

Figure 11: Simulation circuit

As seen in the previous sections, power flow is controlled through DPFC which is achieved by injecting voltage by the series converter. Figs 15-19 shows the behavior of the system for step input.

Fig 13 shows that the series converter voltage is stabilized after the step change.

Fig.18 illustrates the active and re- active power injected by the series converter. It is observed from the results that active and reactive power can be injected or absorbed by using series converters.

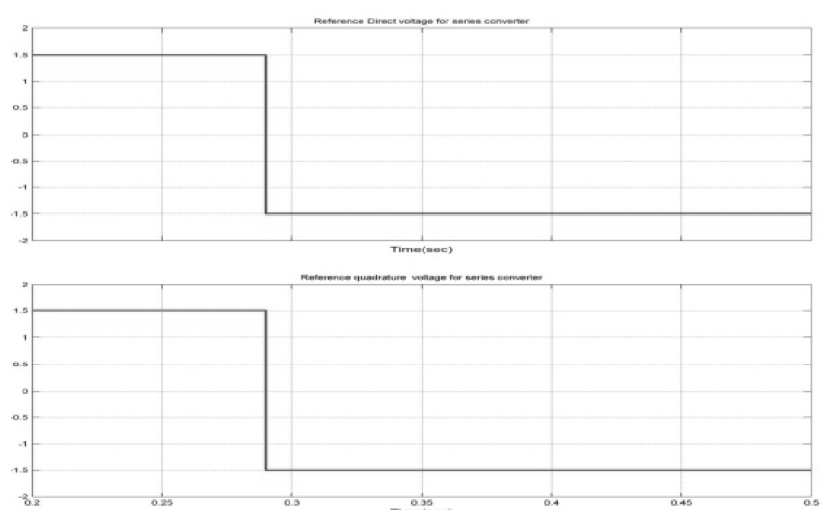

Figure 12: Reference voltage for the series converter

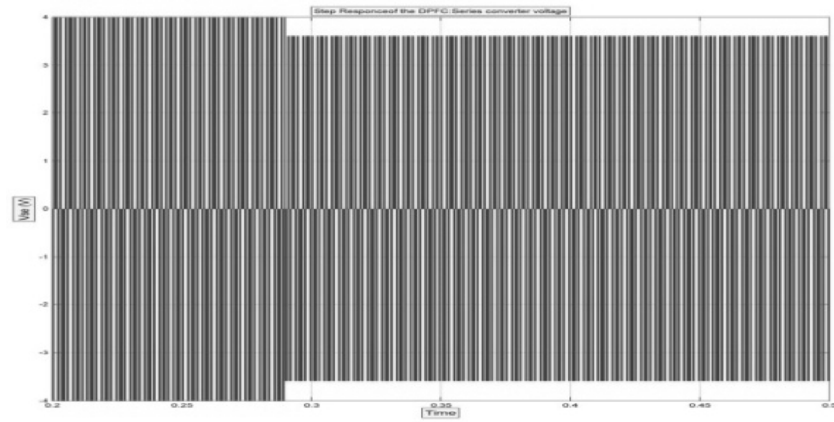

Figure 13: Response of DPFC for step input: Series converter voltage

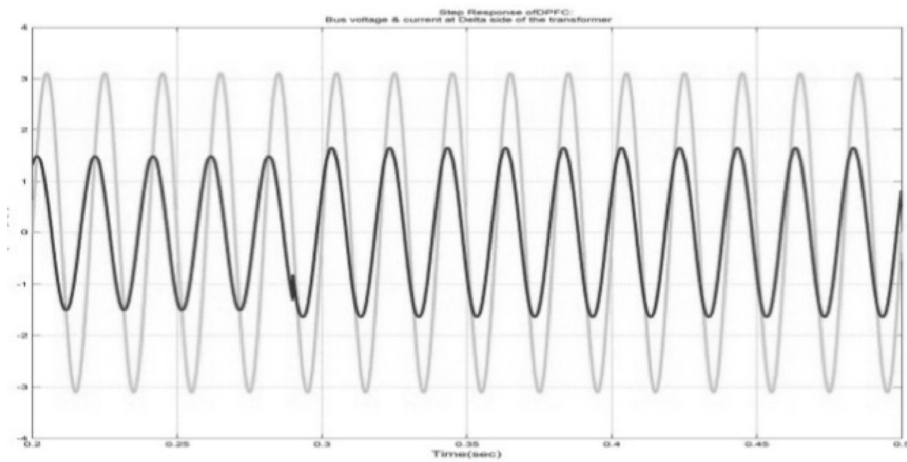

Figure 14: Response of DPFC for step input: Bus voltage and current at the delta side of the transformer

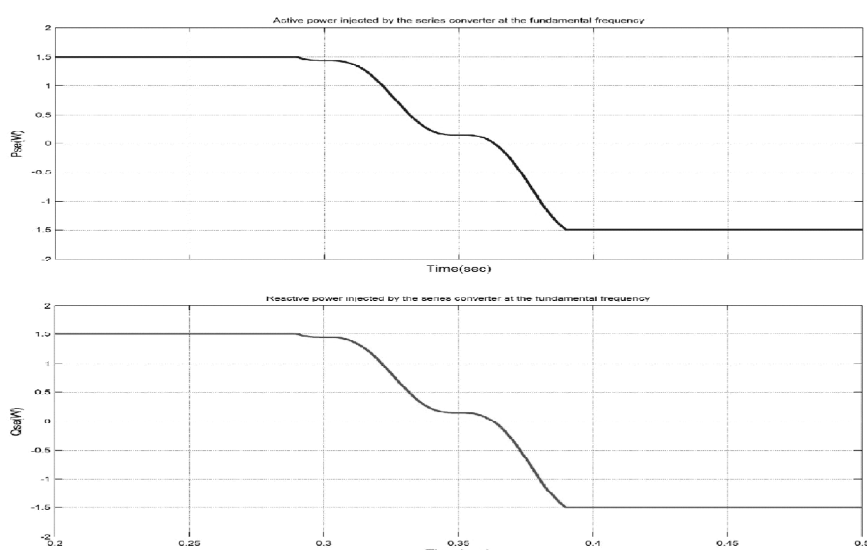

Figure 15: Response of DPFC for step input: Active and reactive power injected by the series converter at the fundamental frequency

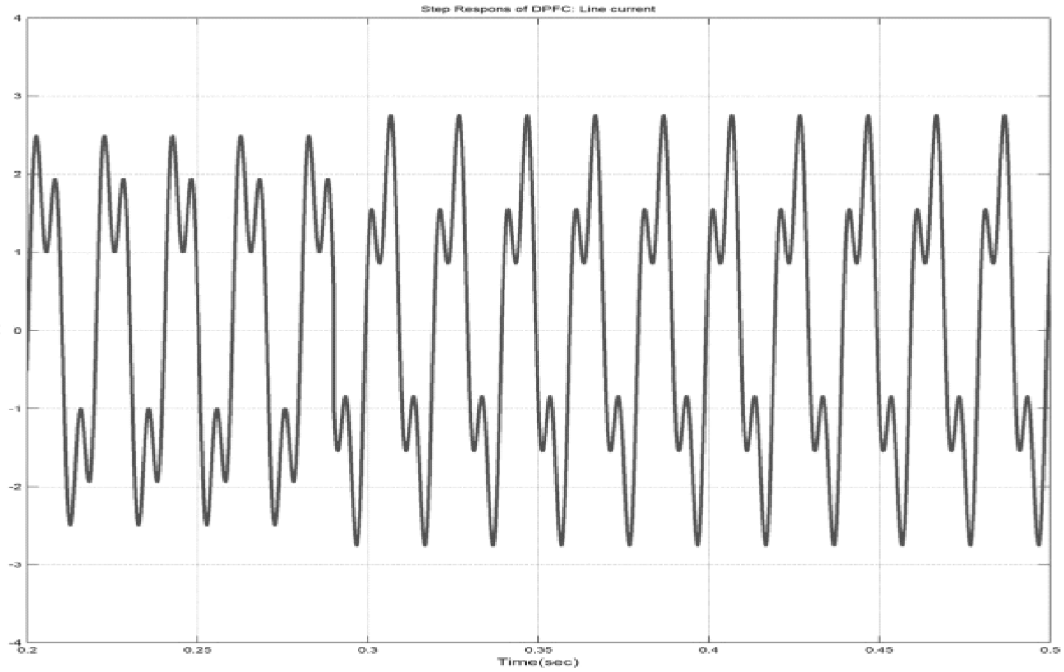

Figure 16: Step response of the DPFC: line current

5. CONCLUSION

This paper has introduced DPFC concept which has the features of UPFC with elimination of common DC link. It has the control capability as that of UPFC. The power flow takes place at 3rd harmonic frequency. The series converter employed in DPFC uses D-FACTS concept. Based on the experimental results it is observed that shunt and series converters exchange active power at 3rd harmonic frequency.

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