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INTEGRATION OF DISTRIBUTED GENERATION TO UPQC WITH UNIT VECTOR THEORY

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ABSTRACT

Power system quality is very much important in present days due to increasing non-linearity in the system. Many compensating devices were developed to improve power quality in the power system. Unified power quality conditioner is one of the FACTS devices that can effectively improve power quality. This paper discusses the integration of distributed generation (DG) to Unified Power Quality Conditioner (UPQC). DG delivers power to system and also stabilizes the DC link capacitor in UPQC. Unit vector control strategy was used to control the UPQC. While transferring active power to the system, DG integration gives stability to power system. Results were given when DG was not integrated to the system and when DG was integrated to the system. Results were also shown if DG was integrated to the system with variable load condition. THDs were shown for source current and load current showing how effective the UPQC works for improving power quality.

Keywords: *UPQC, Power Quality, Distributed Generation, Integration, DC Link.*

1. INTRODUCTION

Power quality is the major constraint in power sector in these modern days due to increase in variety of load natures. Industrial loads and commercial loads use majority of non-linear natured loads. Advancements in power electronics also lead to developments of house hold devices with non-linear nature. Non-linear natured loads only draws non-linear currents from the source instead of sinusoidal currents distorting the source components. Source components like source currents and voltages might be distorted to varied load nature. Flexible AC Transmission (FACTS) is a subject developed to induce device compensators to increase the power handling capability of the power line and to improve power factor of the system. Custom power devices (CUPS) are the induction of power electronic converters to compensate the source components in power system. Compensation type of custom devices is meant for compensation of source components like voltage and current.

Shunt compensators, series compensators and combination of series-shunt compensators are types of compensation type CUPS. UPQC is a compensator meant to compensate voltage, harmonics, power factor and reactive power in the main line of power system. UPQC is a series-shunt combinational compensator addressing almost majority of the power quality issues. UPQC consists of back-to-back voltage source converters coupled with a common DC link capacitor. UPQC while using active power from the capacitor for compensating operation discharges the capacitor. The stiff voltage across DC link is to be maintained for effective compensation through UPQC. A pollution free power generation like distributed generation (DG) can stabilize the voltage across DC link capacitor.

Figure 1 shows the general schematic arrangement of grid connected RES. PV system is connected through boost converter to increase the voltage. This DC is inverted to AC using inverter. But the non-linearity in the system induces harmonics and many other undesirable consequences into the system reducing power quality. Many compensation techniques were developed to improve power quality. Active and passive filters can improve power quality. Passive

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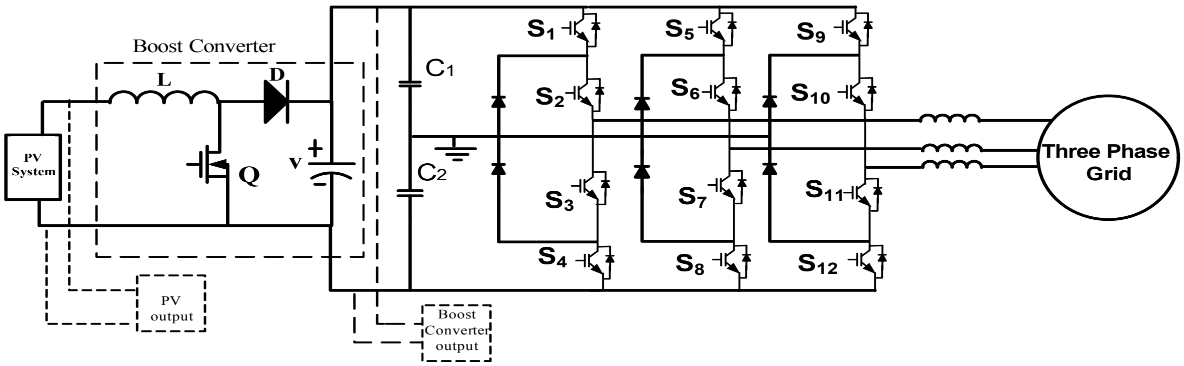

Fig 1: General DG integration scheme to grid

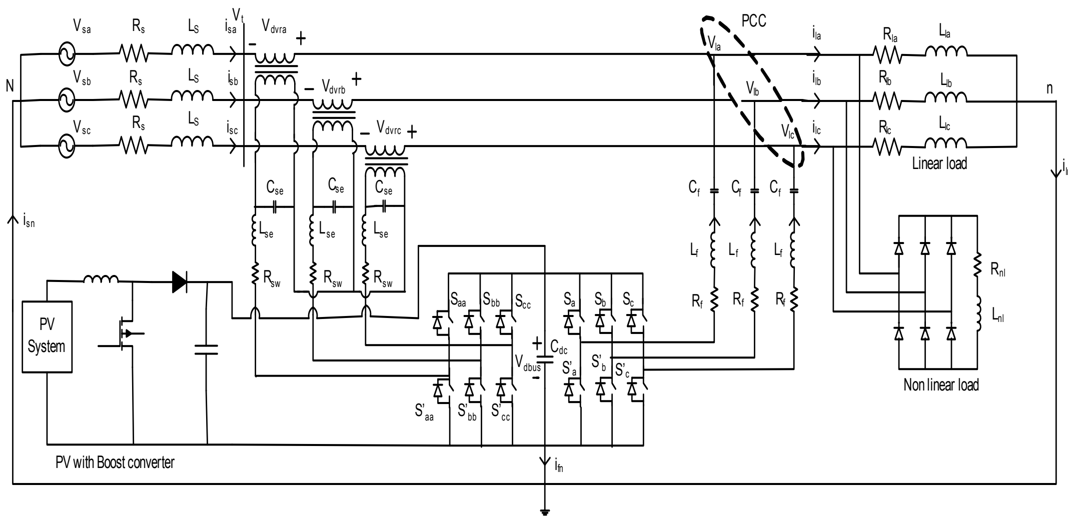

Fig.2 Block diagram of the proposed UPQC with DG integration topology

filters can improve the quality in power system for some extent and have some limitations. Thus active filters can be a very good option for the improvement of power quality. FACTS controllers are active filters which use power electronic components for their operation in improving power quality. Series controllers, shunt controllers, combination of series-series, combination of series-shunt are some of the types of FACTS devices depending on their connection. UPQC is a type of FACTS device [11-14] classified under combination of series-shunt which can reduce voltage swell/sag, harmonics and other disturbances in the power system.

This paper discusses the integration of distributed generation (DG) to Unified Power Quality Conditioner (UPQC). DG delivers power to system and also stabilizes the DC link capacitor in UPQC. Unit vector control strategy was used to control the UPQC. While transferring active power to the system, DG integration gives stability to power system. Results were given when DG was not integrated to the system and when DG was integrated to the system. Results were also shown if DG was integrated to the system with variable load condition.

2. UNIFIED POWER QUALITY CONDITIONER WITH DG

Figure 2 depicts block diagram of the proposed UPQC with DG integration. A PV system generates low voltage power which is boosted with the help of boost converter and voltage from PV is increased to required level to stabilize DC link capacitor in UPQC. UPQC is a combination of series-shunt compensation and performs task of compensating harmonics, voltage, and power factor. Since load is non-linear load, harmonics are induced and load variations might also cause voltage stability problems. Harmonics are addressed from shunt compensator connected to line through interfacing inductors. Voltage stability issues will be addressed through series compensator connected to grid through coupling transformer.

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3. OPERATION AND DESIGN OF BOOST CONVERTER

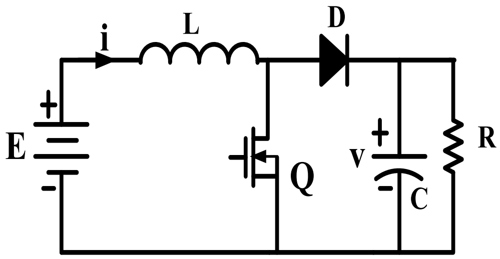


Fig. 3 Boost DC-DC Converter

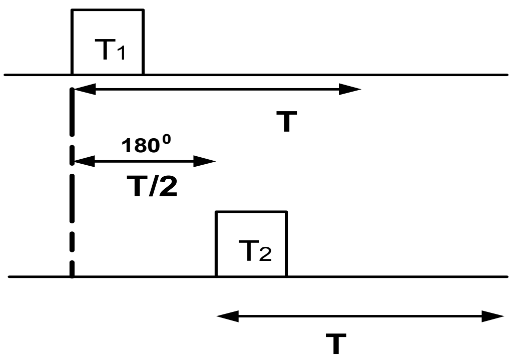


Fig.4 Timing diagram of Control Signal

During the period of switch ON, inductor charges through switch forming a circuit. Current (I_L) flowing through the inductor during a time period (t) by:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L} \qquad (1)$$

When switch is OFF, stored energy in inductor discharges and the supply also drives the load, thus increasing the output voltage. The voltage KVL can be written as:

$$V_i - V_0 = L\frac{dI_L}{dt} \qquad (2)$$

3.1 Design of Boost Converter:

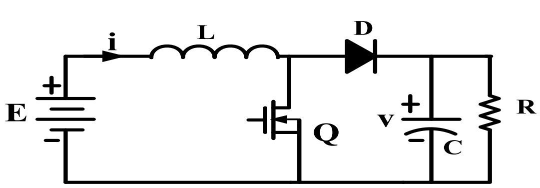
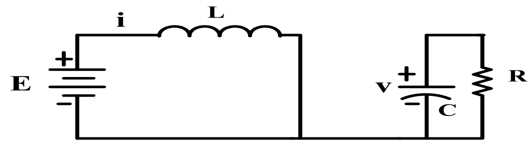


Fig.5. boost converter

Mode1: T1 ON

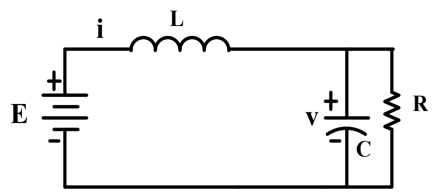


Assume $\Delta I = I_2 - I_1$

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

$$t_1 = \frac{L \times \Delta I}{V_{in}} \qquad (3)$$

Mode 2: DuringT1 off



For inductor L_1

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

$$t_2 = \frac{\Delta I L_1}{V_0 - V_{in}} \qquad (4)$$

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

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

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

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

$$\frac{V_0}{V_{in}} = \frac{1}{1-D} \qquad (5)$$

Total time period

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

$$T = \frac{\Delta I L V_0}{V_{in}(V_0 - V_{in})} \quad (6)$$

Peak to peak ripple current

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

$$\Delta I = \frac{V_{in}(V_0 - V_{in})}{f L V_0} \quad (7)$$

$$\frac{\Delta I = V_{in} D}{f L} \quad (8)$$

For output capacitor

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

Substitute

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

$$\Delta V_c = \frac{I_0 K}{f c} \quad (9)$$

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

$$\Delta I = \frac{V_s K}{f L} = 2 I_L = 2 I_0 = 2 \times \frac{V_0}{R} = \frac{2 \times V_{in}}{(1 - K) R}$$

$$L_{critical} = \frac{K(1-K)R}{2f} \quad (10)$$

Take worst case ripple for capacitor

$$\Delta V_c = 2 V_0$$

$$2 V_0 = \frac{I_0 K}{f c} = 2 I_0 R$$

$$C_{critical} = \frac{K}{2 f R} \quad (11)$$

Specifications

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

F=20 KHz; R=42.666Ω

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

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

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

$$L_{critical} = \frac{(1 - D) \times D R}{2f} = \frac{\left(1 - \frac{1}{2}\right) \times \frac{1}{2} \times 42.666}{2 \times 20 \times 10^3} = \frac{42.666}{4 \times 20 \times 10^3} = 0.5333 mH$$

In order to operate in CCM mode

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

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

In order to operate in CCM Mode we are choosing

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

Ripple current is

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

Ripple Voltage is

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

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4. CONTROL OF UPQC

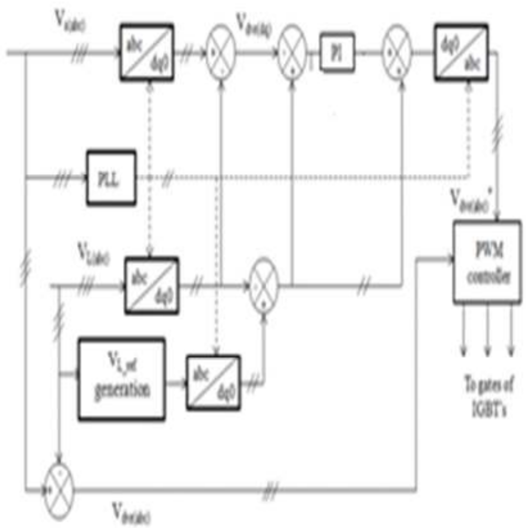

Fig.6 Block diagram of the control for UPQC

In UPQC, the series and shunt controllers are controlled with a single controller as shown in figure 6. The source voltage is sent to PLL to obtain the information regarding sine and cos. Simultaneous source voltage is transformed from abc to dq components using parks transformation. DC link voltage is measured from actual value and is compared to reference value. The error voltage signal is sent to PI controller to get voltage magnitude value. The sinusoidal information from PLL is mux to obtain voltage reference wave and is inverse transformed to abc from dq coordinates using inverse parks transformation. Signal is sent to PWM generator to generate trigger pulses to IGBTs of UPQC. Table 1 represents system parameters used for simulation.

5. RESULTS AND DISCUSSIONS

Table.1. Simulation Model Parameters

Input voltage	400V
Inductors	1.5999mH
Capacitor	200μF
Resistance	42.666Ω

5.1 UPQC without DG

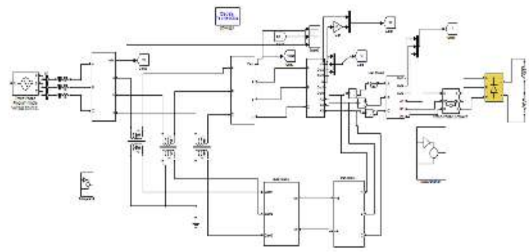

Fig 7: Matlab model of UPQC without DG

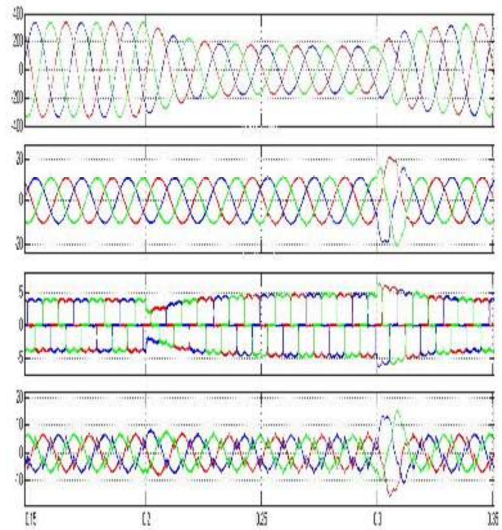

Fig 8: Results showing source voltage, source current, load current and filter currents of UPQC without DG

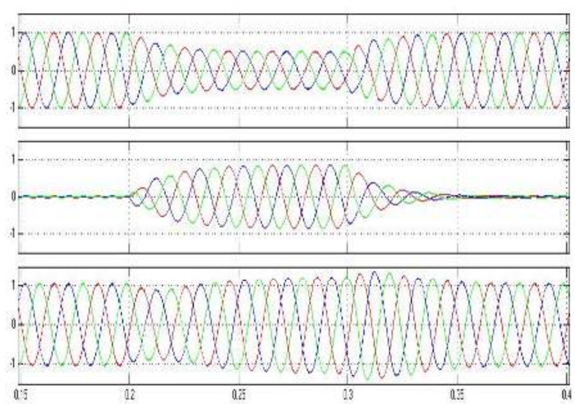

Fig 9: Results showing source voltage, induced voltage through filter, load voltage of UPQC without DG

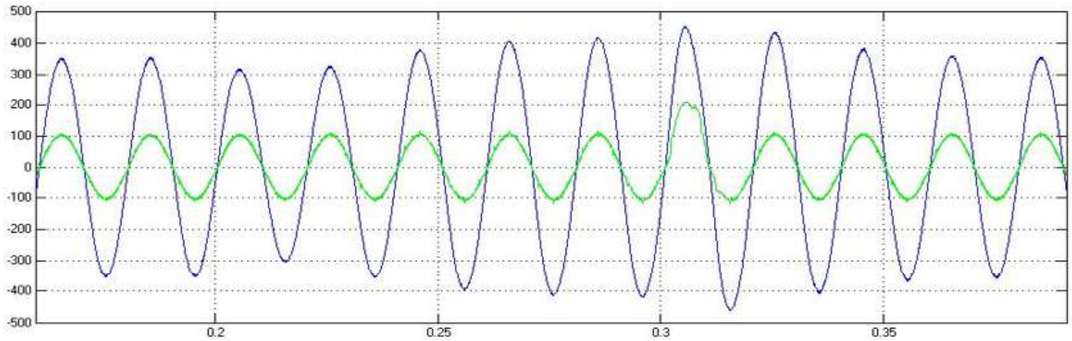

Fig 10: Results showing power factor of UPQC without DG

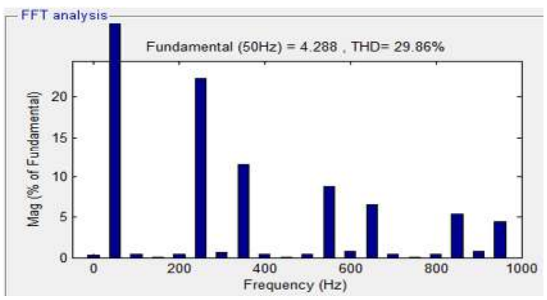

Fig 11: Result of THD in load current for UPQC without DG

Figure 7 shows Matlab model of UPQC without DG and figure 8 shows results of source voltage, source current, load current and filter currents of UPQC without DG. Figure 9 is Result showing source voltage, induced voltage through filter, load voltage of UPQC without DG. Figure 10 is result showing power factor of UPQC without DG. Drop in source voltage can be observed from figure 8 and the source current remains almost same throughout the time period. Load current is observed to have harmonics since the connected load is of non-linear type. This non-linear load induces harmonics in the system and they were compensated by the filter induced currents. The sag in source voltage is compensated by inducing voltage to the system through filter.

Figure 11 shows THD in load current for UPQC without DG and figure 12 shows THD in source current for UPQC without DG. THD in load current is 29.8 % high in value since load draws non-linear components and when UPQC is connected the source current distortions are reduced to 5 % maintained nominal.

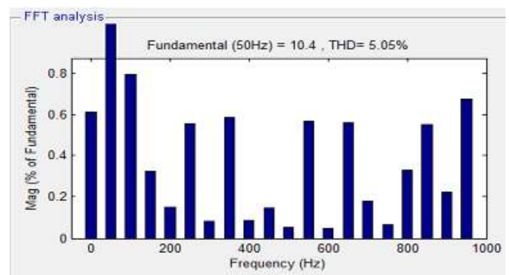

Fig 12: Result of THD in source current for UPQC without DG

5.2 UPQC with integration of DG and fixed load

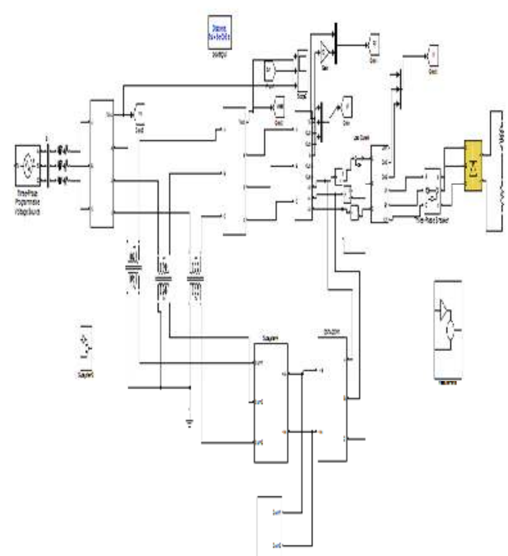

Fig 13: Matlab model of UPQC with DG and fixed load

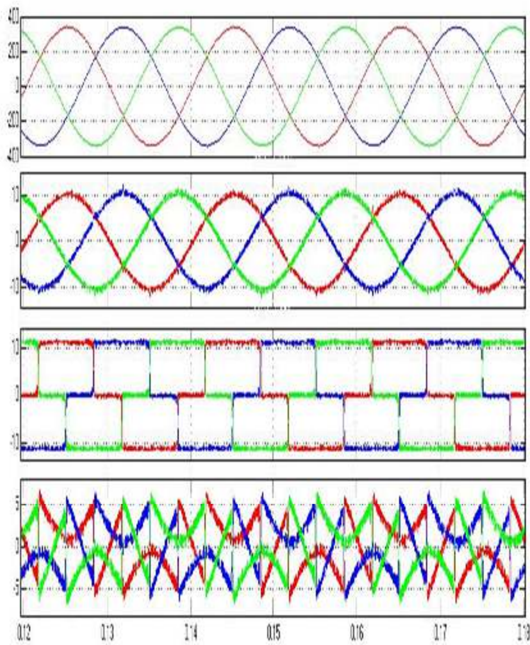

Fig 14: Results showing source voltage, source current, load current and filter currents of UPQC with DG and fixed load condition

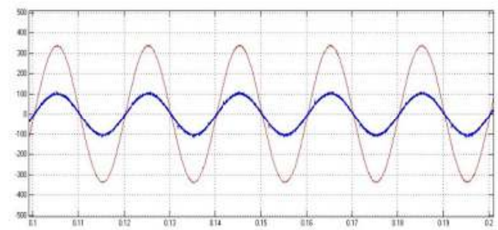

Fig 15: Results showing power factor of UPQC with DG and fixed load condition

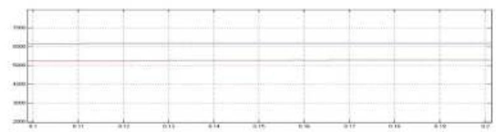

Fig 16: Result of active power in source and load for UPQC with DG and fixed load

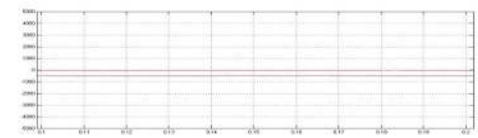

Fig 17: Result of reactive power in source and load for UPQC with DG and fixed load

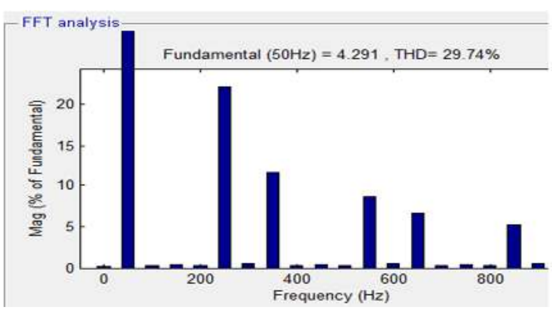

Fig 18: Result of THD in load current for UPQC with DG and fixed load

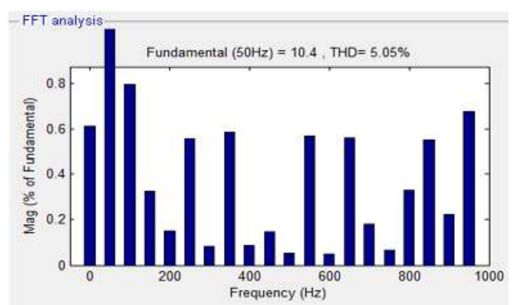

Fig 19: Result of THD in source current for UPQC with DG and fixed load

Figure 13 shows Matlab model of UPQC with DG fixed load and figure 14 shows results of source voltage, source current, load current and filter currents of UPQC with DG fixed load. It can be observed the source voltage and current are well in shape indicating no harmonic content due to the presence of UPQC. Load current contains harmonics as the load is of non-linear type. The harmonics induced by the load are compensated by filter currents shown. Figure 15 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 16 is result showing active power of both source and load of UPQC with DG fixed load. Figure 17 is result showing reactive power of both source and load of UPQC with DG fixed load.

Figure 18 shows THD in load current for UPQC with DG fixed load and figure 19 shows THD in source current for UPQC with DG. THD in load current is 29.74 % which is high since load is of non-linear type and when UPQC is connected the source current distortions are reduced to 5.05 % maintained nominal which is acceptable.

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5.3 UPQC with integration of DG and variable load

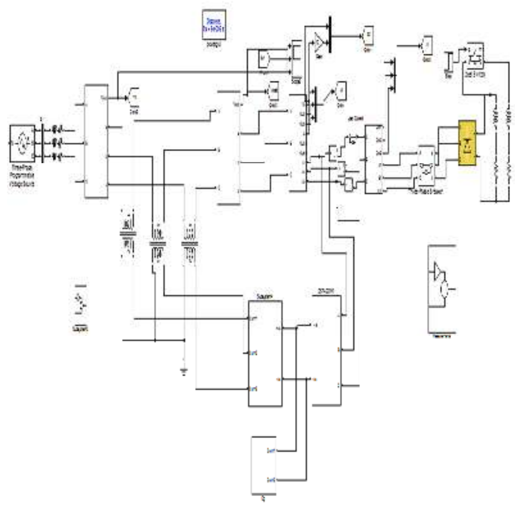

Fig 20: Matlab model of UPQC with DG and variable load

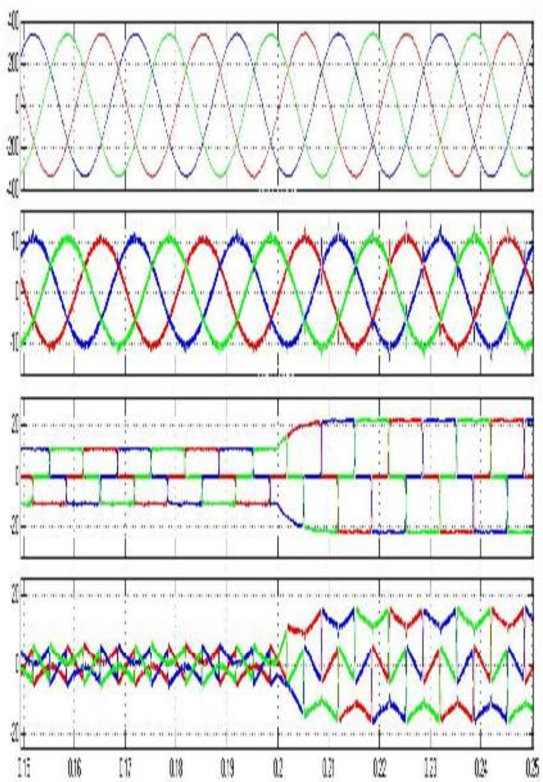

Fig 21: Results showing source voltage, source current, load current and filter currents of UPQC with DG and variable load condition

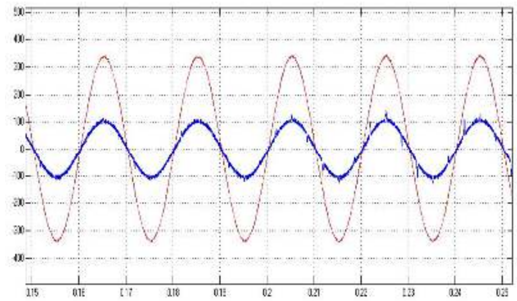

Fig 22: Results showing power factor of UPQC with DG and variable load condition

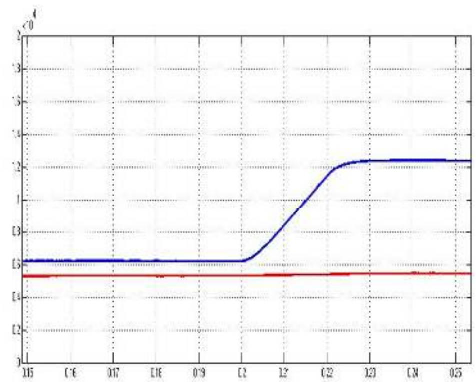

Fig 23: Result of active power in source and load for UPQC with DG and variable load

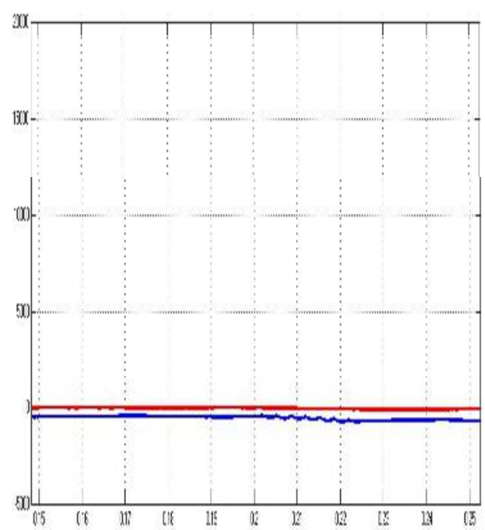

Fig 24: Result of reactive power in source and load for UPQC with DG and variable load

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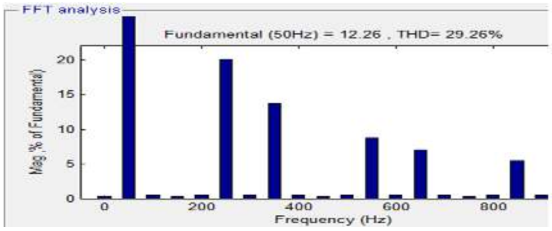

Fig 25: Result of THD in load current for UPQC with DG and variable load

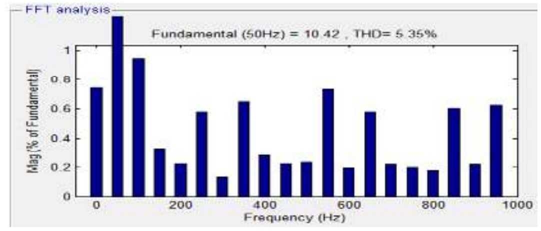

Fig 26: Result of THD in load current for UPQC with DG and variable load

Figure 20 shows Matlab model of UPQC with DG variable load and figure 21 shows results of source voltage, source current, load current and filter currents of UPQC with DG variable load. Load variation can be observed with increase in load current. Though the load is increased the source current and voltage remains same at 10A and 320V respectively. Load initially was the 10A and after load is increased it demanded at 20A. this increased load demand was met by DG through filter. Figure 22 is Result showing power factor of UPQC with DG variable load. No phase shift was observed between source voltage and current thus maintaining power factor nearer to unity. Figure 23 is result showing active power of both source and load of UPQC with DG variable load. Active power demand of the load is increased due to increase in load. Figure 24 is result showing reactive power of both source and load of UPQC with DG variable load which are maintained almost constant even when the load is increased.

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 5.35 % maintaining nominal value.

6. CONCLUSION

Power system quality is extremely abundant vital in these days because of increasing non linearity within the system. Several compensating devices were developed to enhance power quality within the power grid. Unified power quality conditioner is one in many of the FACTS devices that may effectively improve power quality. This paper discusses the combination of distributed generation (DG) to Unified Power Quality Conditioner (UPQC). DG delivers power to system and conjointly stabilizes the DC link capacitance in UPQC. Unit vector management strategy was accustomed to control the UPQC. Whereas transferring active power to the system, DG integration offers stability to power grid. Results were explained once for DG wasn't integrated to the system and once DG was integrated to the system. Results were conjointly shown if DG was integrated to the system with variable load condition. THDs were shown for supply current and load current showing however effective the UPQC works for rising power quality.

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