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Integration of PV with Interleaved Boost Converter to UPQC

N.C. Kotaiah[*] and K. Chandra Sekhar[**]

Abstract: Power quality is a major concern for power engineers these days. Power quality is a resemblance of practical power system to ideal power system. But delivering power with fine quality is a hard task due to increased load demands and type of loads connected. A linear load doesn't retune the source voltage and current but non-linear loads induce harmonics in to the system disturbing the complete operation of power system. Presence of reactance in AC system and increased load demand can cause reactive power to drop which influences the supply voltage. This paper depicts the functioning of UPQC for elimination of harmonics and maintaining required reactive power in the power system. Paper discusses the stability of a system when a distributed generation was included at UPQC DC bus. This distributed generation can stabilize DC bus voltage and can deliver required active power when there is a change in load demand delivering power through UPQC. Output f distributed generation was stepped up using an interleaved boost converter; analysis of interleaved boost converter was explained. A suitable control strategy was employed to control UPQC and results were discussed for the cases without distributed generation, with distributed generation fixed load and variable load conditions. THD was shown for the cases explained.

Keywords: UPQC, power quality, Distributed Generation, integration.

1. INTRODUCTION

Disadvantage of fossil fuels finds a solution to conserve environmental conditions. Emission of high pollution in to atmosphere and availability is the most set-back for fossil fuels. Lack of availability increases the cost of fuel and thus increasing the running cost of the plants when run with fossil fuels like coal, gas etc. and researchers searched for alternative fuel that can reduce the pollution with less running cost for power generation. Renewable source of energy is freely available from the environment decreasing running cost of power generation. Also renewable sources produce energy with pollution free [1-6].

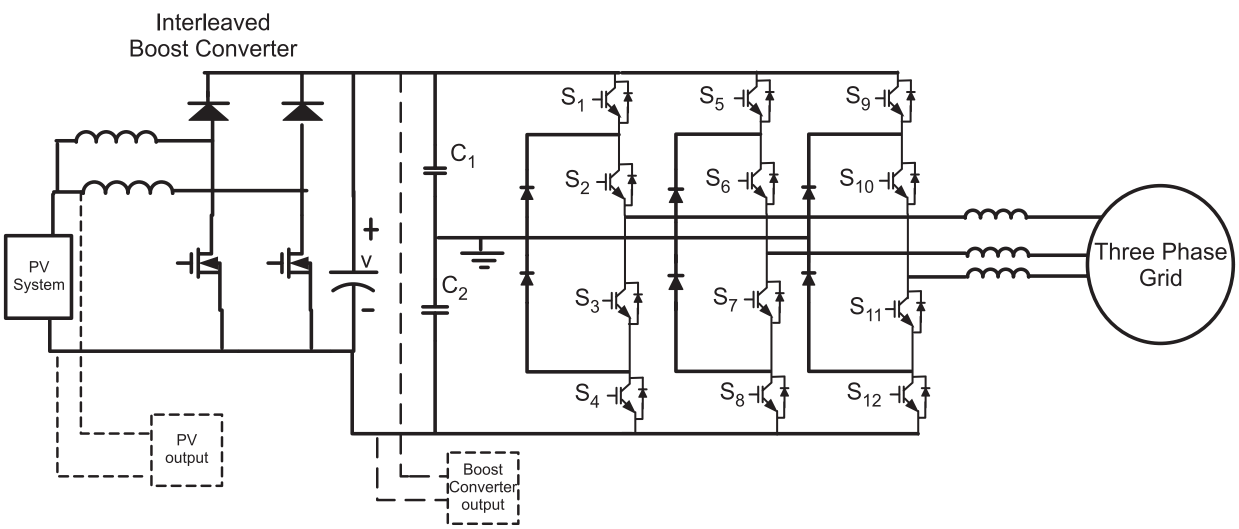

Figure 1: General DG integration scheme to grid

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Power quality is the major constraint in power system these modern days due to increased variants of load. The nature of load can deteriorate the quality of power in power system. Due to advancements in variety of devices used as loads, power quality is reduced and is a major constraint. Majority of the loads from industries and commercial loads are of non-linear type. House hold equipments are also installed with non-linear natured devices for their operation [7-11]. This non-linear nature of devices at load centers induces harmonics in to the power system deteriorating the quality of power. Increase in loads can also draw high reactive power and thus creating voltage stability problems as voltage is directly related to reactive component of total power.

FACTS devices [12-15] are viable answer to address voltage and harmonic problems. Use of one custom power device for harmonic elimination and the other for voltage stability increases the cost and unified power quality conditioner is a single custom power device that can address the issues of voltage and harmonics simultaneously. UPQC is a combination of series and shunt controllers controlled with a single controller.

This paper addresses the viability of integrating distributed generation like photo-voltaic system for power generation and integrated to custom power device UPQC to transmit active power to grid. The power from PV system is low voltage and is boosted using an interleaved boost converter. Interleaved boost converter increases the voltage from PV system and transmits power to UPQC. UPQC performs the task of inverting DC power to AC and supplies power to grid. UPQC also eliminates harmonics presence in power system ans stabilizes the voltage. Figure 1 shows the general schematic arrangement of grid connected RES [16].

2. PV WITH INTERLEAVED BOOST CONVERTER

The diagrammatic representation of the interleaved boost converter is shown in below Figure 2. As the interleaved boost Converter consist of two boost converters which are connected in parallel and are controlled by phase-shifted switching function. The interleaved boost converter switching operation is shown in Figure 3. As we have chosen only Dual interleaved boost converter each switch is phase shifted 180° with one another. As the number of converters connected parallel increases the phase shift angle decreases.

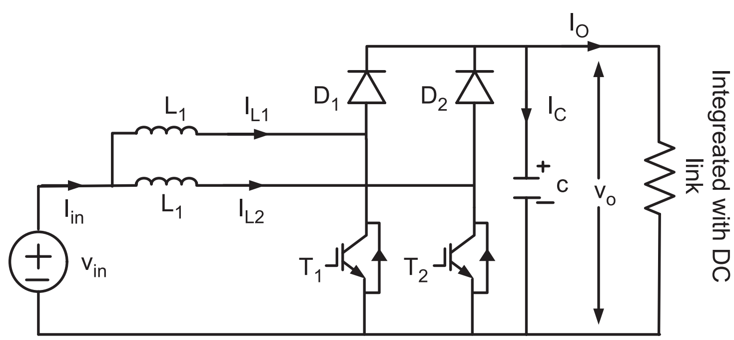

Figure 2: Interleaved Boost DC-DC Converter

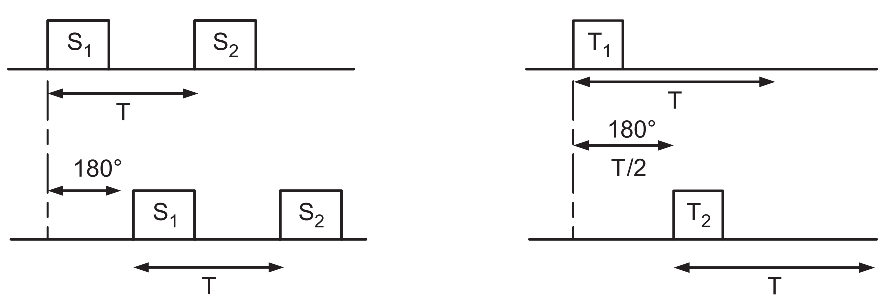

Figure 3: Timing diagram of Control Signal

DESIGNING OF INTERLEAVED BOOST CONVERTER

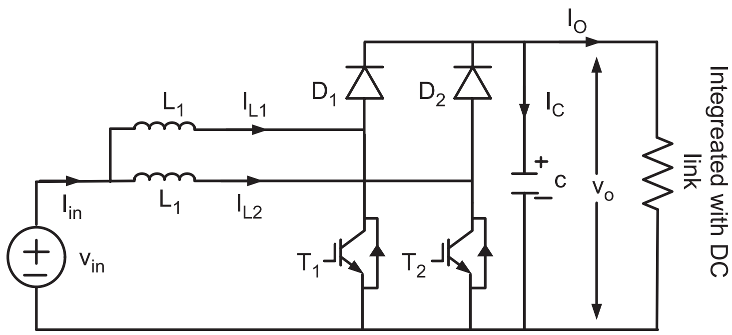

Figure 4: Inter leaved boost converter

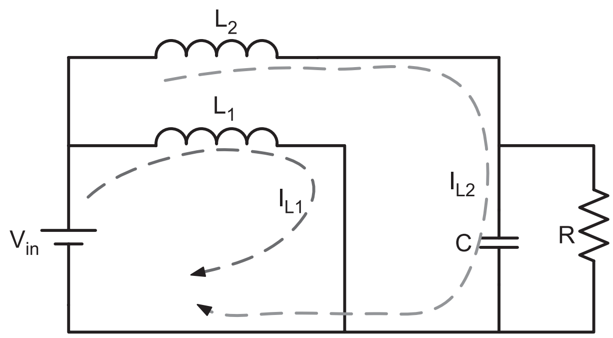

Figure 5: Inter leaved boost converter when switch T1 ON condition

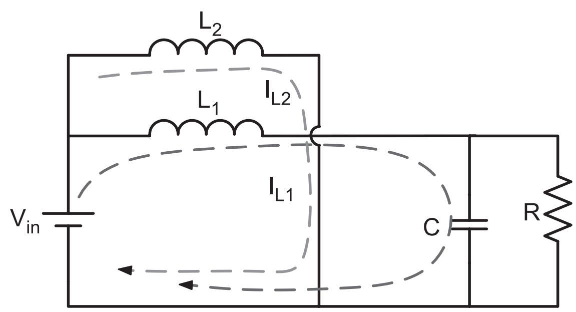

Figure 6: Inter leaved boost converter when T_1 OFF &T_2 ON

Mode 1: T_1 ON

For inductor L_1

$$V_{in} = L_1 \frac{dI_1}{dt}$$

For inductor L_2

$$V_{in} - V_0 = L_2 \frac{dI_2}{dt}$$

Assume $$\Delta I = I_2 - I_1$$

$$V_{in} = L_1 \frac{\Delta I}{t_1}$$

$$t_1 = \frac{L \times \Delta I}{V_{in}} \tag{1}$$

Mode 2: During T_1 OFF & T_2 ON

For inductor L_1

$$V_{in} - V_0 = -L_1 \frac{dI}{dt}$$

$$t_2 = \frac{\Delta IL_1}{V_0 - V_{in}} \tag{2}$$

Substitute $t_1 = DTs$ and $t_2 = (1 - D)T_s$

$$\Delta I = \frac{V_{in} \times t_1}{L}$$

$$\Delta I = \frac{V_0 - V_{in} \times t_2}{L}$$

$$\frac{V_{in} \times DT_s}{L} = \frac{(V_0 - V_{in})}{L}(1 - D)\,T_s$$

$$\frac{V_0}{V_{in}} = \frac{1}{1 - D} \tag{3}$$

Total time period

$$T = t_1 + t_2 = \frac{\Delta IL}{V_{in}} + \frac{\Delta IL}{V_0 - V_{in}}$$

$$T = \frac{\Delta ILV_0}{V_{in}(V_0 - V_{in})} \tag{4}$$

Peak to peak ripple current

$$T = \frac{1}{f}$$

$$\Delta I = \frac{V_{in}(V_0 - V_{in})}{fLV_0} \tag{5}$$

$$\Delta I = \frac{V_{in}D}{fL} \tag{6}$$

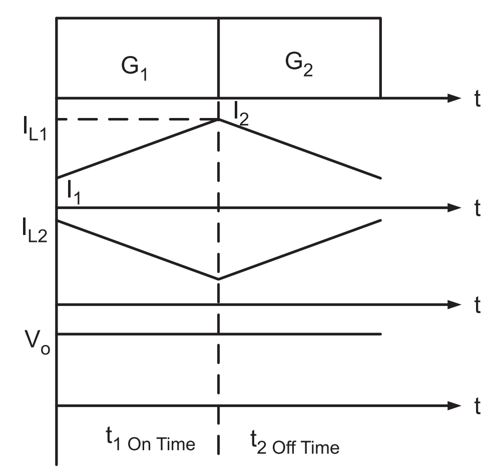

Figure 7: Operating Waveform

For output capacitor

$$\Delta V_c = V_c - V_c(t=0) = \frac{1}{c}\int_0^{t_1} I_c\, dt = \frac{It_1}{c}$$

Substitute
$$t_1 = \frac{(V_0 - V_{in})}{V_0 \times f}$$

$$\Delta V_c = \frac{I_0 K}{fc} \quad (7)$$

Condition for CCM operation. Take worst case ripple $\Delta I = 2I_L$

$$L_{critical} = \frac{V_s K}{f L} = 2I_L = 2I_0 = 2 \times \frac{V_0}{R}$$

$$= \frac{2 \times V_{in}}{(1-K)R}$$

$$L_{critical} = \frac{K(1-K)R}{2f} \quad (8)$$

Take worst case ripple for capacitor

$$\Delta V_c = 2V_0$$

$$2V_0 = \frac{I_0 K}{fc} = 2I_0 R$$

$$C_{critical} = \frac{K}{2fR} \quad (9)$$

Specifications

$$P = 15\text{ KW};\ V_0 = 800\text{ V};\ I_0 = \frac{P}{V_0} = \frac{15 \times 10^3}{800} = 18.75\text{ A}$$

$$F = 20\text{ KHz};\ R = 42.666\ \Omega$$

$$\frac{V_0}{V_{in}} = \frac{1}{1-D} = \frac{800}{400} = \frac{2}{1}$$

$$1 - D = \frac{1}{2}$$

$$D = 1 - \frac{1}{2} = \frac{1}{2}$$

$$L_{critical} = \frac{(1-D) \times DR}{2f} = \frac{\left(1 - \frac{1}{2}\right) \times \frac{1}{2} \times 42.666}{2 \times 20 \times 10^3}$$

$$= \frac{42.666}{4 \times 20 \times 10^3} = 0.5333\text{ mH}$$

In order to operate in CCM mode

$$L = 3 \times L_{critical} = 1.5999\text{ mH}$$

$$C_{critical} = \frac{D}{2fR} = \frac{1}{2\times 2\times 42.666\times 20\times 10^{3}} = 0.02\ \mu F\ (approx)$$

In order to operate in CCM Mode we are choosing

$$C_{operate} = 200 \times C_{critical} = 4\ \mu F$$

Ripple current is

$$\Delta I = \frac{V_{ink}}{f\times L} = \frac{400}{2\times 20\times 10^{3}\times 1.59\times 10^{-3}} = 6.2539\ A$$

Ripple Voltage is

$$\Delta V_c = \frac{I_0 \times K}{fc} = \frac{18.75\times\frac{1}{2}}{20\times 10^{3}\times 4\times 10^{-6}} = \frac{7.8}{2} = 117\ V$$

3. UNIFIED POWER QUALITY CONDITIONER WITH DG

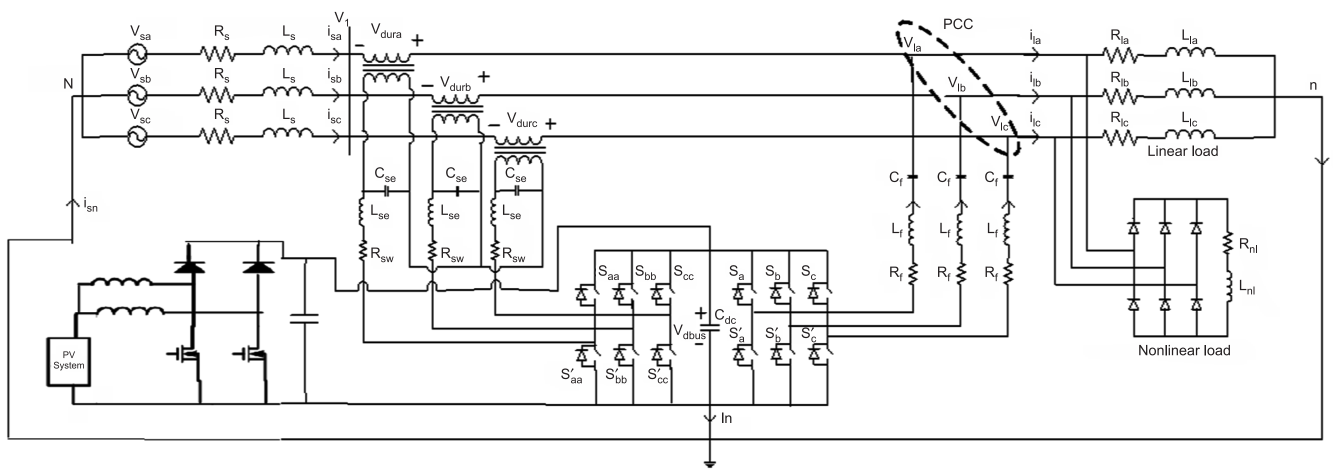

Figure 8: Block diagram of the proposed UPQC with DG integration topology

Figure 6 illustrates the block diagram of proposed UPQC with DG integration. UPQC is a combination of back-to-back converters connected through a common DC link capacitance. The generated power from DG or from PV system is boosted using an interleaved boost converter and the power is fed to DC link capacitor. The capacitor is a common DC link between two converters of UPQC and while operating as UPQC capacitor discharges. The power from DG stabilizes the voltage across capacitor and allows UPQC to transfer active power to grid by inverting to AC. UPQC performs two tasks by converting DC to AC from DG and integrating active power from DG to grid and also UPQC eliminates harmonics stabilizing voltage in main grid.

4. CONTROL OF UPQC

Block diagram controlling the UPQC is shown in Figure 7. The source voltage is sensed and the three phase voltage is sent to PLL for the information regarding sin, cos and phase angle. The line voltages are sent for parks transformation to conversion from *abc* to *dq* conversion. The DC voltage is measured and is compared with reference DC voltage to get error fed to PI controller to obtain reference signal magnitude The sinusoidal shape information from PLL is multiplied to magnitude and reference signal is obtained. The reference in *dq* frame is inverse transformed to *abc* using inverse parks transformation and the pulses are generated from PWM controller to the gates of IGBT in UPQC.

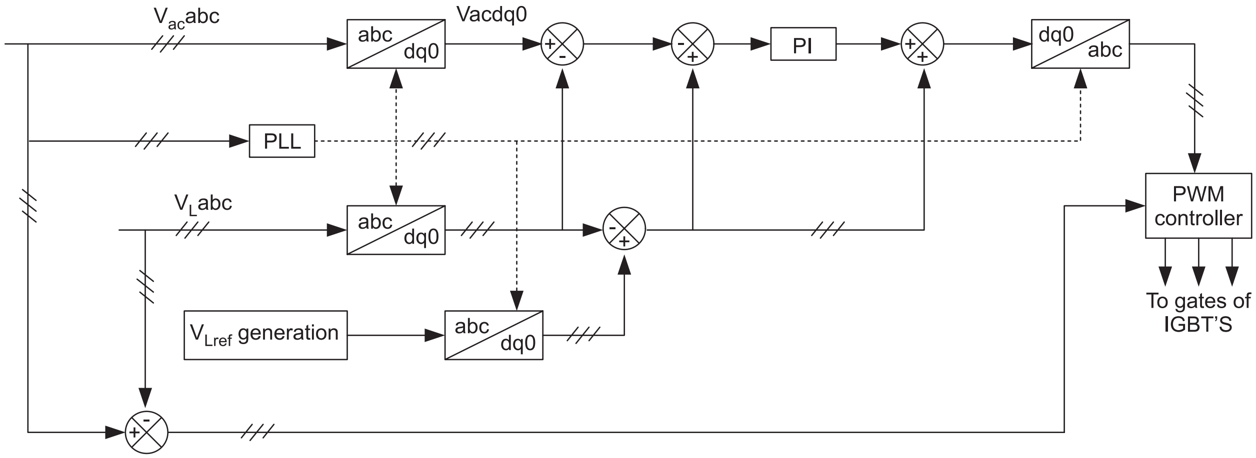

Figure 9: Block diagram of the control for UPQC

5. MATLAB/SIMULINK RESULTS AND DISCUSSIONS

Case 1: UPQC without DG

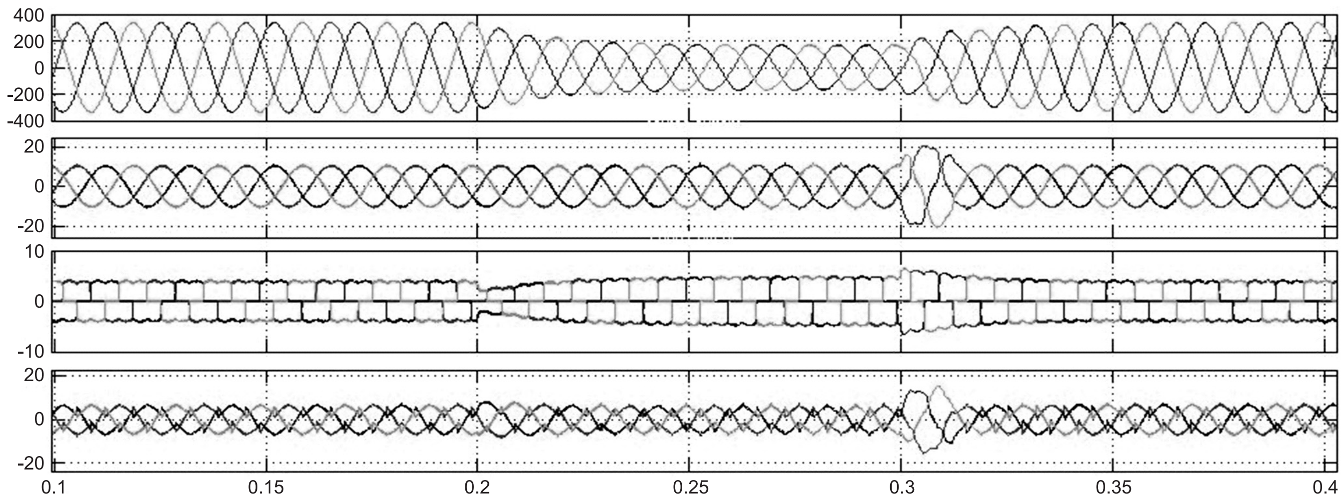

Figure 10: Results showing source voltage, source current, load current and filter currents of UPQC without DG

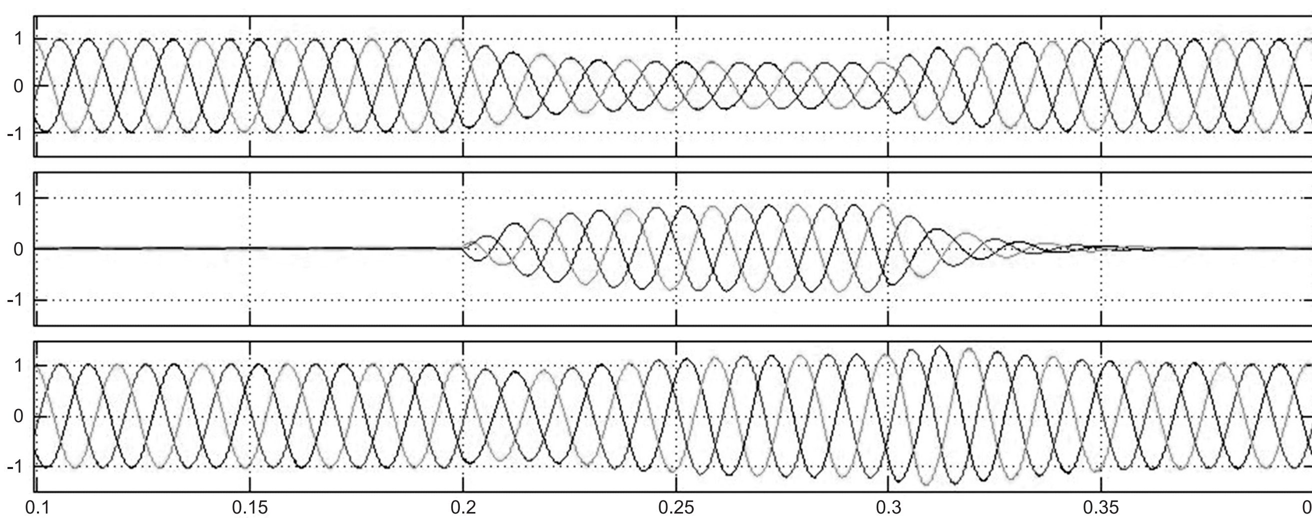

Figure 11: Results showing source voltage, induced voltage through filter, load voltage of UPQC without DG

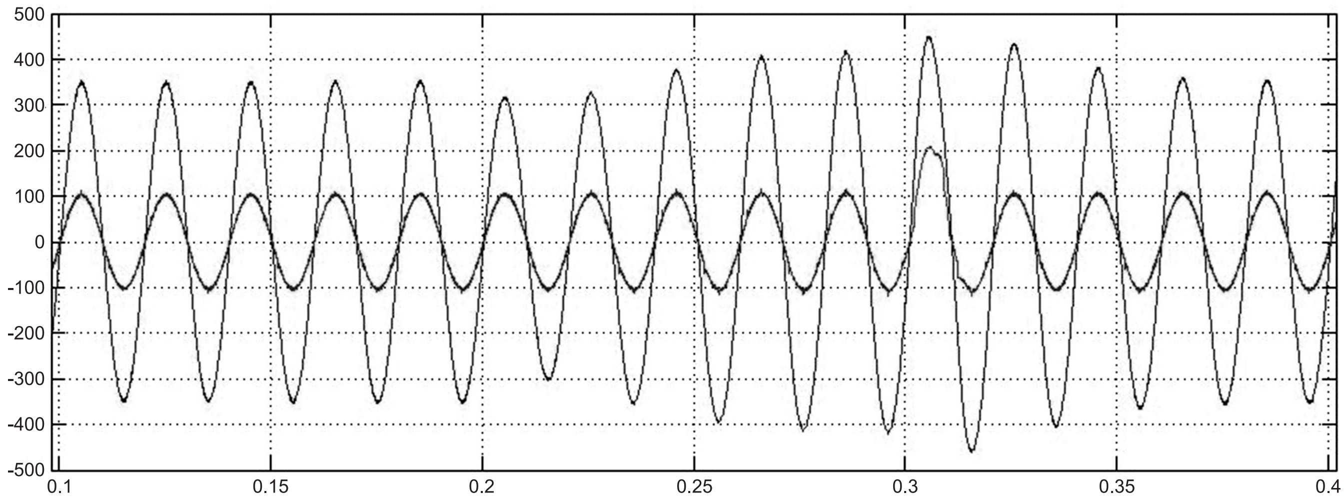

Figure 12: Results showing power factor of UPQC without DG

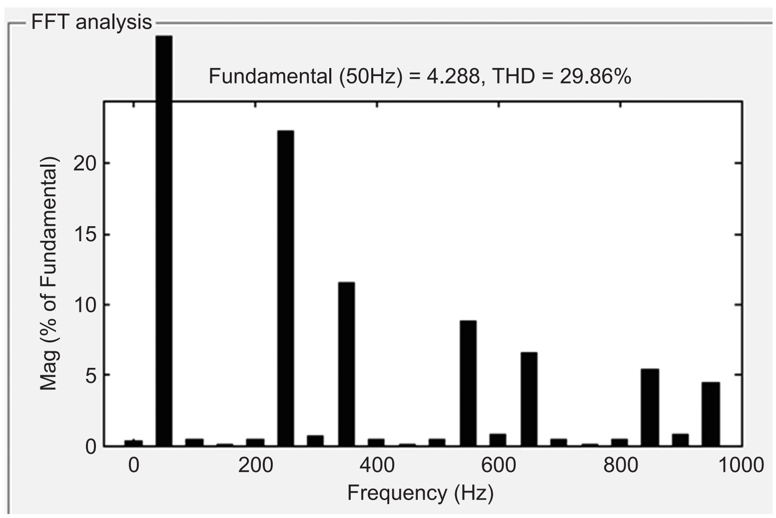

Figure 13: Result of THD in load current for UPQC without DG

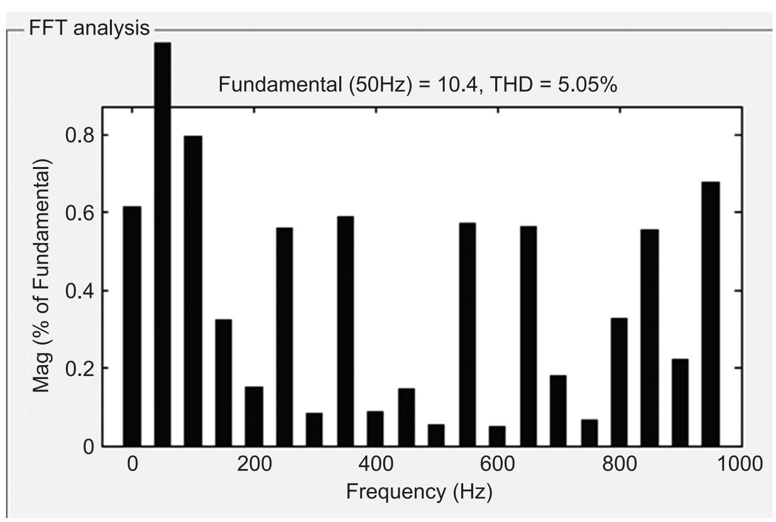

Figure 14: Result of THD in source current for UPQC without DG

Figure 10 shows results of source voltage, source current, load current and filter currents of UPQC without DG. Figure 11 is Result showing source voltage, induced voltage through filter, load voltage of UPQC without DG. Figure 12 is result showing power factor of UPQC without DG. Figure 13 shows THD in load current for UPQC without DG and figure 14 shows THD in source current for UPQC without DG. THD in load current is 29.8 % and while UPQC is connected the source current distortions are reduced to 5% maintained nominal due to presence of UPQC.

Case 2: UPQC with Integration of DG and Fixed Load

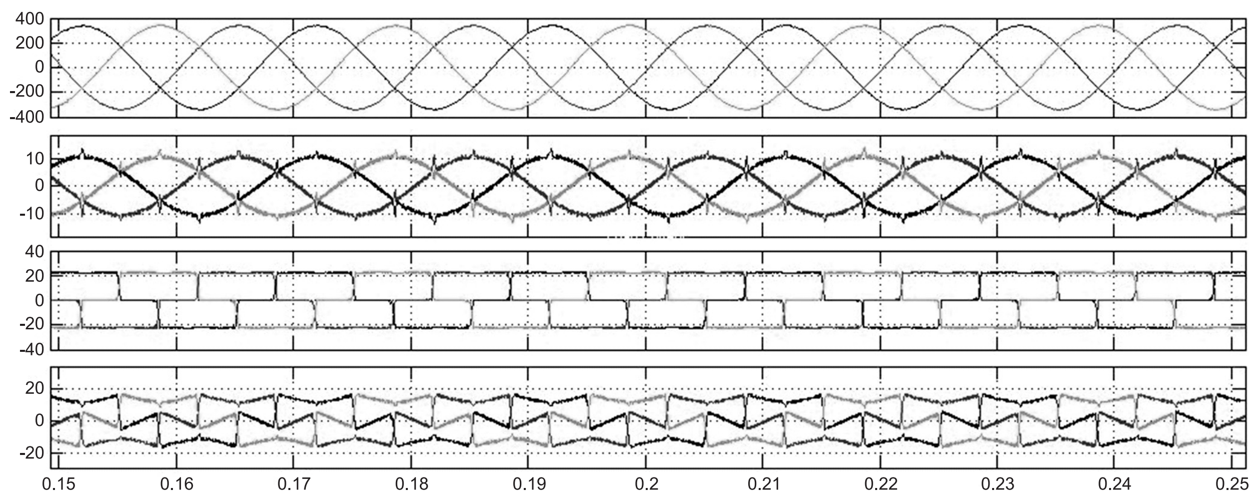

Figure 15: Results showing source voltage, source current, load current and filter currents of UPQC with DG and fixed load condition

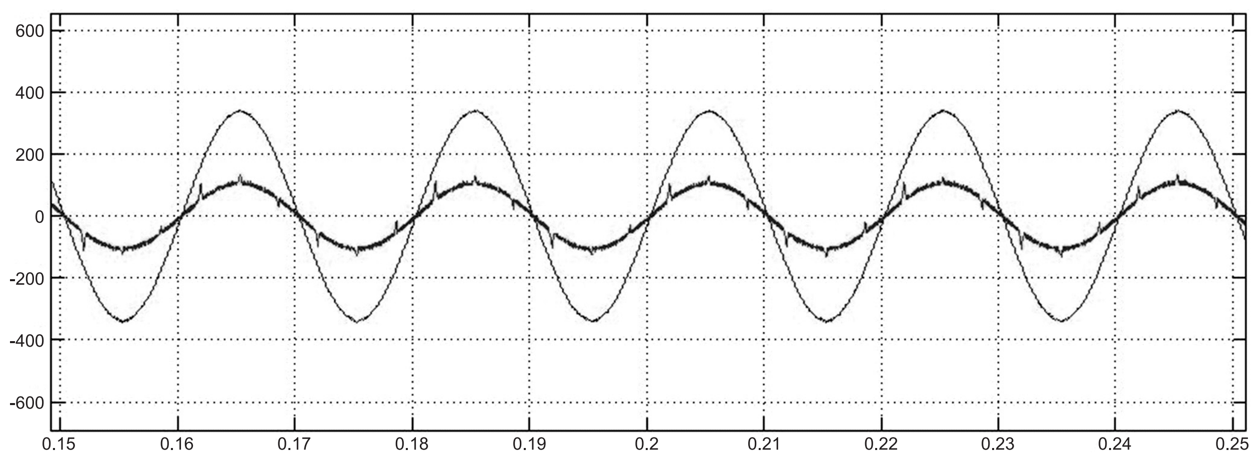

Figure 16: Results showing power factor of UPQC with DG and fixed load condition

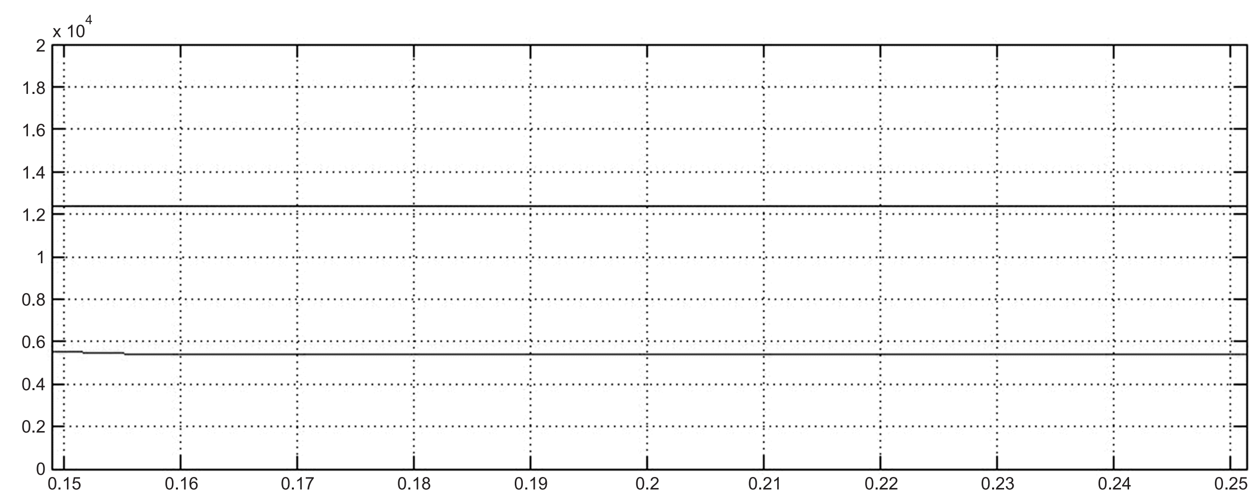

Figure 17: Result of active power in source and load for UPQC with DG and fixed load

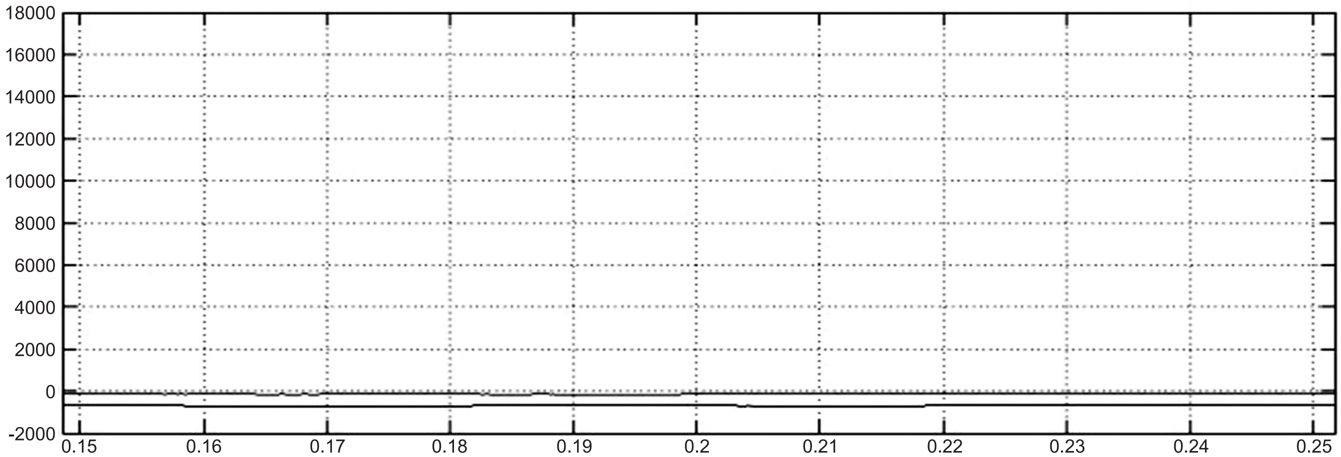

Figure 18: Result of reactive power in source and load for UPQC with DG and fixed load

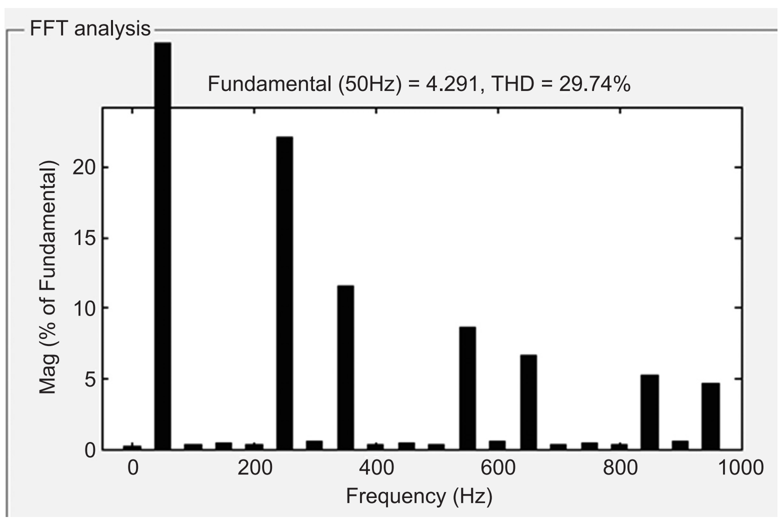

Figure 19: Result of THD in load current for UPQC with DG and fixed load

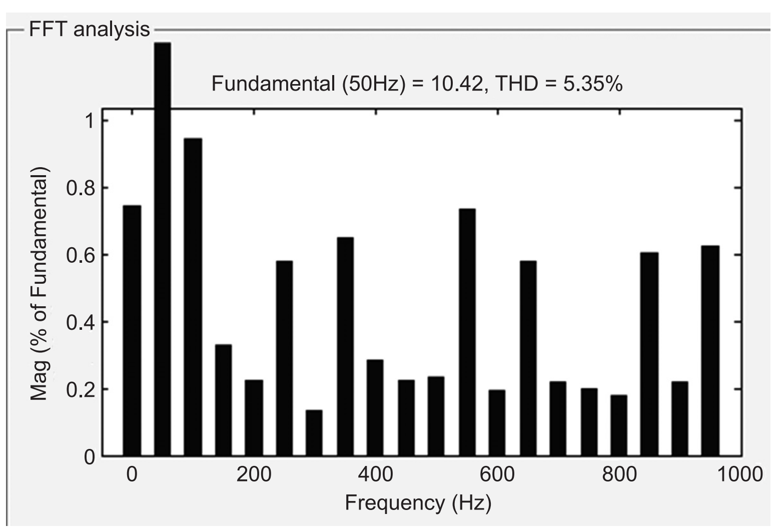

Figure 20: Result of THD in source current for UPQC with DG and fixed load

Figure 14 shows Matlab model of UPQC with DG fixed load and figure 15 shows results of source voltage, source current, load current and filter currents of UPQC with DG fixed load. Source voltage and current does not contain any harmonics due to presence of UPQC. Figure 16 is Result showing power factor of UPQC with DG fixed load. Power factor is maintained nearer to unity as there is no phase difference between source voltage and current. Figure 17 is result showing active power of both source and load of UPQC with DG fixed load. Figure 18 is result showing reactive power of both source and load of UPQC with DG fixed load.

Figure 19 shows THD in load current for UPQC with DG fixed load and figure 20 shows THD in source current for UPQC with DG. THD in load current is 29.74 % and while UPQC is connected the source current distortions are reduced to 5 % within nominal.

Case 3: UPQC with Integration of DG and Variable Load

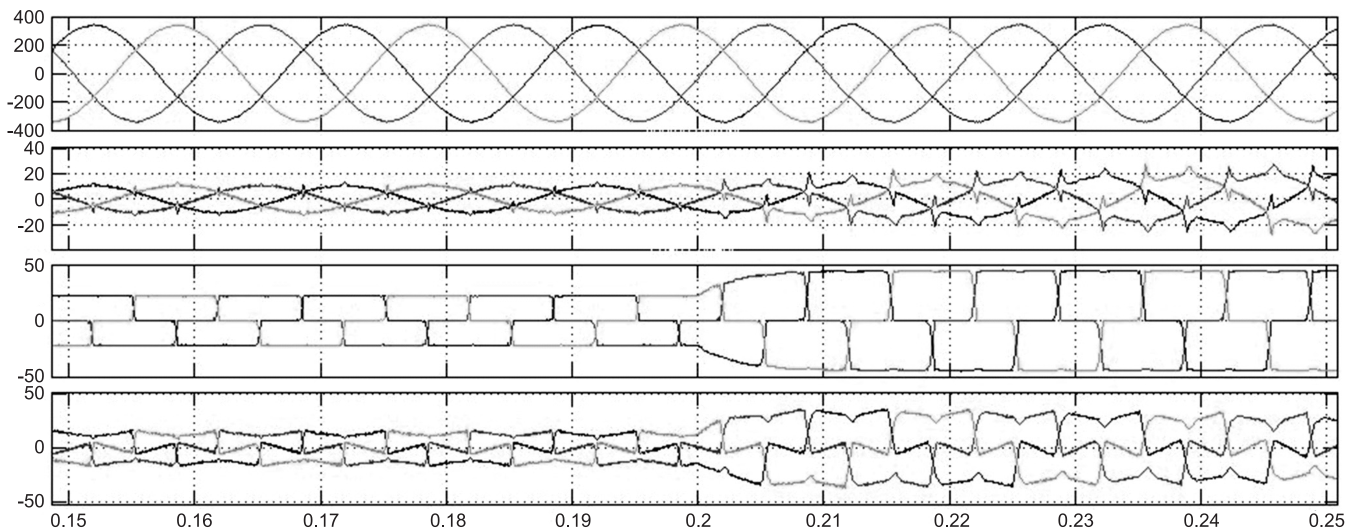

Figure 21: Results showing source voltage, source current, load current and filter currents of UPQC with DG and variable load condition

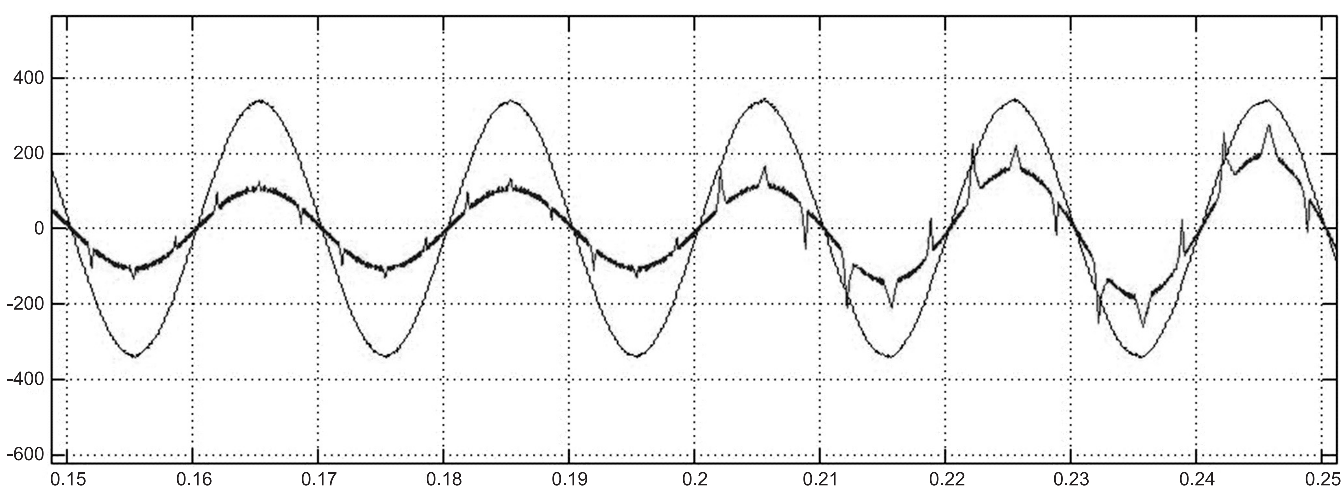

Figure 22: Results showing power factor of UPQC with DG and variable load condition

Figure 21 shows results of source voltage, source current, load current and filter currents of UPQC with DG variable load. Load demand is met from the distributed generation through filter. Figure 22 is Result showing power factor of UPQC with DG variable load. Power factor is maintained nearer to unity as there is no phase difference between source voltage and current. Figure 23 is result showing active power of both source and load of UPQC with DG variable load. Figure 24 is result showing reactive power of both source and load of UPQC with DG variable load. Active power demand is met from the distributed generation and reactive power is maintained constant even when the load demand is increased.

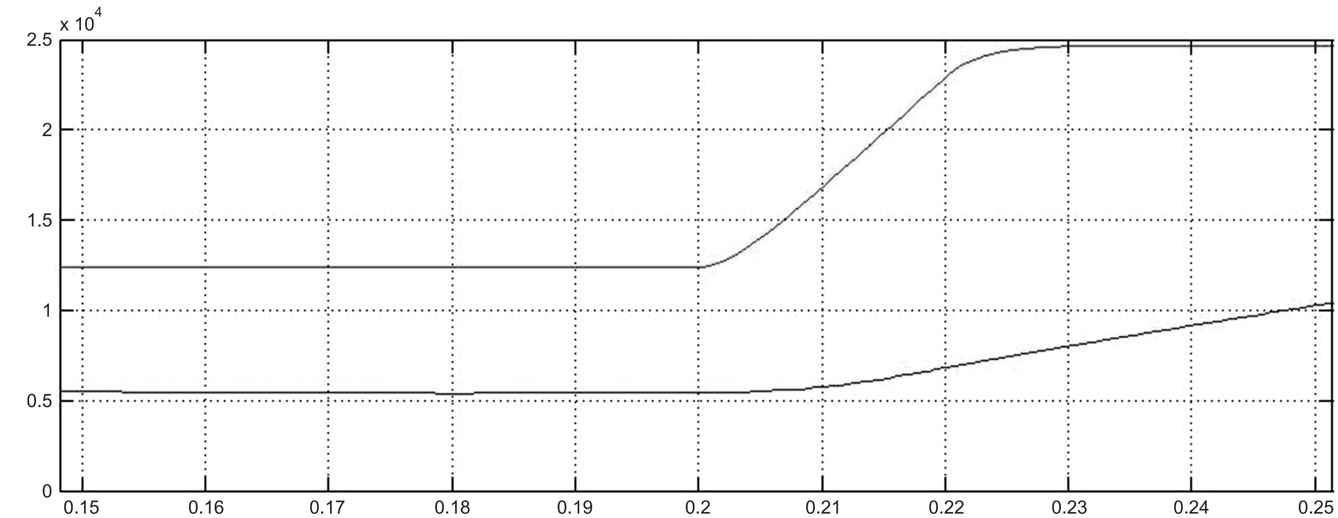

Figure 23: Result of active power in source and load for UPQC with DG and variable load

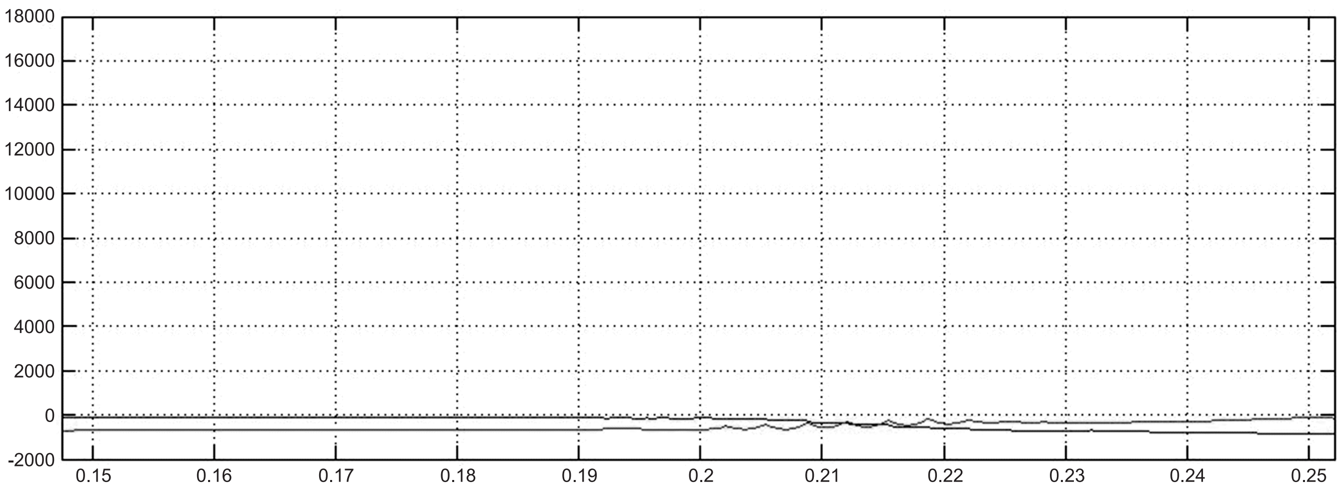

Figure 24: Result of reactive power in source and load for UPQC with DG and variable load

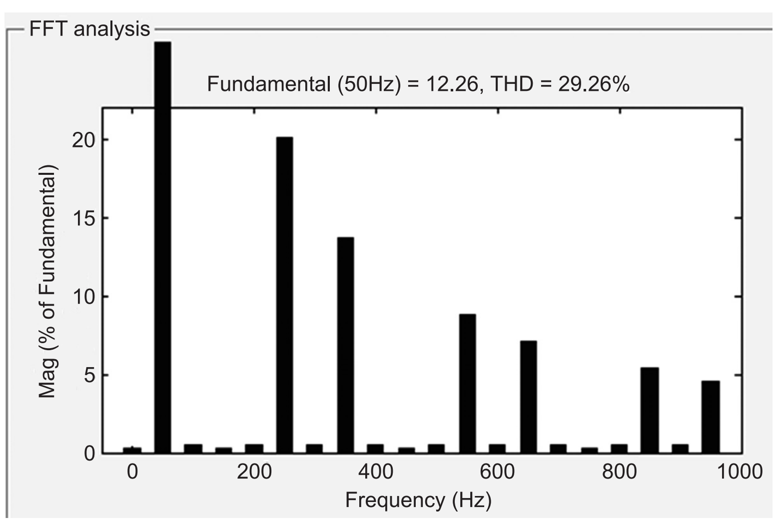

Figure 25: Result of THD in load current for UPQC with DG and variable load

Figure 25 shows THD in load current for UPQC with DG variable load and figure 26 shows THD in source current for UPQC with DG. THD in load current is 29.26 % and while UPQC is connected the source current distortions are reduced to 5 % maintained nominal.

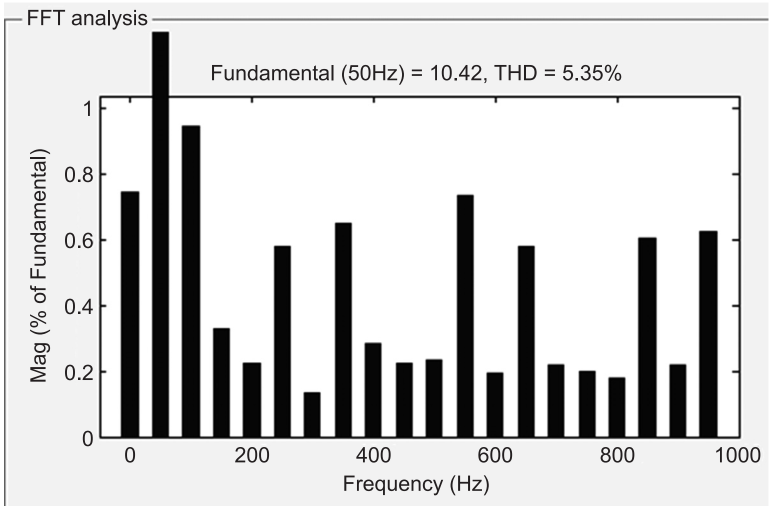

Figure 26: Result of THD in load current for UPQC with DG and variable load

6. CONCLUSION

The problems due to increased load demand and quality in load are a constraint for power engineers. Non-linear loads induce harmonics and increased loads can create voltage stability problems. UPQC is a custom power device addressing both the said issues. Voltage stability across DC link voltage is a constraint with UPQC employing two back-to-back converters. A DG source, a PV system is integrated to UPQC to stabilize voltage across DC link capacitor and also to send active power to grid while UPQC addressing its operation for harmonics and voltage stability in grid. THDs with DG and without DG, DC link voltage with and without DG integration is shown and maintained within nominal values. Source currents along with load currents and filter currents induced are shown. The proposed work shows viability of UPQC with DG integration to grid.

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