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A Proportional Investigation among UPFC and DPFC in a Grid Associated Photovoltaic Organization

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Abstract: In this paper a proportional investigation between Unified Power Flow Controller (UPFC) and Distributed Power Flow Controller (DPFC) in a grid incorporated photovoltaic system is performed. A grid connected solar generation scheme with boost converter and voltage source inverter (VSI) is taken as the key model. Due to power quality issues like power oscillations, harmonic distortions, voltage sags and swells, the grid side system has to be absolutely monitored and restricted. One way to mitigate these power quality troubles is by using reactive elements like shunt/series reactor and shunt/series capacitor. The drawback on using these reactive elements is sub synchronous resonance phenomenon. Gratitude to FACTS equipment, which emerged out as power conditioning units and helps to feed power with required standards and free from power quality issues. Among them, the contemporary FACTS devices are Controller Distributed Power Flow (DPFC) and Unified Power Flow Controller (UPFC). Though the aims of both the devices are same but their working principles are different. In this paper the effect of adding a DPFC and UPFC to a solar PV generation system is analysed. A detailed working principle and operation of both the devices were presented. At last, MATLAB/SIMULINK environment is used to evaluate the performances of above-mentioned devices.
Keywords: Renewable Energy, DPFC, UPFC, FACTS, Solar PV system.

I. INTRODUCTION

The demand for power is growing at a fast pace. This in turn demands the increase of power generation as well as power transmission. The renewable energies are taking up the market as far as power generation is concerned. For increasing power transmission, one way is, to increase the number of lines throughout the grid; this is hectic, and the other way is to upgrade the existing lines. Again the high demand of power flow in power systems is increasing day by day. Flexible AC transmission system abbreviated as FACTS are the devices which have the capability to control transmission line parameters, in other words, these devices control the flow of power through high voltage lines and can utilize those lines to their respective maximum possible thermal limits as stated in [2].

Flexible AC Transmission Systems (FACTS) gives great improved solutions to today's power systems problems. It enhances the capability to transfer flow of power, continuous control over the system voltage, also decreases system oscillations within the network etc. The technology of FACTS includes high rated power electronics equipped instruments. Power flow is control is achieved by adjusting the variable parameters of a system, such as voltage magnitude, transmission angle and impedance of the line. Based on device connectivity in a system, FACTS can be classified into series devices, shunt devices and combined series-shunt devices [3]. The UPFC is the union of a Static Synchronous Series Compensator (SSSC) Static Synchronous and Compensator a connected using (STATCOM), that re common dc link which allows both the directions of active power between the series (SSSC) and the shunt (STATCOM) converters. The components of the UPFC handles the currents and voltages with high level rating; hence, the price of the whole setup is enhanced [3][4]. On the other hand, DPFC falls under Distributed FACTS category, considered as a modified version of UPFC, where instead of a single three-phase converter in SSSC, several single-phase converters are distributed. The connection linking shunt-series converter, as in UPFC, is expunged. The transfer of power amongst the controllers is done using the high voltage transmission line itself. The most interesting fact about DPFC is, it uses the third harmonic component of current. According to power theory of non-sinusoidal components, transfer of power using harmonic frequency does not affect the power transfer using fundamental frequency as explained in [5]. The eliminated dc link offers flexibility in independent installation of series converters. More over the series converters are of low rating and they don't need any high voltage isolation with the ground. Hence the cost is reduced comparatively [6].

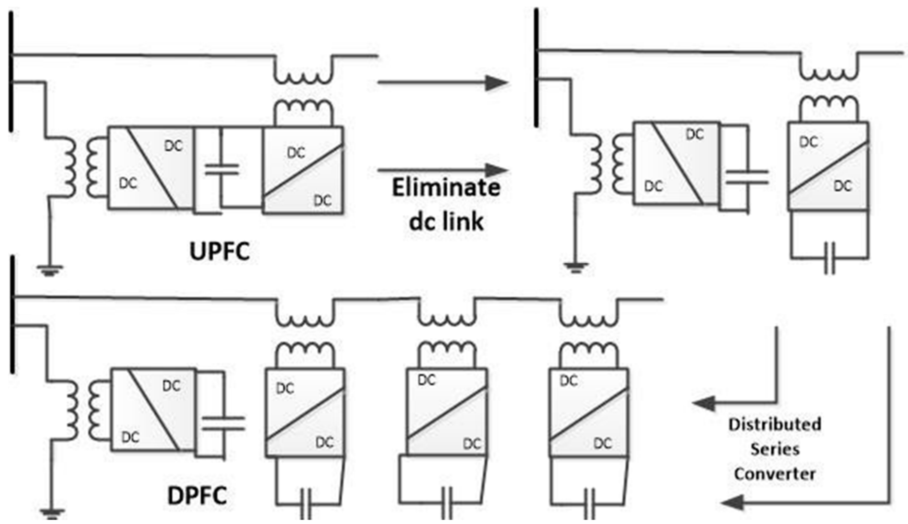

Fig. 1 A schematic diagram which represents UPFC to DPFC conversion

In brief, to change UPFC to DPFC: 1) eliminate dc link connection linking shunt and series converter, 2) change all three phase converters to single phase converters and 3) series converters are distributed as shown in Figure.1. The paper begins with main model description which is explained in section-II, followed by working principles of DPFC section-III and UPFC in section-IV. The simulation results by utilizing MATLAB/SIMULINK environment shown in section-V. Section-VI consists of conclusion and is followed by references.

II. SYSTEM DESCRIPTION

1) *Solar PV System:* The system understudy is a grid connected PV model. It comprises of a solar generator and its modeling explained in [7], followed by a boost dc-dc chopper [8] and grid connected voltage sourced inverter (VSI) [10] through a transformer as shown in Fig.2. Perturb & Observe algorithm (P & O)[9] is followed for tracking the maximum power from the solar panel. The solar panel used is Mitsubishi PV with 5 numbers of series connected modules and only 1 parallel connected module. The model variables are displayed in Table 1.

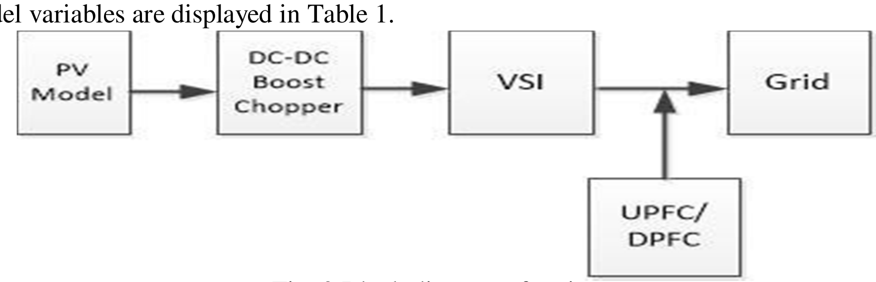

Fig. 2 Block diagram of entire system

Table I SOLAR PV SPECIFICATIONS

PARAMETERS	VALUES
PV CELL OC VOLTAGE (V_{OC})	30.8 V (V_{mpp}=24.69V)
PV CELL SC CURRENT (I_{SC})	8.23A (I_{mpp}=7.71A)
PV CELL MAX POWER (P_{max})	190 watts
DC LINK REFERENCE (V_{DC})	500V
TRANSFORMER	440V/25KV, 1000VA, 50HZ
GRID VOLTAGE	25KV

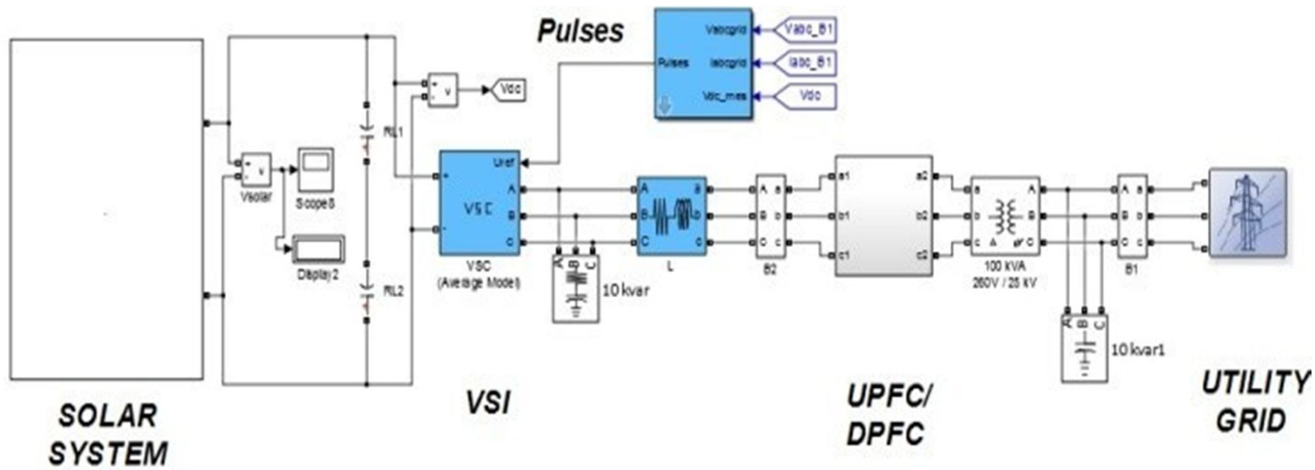

Fig. 3 The PV system in MATLAB/Simulink.

III.UNIFIED POWER FLOW CONTROLLER UNIFIED POWER FLOW CONTROLLER (UPFC)

Unified Power Flow Controller (UPFC) falls under the class of combined FACTS devices. Two three-phase converters are joined back to back in series using a dc link which is common. The series converter executes the prime task of UPFC [3][4]. The series converter introduces desired voltage of desired magnitude and desired angle into line which in turn controls the flow of power through that line. The shunt converter aids the series converter by supplying the needed active power along the dc link capacitor. At the same time the shunt converter also injects controllable current at the point of interconnection to control voltage profile near to 1 p.u.(All the quantities expressed in the paper are in p.u.). The series converter used is Static Series Synchronous Compensator (SSSC) and the shunt converter used is a Static Synchronous Compensator (STATCOM).

1) *Shunt Controller:* The shunt controller in a UPFC works exactly like a STATCOM [11]. The main function is to charge the dc link capacitor voltage, which could be utilized by the series converter for power flow control. Additionally, it also maintains the voltage profile at the connection point. The control structure is shown in Fig.3. It accepts Vdcref and Vref (desired set point) as the reference values. The error which occurs between the Vdcref and shunt dc voltage (Vshdc) is well tuned by a conventional PI regulator which results Idref. Similarly, the Iqref is generated by well-tuned PI regulator which regulates error between desired point and grid side voltage component. The same vector current control method is implemented [12][13].
2) *Series Controller:* The series control strategy uses the same vector current control mechanism explained in [12]. The control structure is shown in Figure.4. The primary purpose of the series converter is to use capacitor voltage of the dc link and generate the exact real and reactive power at the line. It mainly takes two reference values, namely the Pref and Qref. The Idref and Iqref can be obtained by comparing Pref with Vd,grid and Qref with Vd,grid and with the help of PI tuner. The equations performing the above-mentioned process is described below:

$$I_{dref} = \frac{(V_d \times P_{ref}) + \quad (V_q \times Q_{ref})}{\sqrt{V_d^2 + V_q^2}}$$

$$I_{qref} = \frac{(V_d \times P_{ref}) - \quad (V_q \times Q_{ref})}{\sqrt{V_d^2 + V_q^2}}$$

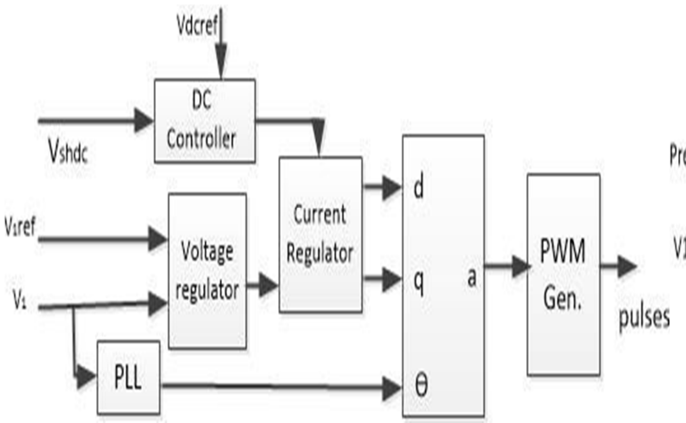

Fig. 4 UPFC shunt control block diagram

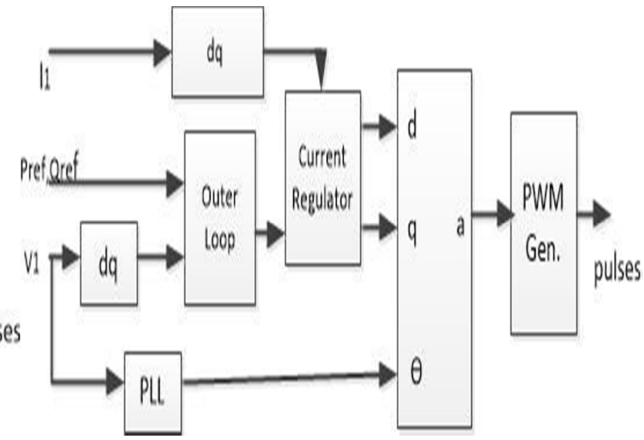

Fig. 5 UPFC series control block diagram

IV. DISTRIBUTED POWER FLOW CONTROLLER

Distributed Power Flow Controller also falls under combined FACTS devices. Its anatomy is same like that of UPFC, but it uses both series and shunt converters without the dc capacitor link [5]. The series converter uses the Distributed series static compensation (DSSC concept)[5].It uses many single phase converters of low rating (one for each phase)connected to the line itself through single turn transformers. This makes the installation of DPFC very easy. The number of series converters utilized depends on the desired power output. In DPFC only one shunt converter is used. Its main objective is to provide real power to the series converters. In addition to these a pair of star delta transformer is also required. The two transformers are used for injecting 3rd harmonic component into the line and later remove it from the line. As delta appears to be an open circuit for 3rd harmonics, by using the proper placement of these transformers, perfect channeling of 3rd harmonic component can be done. Moreover it is easy to filter out 3rd harmonic components from the network i.e. by grounding the neutral of a star delta transformer as displayed in Figure 5.

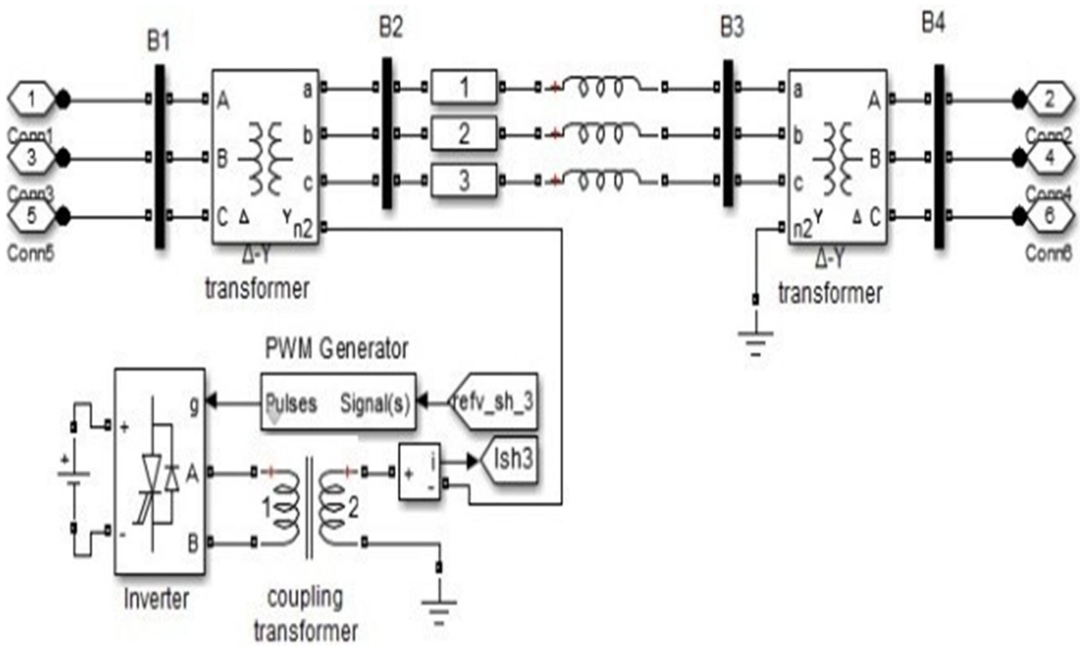

Fig. 6 DPFC structure in MATLAB/SIMULINK.

1) *Shunt Controller:* The function of shunt controller is to introduce a 3rd harmonic current to the transmission line and to retain the capacitor dc link voltage as displayed in Figure.6 and Figure.8. Where Fig. 6 represents the schematic form and Figure.8 represents in MATLAB/ SIMULINK form. Injecting a 3rd harmonic current into the system without affecting the overall system is difficult. That's the reason the star-delta transformers are used. The transformer neutral terminal is used as the path to inject the current. As it is injected at the neutral, the 3rd harmonic component will divide itself equally throughout the three phases. The third harmonic current (Ish3) is resolved into two components mainly (Id and Iq) .The phase angle(šsh) of the grid voltage is extracted through a phased locked loop (PLL) .The phase angle (šsh) and (Id and Iq) are combined together to generate modulated signal. The modulation waveform is compared with triangular carrier signal with frequency (6000Hz) to generate the pulses. B. Series Controller The function of series converter is to charges its own capacitor voltage utilizing the 3rd harmonic component in the line, which is injected by the shunt converter and at the same time it introduces a voltage at the point of interconnection, this in turn manages the real and reactive power flow through the line. The controller accepts three references namely, Vsedcref, Pref and Qref. The interesting fact about this controller is that it charges its capacitor through 3rd harmonic frequency component but injects the voltage at fundamental frequency [5]. As a result it needs two control structures, one for 3rd harmonic and the other for fundamental frequency. The control model is depicted in Figure.7 and Figure.9, where Fig.7 represents the schematic form and Fig.9 represents in MATLAB/ SIMULINK form. In Fig.7.two control strategies can be noticed. In one control strategy, series dc voltage (Vsedc) and Vdcref are compared and the error calculated is processed through a PI tuner that generates Vd.Vq is chosen as zero. The grid current (i) contain both fundamental and 3rd harmonic components. In order to extract 3rd harmonic component, band pass filter of cut-off frequency 150 Hz is used. PLL is used to extract phase angle (šse1) from 3rd harmonic component. Vd ,Vq and šse1 are used to generate a single phase modulating signal. The second control strategy consists of Pref and Qref which generates Idref and Iqref as explained in equations (1)(2) and inner loop generates Vd,Vq and the (šse2) is obtained through PLL in order to generate a single modulating signal. The modulating signal from the first control strategy and from the second control strategy are aided together and compared with triangular carrier generator of 6000Hz to generate pulses to the converter.

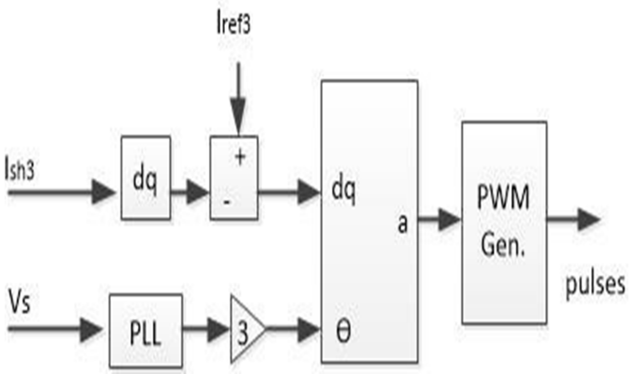

Fig. 7 DPFC shunt control block diagram

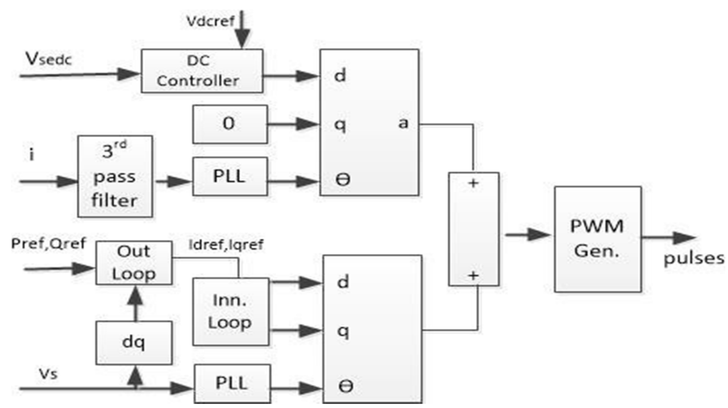

Fig. 8 DPFC series control block diagram

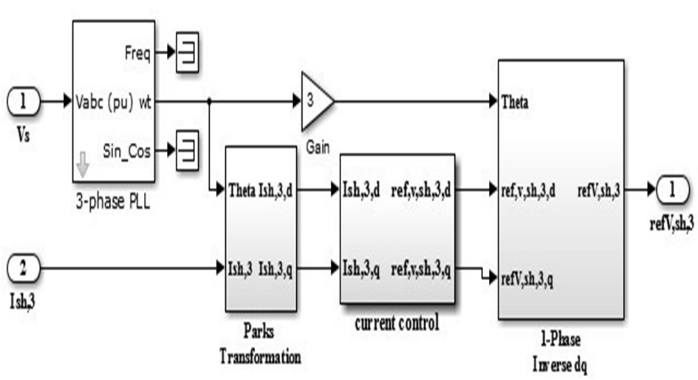

Fig. 9 DPFC shunt control in MATLAB/SIMULINK

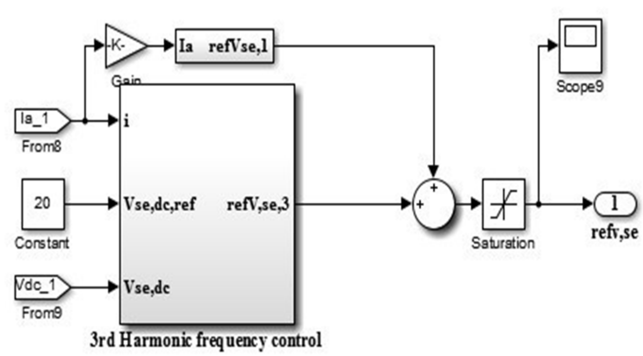

Fig. 10 DPFC series control in MATLAB/SIMULINK

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V. RESULTS AND OBSERVATIONS

The FACTS devices are added exactly after the voltage source inverter. A 1000VA rated UPFC is connected before the grid. The references for Real power and Reactive power are taken as -0.5 p.u initially. At 0.9s the reference value is changed to 0.5 p.u.V1ref is 1 p.u. and Vdcref is 500 volts. For shunt controller KP=0.12 and KI=300. For series controller, KP=0.02 and KI =10. The results for UPFC are shown from Fig. 10 to Fig 13.

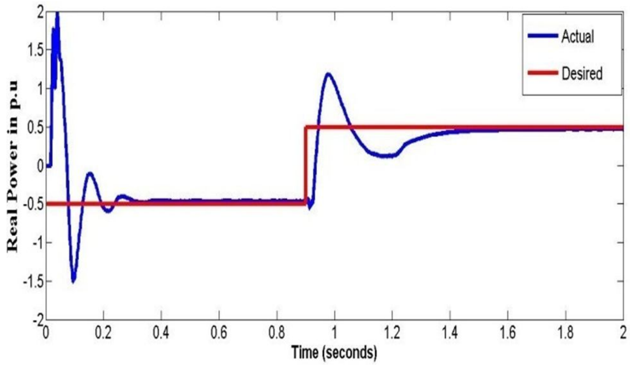

Fig. 11 Real Power plot using UPFC

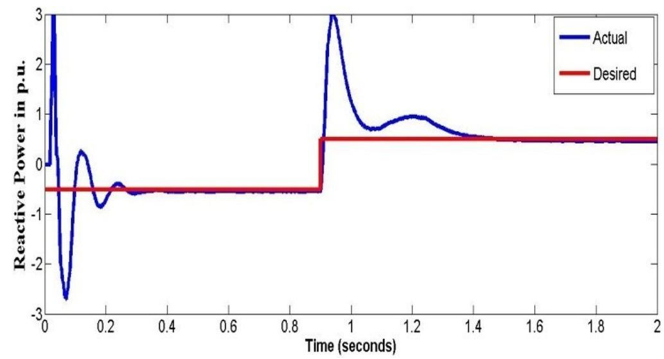

Fig. 12 Reactive Power plot using UPFC

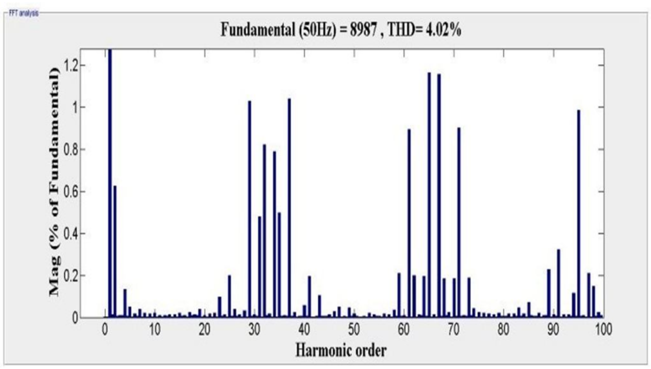

Fig. 13 Voltage THD using UPFC

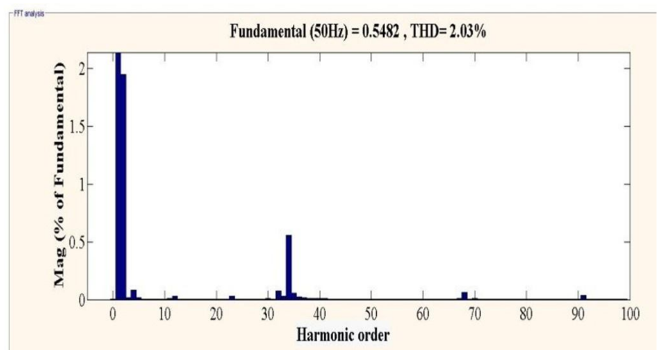

Fig. 14 Current THD using UPFC

The DPFC is connected just between the grid tied inverter and the main grid. The DPFC rated at 1000VA uses one single phase shunt converter and three series converter one for each phase. The I_{shref3} is 3A and the $V_{dcrefsh}$ is 50V. For shunt controller K_P=0.09, K_I= 0.48. For series controller K_P=0.5, K_I=20The results obtainedwith DPFC are shown from Fig. 14 to Fig. 17.

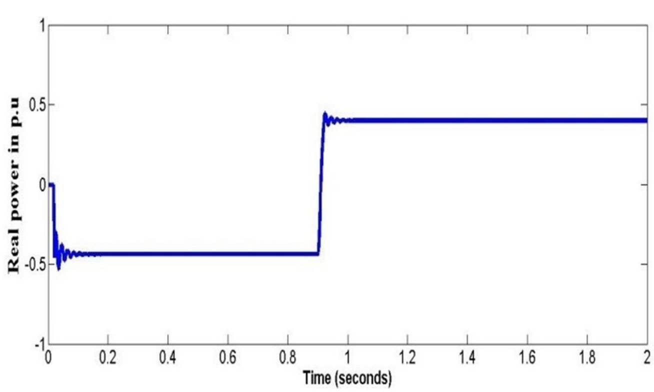

Fig. 15 Real Power plot using DPFC

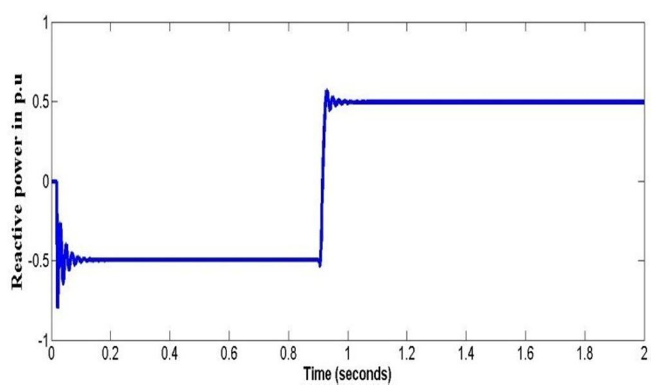

Fig. 16 Reactive Power plot using DPFC

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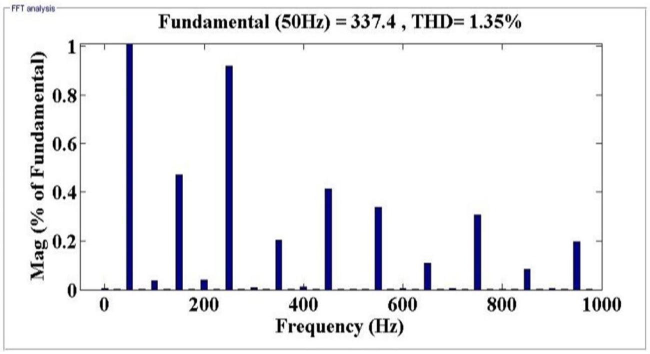

Fig. 17 Current THD using DPFC

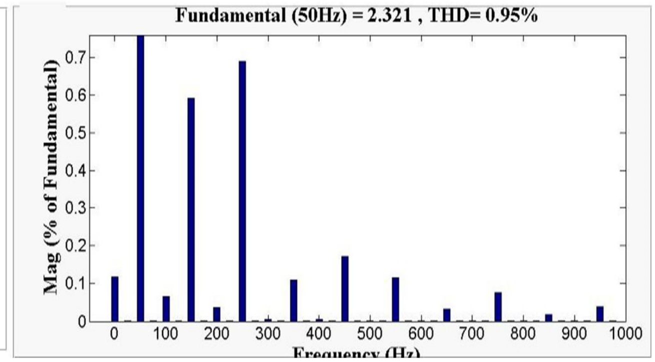

Fig. 18Voltage THD using DPFC

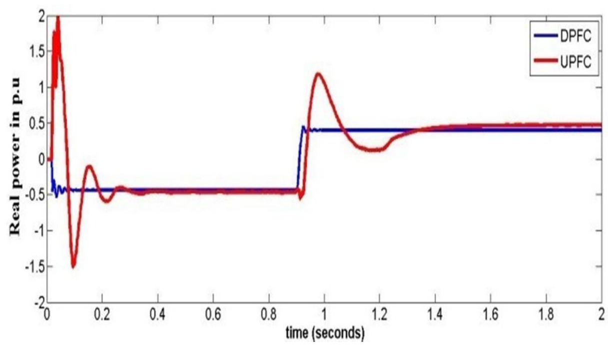

Fig. 19 Real Power plot using UPFC & DPFC.

Parameters	UPFC	DPFC
Real Power (ref: -0.5 to 0.5)	-0.46	-0.49
	0.44	0.44
Reactive Power (ref: -0.5 to 0.5)	-0.55	-0.48
	0.46	0.49
Voltage THD (%)	4.02	0.95
Current THD (%)	2.03	1.35

TABLE II . OBSERVATION TABLE

VI. CONCLUSIONS

The working principle and control structure of UPFC and DPFC is illustrated in detail with corresponding block diagrams. Using the results obtained through MATLAB/SIMULINK it is concluded that DPFC have superior characteristics as compared to UPFC in power tracking and Total harmonic distortion (THD). The detailed comparison is shown in TABLE II which depicts the improvement of voltage THD and current THD at the output terminals. Voltage THD decreases from 2.03% to 0.95 %. On the other hand, current THD is decreased from 4.02% to 1.35%. In brief the disadvantages of UPFC can be overcome using DPFC.

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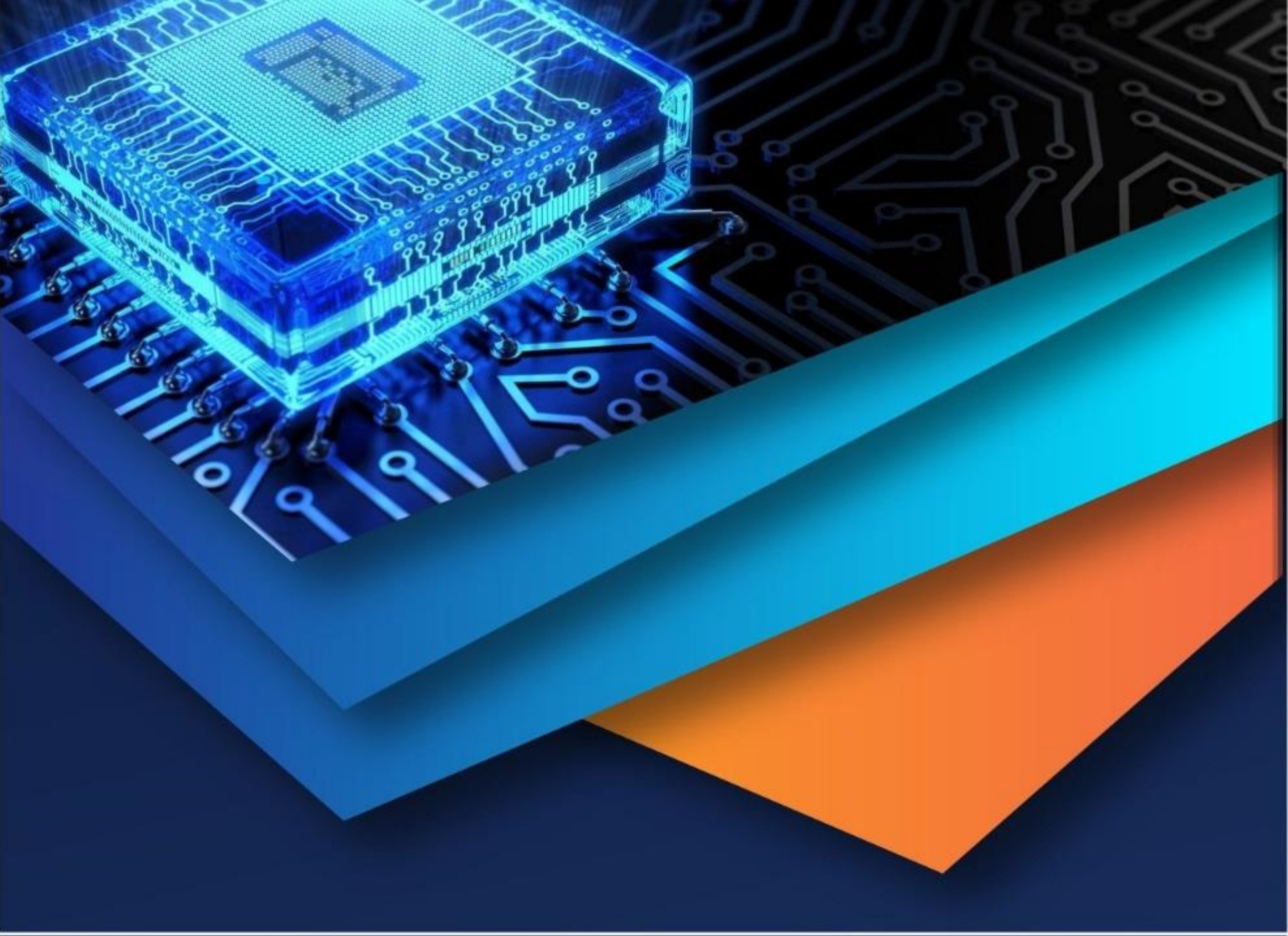

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