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Harmonic analysis and Power factor improvement with UPQC under two Novel control strategies

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Abstract

This paper presents unified power quality conditioner (UPQC)for power quality improvements in terms of harmonics compensation and power factor correction in a three-phase four-wire distribution system.The UPQC is implemented with PWM controlled voltage source converter (VSC) and switching patterns are generated through Indirect PI and Synchronous Reference Frame controller. The selected topology for voltage source converter is the three-leg and six-leg VSC for Indirect PI and Synchronous reference frame (SRF) control strategies respectively. The behavior of UPQC has been analyzed by considering a case study with switching of three phase half bridge diode rectifier and a parallel star connected unbalanced R-L loads. Harmonic spectrum of the source current and load voltage are compared in between without UPQC and with UPQC by considering both control strategies. The complete system has been modeled using MATLAB software with its stimulus's sim power system toolboxes.

Keywords: Unified power quality conditioner (UPQC); Synchronous reference frame (SRF) controller; Indirect PI controller; Voltage source converter (VSC); Power quality (PQ).

I. Introduction

The power quality problems in distribution power systems are not new, but customer awareness of these problems has recently increased. For example, for many years interruptions shorter than several minutes were not considered as a cause of concern to most consumers. Recently this has changed: more and more equipment is sensitive to very short duration events, and more and more customers (domestic as well as industrial) view short interruptions as a serious imperfection of the supply. The quality of the power is effected by many factors like harmonic contamination, due to the increment of non-linear loads, such as large thyristor power converters, rectifiers, voltage and current flickering due to arc in arc furnaces (Hooshmand and Esfahani 2011), sag and swell due to the switching (on and off) of the loads etc. Active filters can resolve this problem, however the cost of active filters is high, and they are difficult to implement in large scale. Extensive and well-documented surveys on the active power filter (APF) technologies covering several aspects are provided in (Akagi 1994; Singh et al 1999;Habrouk et al 2000). This paper focuses on a unified power quality conditioner (UPQC) for power quality improvement. Various methods have been used for controlling UPQC in order to solve several problems of power quality including: neural networks based estimation (Tey et al 2004), application of optimal control (Basu et al 2004), sliding mode control (Kolhatkar et al 2005), wavelet transform (Forghani and Afsharnia 2007), Model predictive control (Kwan et al 2007) and many other creative methods (Monteiro et al 2003; Shu et al 2005; Kazemi et al 2006). However, the complexities of calculations in classic methods and slowness or low quality of response are observed in some methods of frequency domain. Hence an appropriate control strategy in time domain for UPQC control are utilized in this paper, which has high speed and precise response besides the capability of solving some of the problems of power quality. The Indirect PI (Kumar and Nagaraju 2007) as a conventional approach and Synchronous Reference Frame(Padiyar 2007)as a proposed approach have been used for controlling UPQC in terms of power quality improvement.The performance of complete system is demonstrated through simulated waveforms using SimPowerSystems (SPS) MATLAB/Simulink environment. The paper has been organized in the following manner. The UPQC description with its components is discussed in Section II, the control algorithms for UPQC is illustrated in Section III, The SPS MATLAB/Simulink-based model with its simulation results are explained in Section IV and finally Section V concludes the paper.

II. Unified Power Quality Conditioner (UPQC)

There are two important types of active power filter (APF), namely, shunt APF and series APF. The shunt APF is the most promising to tackle the current-related problems, whereas, the series APF is the most suitable to overcome the voltage-related problems. Moran(Moran 1989) described a system configuration in which both series and shunt APFs were connected back to back with a common dc reactor. The back-to-back inverter system configuration truly came into attention when Fujita and Akagi (Fujita and Akagi 1998) proved the practical application of this topology with 20 kVA experimental results. They named this device as unified power quality conditioner (UPQC).

The main purpose of a UPQC is to compensate for supply current power quality problems, such as, harmonics, unbalance, reactive current, and neutral current and load voltage power quality issues, such as, sags, swells, unbalance, flicker, harmonics etc. Fig. 1 shows a single-line representation of the UPQC system configuration. The key components of this system are as follows.

1) Two inverters—one connected across the load which acts as a shunt APF and other connected in series with the line as that of series APF.

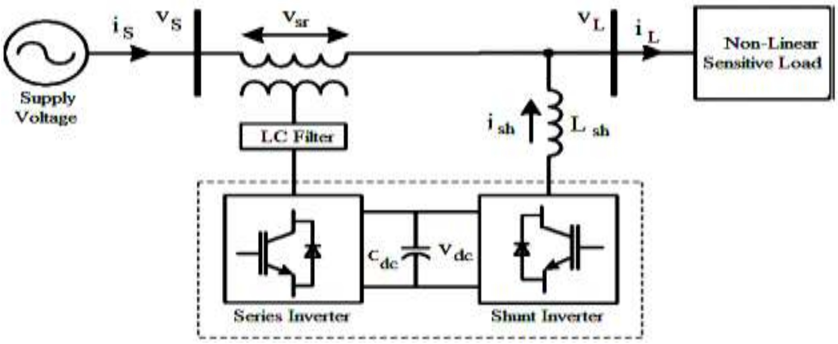


Fig 1 UPQC general block diagram representation

2) Shunt coupling inductor L_{sh} is used to interface the shunt inverter to the network. It also helps in smoothing the current wave shape. Sometimes an isolation transformer is utilized to electrically isolate the inverter from the network.

3) A common dc link that can be formed by using a capacitor or an inductor. In Fig. 1, the dc link is realized using a capacitor which interconnects the two inverters and also maintains a constant self-supporting dc bus voltage across it.

4) An LC filter that serves as a passive low-pass filter (LPF) and helps to eliminate high-frequency switching ripples on generated inverter output voltage.

5) Series injection transformer that is used to connect the series inverter in the network. A suitable turn ratio is often considered to reduce the current or voltage rating of the series inverter.

In principle, UPQC is an integration of shunt and series APFs with a common self-supporting dc bus. The shunt inverter in UPQC is controlled in current control mode such that it delivers a current which is equal to the set value of the reference current as governed by the UPQC control algorithm. Additionally, the shunt inverter plays an important role in achieving required performance from a UPQC system by maintaining the dc bus voltage at a set reference value. In order to cancel the harmonics generated by a nonlinear load, the shunt inverter should inject a current as governed by following equation:

$$i_{Sh}(\omega t) = i_L(\omega t) - i_S^*(\omega t) \quad (1)$$

Where $i_{sh}(\omega t)$, $i_L(\omega t)$ and $i_S^*(\omega t)$ represent the shunt inverter current, load current and reference source current, , respectively.

Similarly, the series inverter of UPQC is controlled in voltage control mode such that it generates a voltage and injects in series with line to achieve a sinusoidal, free from distortion and at the desired magnitude voltage at the load terminal. The basic operation of a series inverter of UPQC can be represented by the following equation:

$$v_{Sr}(\omega t) = v_L^*(\omega t) - v_P(\omega t) \quad (2)$$

Where $v_{Sr}(\omega t)$, $v_L^*(\omega t)$ and $v_P(\omega t)$ represent the series inverter injected voltage, reference load voltage, and PCC voltage, respectively.

III. Control Strategies

Among the several active power filter(APF) control methods presented in the literature, the synchronous reference frame (SRF) based control method is one of the most suitable method. However indirect PI control method has been also discussed to investigate superior features of proposed synchronous reference frame (SRF) control method in terms of power quality improvement.

3.1 Indirect PI controller

The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage. Such error is processed by a PI controller, the output is the angle δ, which is provided to the pulse width modulated (PWM) signal generator. Fig. 2 shows that an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller process the error signal, generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

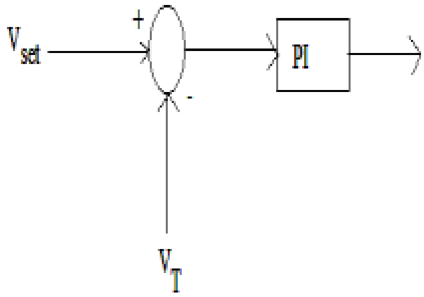


Fig. 2 Indirect PI controller

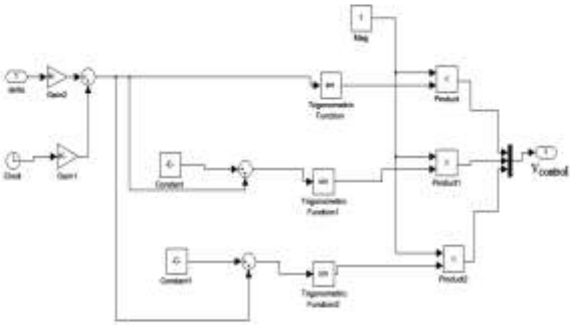


Fig. 3 Phase Modulation of the control angle δ

From Fig. 3 the sinusoidal signal $V_{control}$ is phase-modulated by means of the angle δ as follow:

$$V_A = Sin(\omega t + \delta)$$
$$V_B = Sin(\omega t + \delta - 2\pi / 3)$$
$$V_C = Sin(\omega t + \delta + 2\pi / 3) \quad (3)$$

The modulating angle is applied to the PWM generators in phase A. The angles for phases B and C are shifted by 120^0 and 240^0 respectively. It can be seen in that the control implementation is kept very simple by using only voltage measurements as the feedback variable in the control scheme. Fig. 4 shows Simulink model of UPQC Controller. The speed of response and robustness of this control scheme is clearly shown in the simulation results.

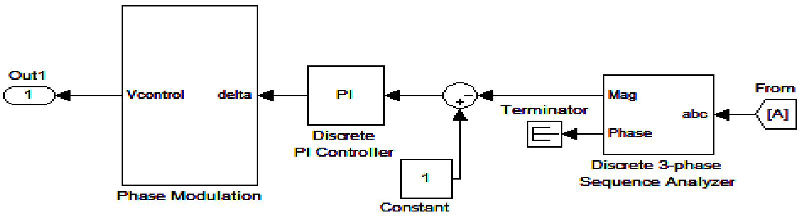


Fig. 4 Simulink model of UPQC Controller

3.2 Proposed Synchronous Reference Frame Controller

The control scheme for the shunt compensator is shown in Fig. 5. The shunt compensator regulates the DC bus voltage in addition to compensate the harmonics and unbalance in the load.

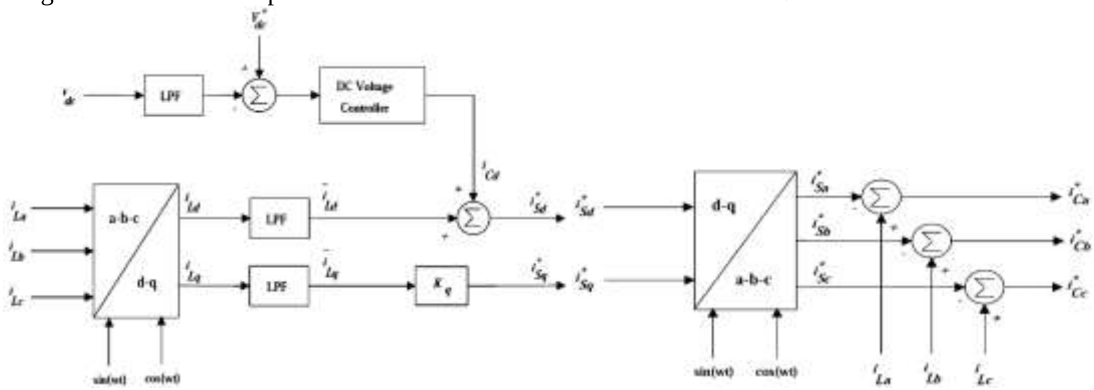


Fig. 5 Shunt compensator control scheme for generation of reference compensator currents

The load currents (i_{La}, i_{Lb}, i_{Lc}) and dc bus voltage (v_{dc}) are sensed as feedback signals. The load currents from the *a–b–c* frame are first converted to the *α–β* frame and then to the *d–q* frame using the following formulation

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \tfrac{2}{3}\begin{Bmatrix} 1 & -\tfrac{1}{2} & -\tfrac{1}{2} \\ 0 & -\tfrac{\sqrt{3}}{2} & \tfrac{\sqrt{3}}{2} \end{Bmatrix}\begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{Bmatrix} \cos\omega t & -\sin\omega t \\ \sin\omega t & \cos\omega t \end{Bmatrix}\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix}$$

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \tfrac{2}{3}\begin{Bmatrix} \cos\omega t & \cos\left(\omega t - \tfrac{2\pi}{3}\right) & \cos\left(\omega t + \tfrac{2\pi}{3}\right) \\ \sin\omega t & \sin\left(\omega t - \tfrac{2\pi}{3}\right) & \sin\left(\omega t + \tfrac{2\pi}{3}\right) \end{Bmatrix}\begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (4)$$

The average value of i_{Ld} and i_{Lq} are obtained as output of two identical low pass filter and are defined as

$$\begin{bmatrix} \overline{i_{Ld}} \\ \overline{i_{Lq}} \end{bmatrix} = G(s)\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} \quad (5)$$

Where G(s) is chosen as transfer function of a 2nd order Butterworth low pass filter (with a corner frequency of 30 Hz).

The synchronous reference frame (SRF) controller extracts dc quantities by a low-pass filter, and hence, the non-dc quantities (harmonics) are separated from the reference signal.

The DC voltage controller is designed as a proportional controller.

The output of the proportional (P) controller at the dc bus voltage is considered as the current i_{Cd}. When PF is to be controlled, K_q is determined by required power factor as follows

$$K_q = \tfrac{Q_s^*}{\overline{Q_L}} \quad (6)$$

Where Q_S^* reference reactive power is supplied by source (at PCC) and $\overline{Q_L}$ is average reactive power defined by

$$\overline{Q}_L = |V_t|\,\overline{i}_{Lq} \quad (7)$$

For unity power factor, $\cos\varphi = 1$, so $\varphi = 0$

$$Q_S^* = VI\sin\varphi = 0 \quad (8)$$

$$K_q = 0$$

The desired source currents (in d-q component) are obtained as

$$i_{Sd}^* = \overline{i_{Ld}} + i_{Cd}$$
$$i_{Sq}^* = K_q\overline{i_{Lq}} \quad (9)$$

The reference for the source current in the *d-q* frame are first converted to the *α–β*frame and then to the *a-b-c* frame using the following formulation

$$\begin{bmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix} = \begin{Bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{Bmatrix}\begin{bmatrix} i^*_{sd} \\ i^*_{sq} \end{bmatrix}$$

$$\begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = \tfrac{2}{3}\begin{Bmatrix} 1 & 0 \\ -\tfrac{1}{2} & -\tfrac{\sqrt{3}}{2} \\ -\tfrac{1}{2} & \tfrac{\sqrt{3}}{2} \end{Bmatrix}\begin{bmatrix} i^*_{s\alpha} \\ i^*_{s\beta} \end{bmatrix}$$

$$\begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = \tfrac{2}{3}\begin{Bmatrix} \cos\omega t & \sin\omega t \\ \cos\left(\omega t - \tfrac{2\pi}{3}\right) & \sin\left(\omega t - \tfrac{2\pi}{3}\right) \\ \cos\left(\omega t + \tfrac{2\pi}{3}\right) & \sin\left(\omega t + \tfrac{2\pi}{3}\right) \end{Bmatrix}\begin{bmatrix} i^*_{sd} \\ i^*_{sq} \end{bmatrix} \quad (10)$$

The reference for the source current vector ($i_{Sa}^*, i_{Sb}^*, i_{Sc}^*$) is computed and the desired compensator currents ($i_{Ca}^*, i_{Cb}^*, i_{Cc}^*$) are obtained as the difference between the load and the source (reference) currents. The determination of reference source current vector is based on synchronous reference frame (SRF) theory.

$$i_{Ca}^* = i_{La} - i_{Sa}^*$$
$$i_{Cb}^* = i_{Lb} - i_{Sb}^*$$
$$i_{Cc}^* = i_{Lc} - i_{Sc}^*$$

Note that ω is the supply frequency expressed in radians/sec. The unit vectors sinωt and cosωt are obtained from phase-locked loop (PLL) which is locked to the point of common coupling (PCC) voltage.

The control scheme for the series compensator is shown in Fig. 6.

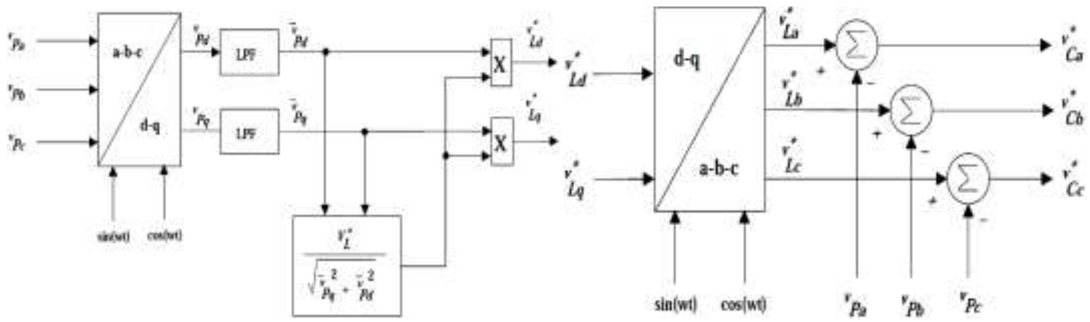


Fig.6 Series compensator control scheme for generation of reference compensator voltages

The point of common coupling (PCC) voltage V_{Pa} , V_{Pb} and V_{Pc} are transformed into d-q components using a-b-c to α-β and α-β to d-q transformation:

$$\begin{bmatrix} V_{P\alpha} \\ V_{P\beta} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{Pa} \\ V_{Pb} \\ V_{Pc} \end{bmatrix} \quad (11)$$

$$\begin{bmatrix} V_{Pd} \\ V_{Pq} \end{bmatrix} = \begin{bmatrix} \cos\omega_0 t & -\sin\omega_0 t \\ \sin\omega_0 t & \cos\omega_0 t \end{bmatrix} \begin{bmatrix} V_{P\alpha} \\ V_{P\beta} \end{bmatrix} \quad (12)$$

where ω_0 is the operating system frequency. The DC components in V_{Pd} and V_{Pq} are extracted by using a low pass filter. Thus

$$\begin{bmatrix} \overline{V}_{Pd} \\ \overline{V}_{Pq} \end{bmatrix} = G(s) \begin{bmatrix} V_{Pd} \\ V_{Pq} \end{bmatrix} \quad (13)$$

$\overline{V_{Pd}}$ and $\overline{V_{Pq}}$ are the DC components and G(s) is the transfer function of low pass filter.

$$V^*_{Ld} = \overline{V}_{Pd} \left(V^*_L \Big/ \sqrt{\overline{V}^2_{Pq} + \overline{V}^2_{Pd}} \right) \quad (14)$$

$$V^*_{Lq} = \overline{V}_{Pq} \left(V^*_L \Big/ \sqrt{\overline{V}^2_{Pq} + \overline{V}^2_{Pd}} \right) \quad (15)$$

From the reference values of V^*_{Ld} and V^*_{Lq} we can obtain the desired load voltages in phase coordinates of a-b-c components using d-q to α-β and α-β to a-b-c transformation:

$$\begin{bmatrix} V^*_{L\alpha} \\ V^*_{L\beta} \end{bmatrix} = \begin{bmatrix} \cos\omega_0 t & \sin\omega_0 t \\ -\sin\omega_0 t & \cos\omega_0 t \end{bmatrix} \begin{bmatrix} V^*_{Ld} \\ V^*_{Lq} \end{bmatrix} \quad (16)$$

$$\begin{bmatrix} V^*_{La} \\ V^*_{Lb} \\ V^*_{Lc} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V^*_{L\alpha} \\ V^*_{L\beta} \end{bmatrix} \quad (17)$$

Finally, the reference compensated voltages are given by

$$V^*_{Ca} = V^*_{La} - V_{Pa}$$
$$V^*_{Cb} = V^*_{Lb} - V_{Pb} \quad (18)$$
$$V^*_{Cc} = V^*_{Lc} - V_{Pc}$$

IV. Simulation of Unified Power Quality Conditioner (UPQC): A case Study

To demonstrate performance analysis of UPQC in terms of power quality improvement a case study has been considered for the three phase four wire distribution system under a load of three phase half bridge diode rectifier in parallel with a Y connected unbalanced R - L impedances (Padiyar 2007). System data for the case study has been given in Table1 and the system diagram is shown in Fig. 7.A UPQC of suitable rating is connected in series - parallel with the load.

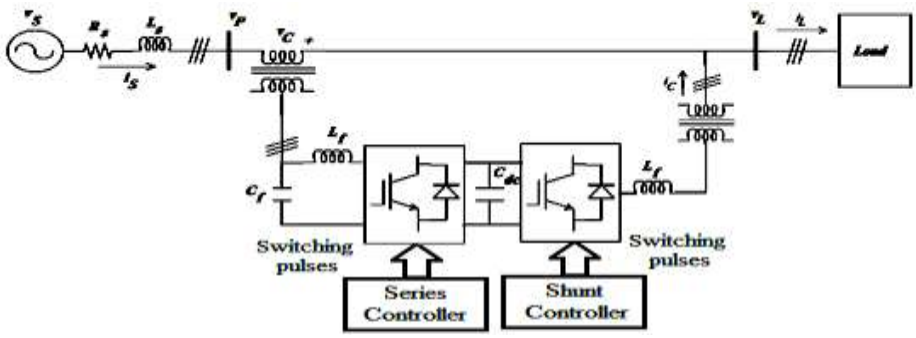
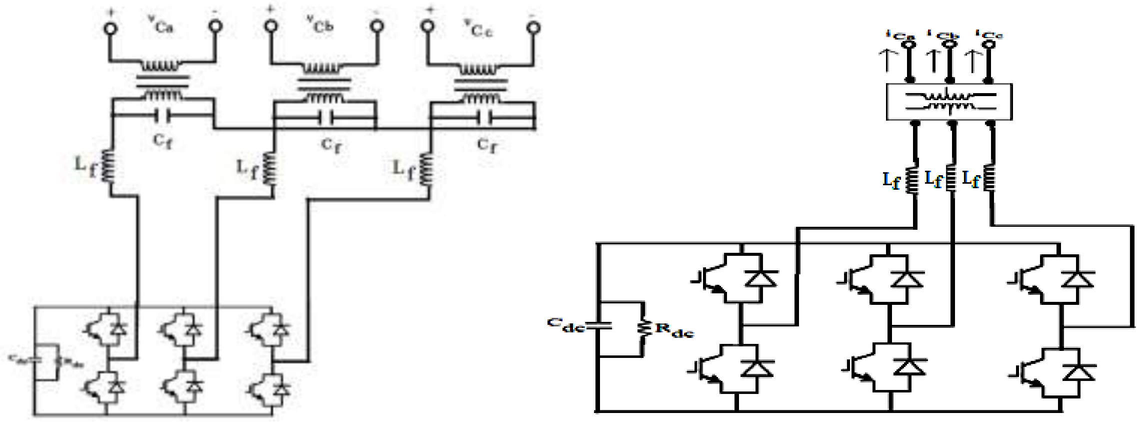


Fig.7 System Configuration of UPQC

Table 1:System parameters

Parameter	Value
AC source voltage and frequency	V_s = 415V , f = 50 Hz
Line Impedance	L_s = 40 mH, R_s = 1.57 Ω
Unbalanced R-L load	R_a = 50 Ω , L_a = 200 mH
	R_b = 75 Ω , L_b = 225 mH,
	R_c = 25 Ω , L_c = 175 mH
Nonlinear load (diode rectifier)	R_{on} = 0.001 Ω , L_{on} = 0 H, V_f = 0.8 V
Filter parameter	L_f = 9.6 mH, C_f = 4.2 μF, L_f = 25 mH
DC capacitance and resistance	C_{dc}= 5000μF, R_{dc} = 6000 Ω
Controller Parameter (Proportional)	K_p = 0.6
PWM switching frequency	1080 Hz
Power Converter	IGBTs/Diodes

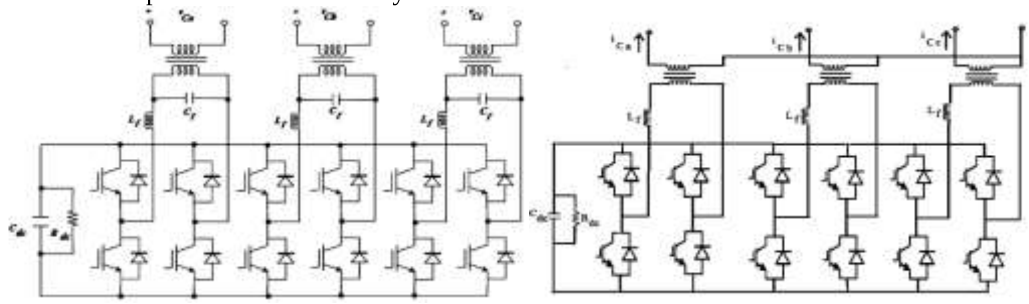
Fig.8(a & b) show the power circuit of series and shunt connected three-leg voltage source converter based UPQC integrated with three phase transformer for indirect PI control.



(a) (b)

Fig .8Power circuit of UPQC for indirect PI control (a) Series Converter (b) ShuntConverter

Fig. 9(a & b) show the power circuit of series and shunt connected six-leg voltage source converter based UPQC integrated with three phase transformer for synchronous reference frame control.

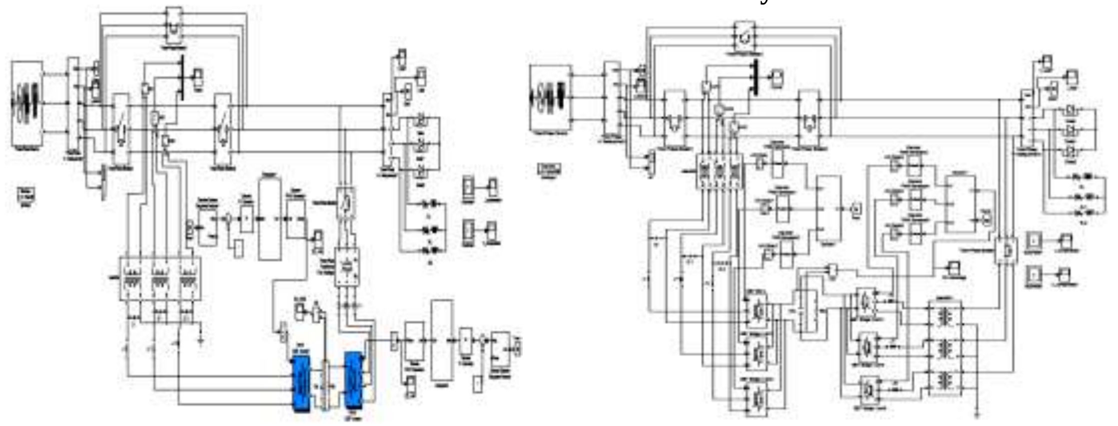


(a) (b)

Fig.9 Power circuit of UPQC for SRFC (a) Series Converter (b) Shunt converter

It contains full bridge converters connected to a common DC bus.The DC bus voltage is held by the capacitor C_{dc} .The function of dc capacitor C_{dc} is to produce a smooth dc voltage. The switches in the converter represent controllable semiconductors, such as insulated gate bipolar transistor (IGBT) or power transistors. The IGBTs are connected anti parallel with diodes for commutation purposes and charging of the DC capacitor. PWM generators are used to generate gating pulses for the IGBT switches of the VSC of the UPQC. IGBTs are used in this work because it is easy to control the switch on and off of their gates and suitable for the UPQC.

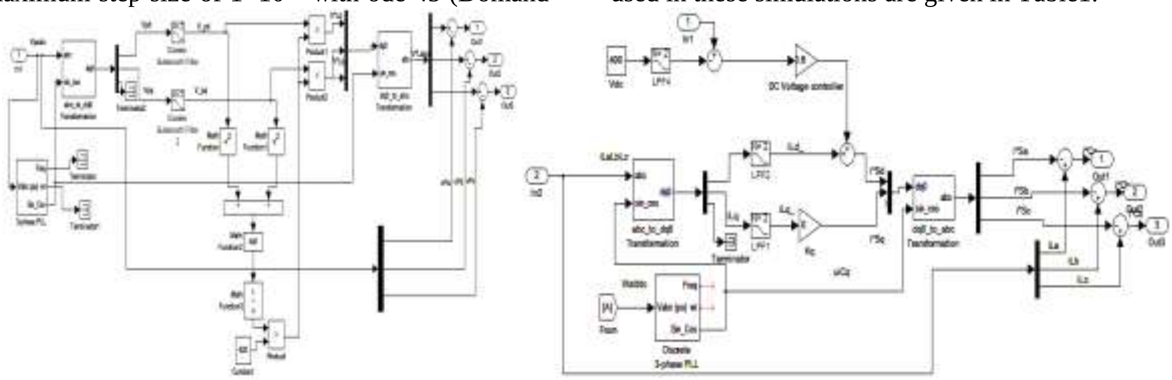
V. Simulation Results and Analysis



(a) (b)

Fig.10 Simulink model of UPQC with (a) Indirect PI and (b) Synchronous reference frame control

Fig.10 (a & b) show the basic simulation model of three-phase four-wire UPQC system that correlates to the system configuration shown in Fig. 7 in terms of source, load, UPQC and control block. The injection transformer in series with the load, coupling transformer inparallel to the load, the three-phase source, the series and shuntconnected voltage source converter are connected as shown in Fig.10 (a & b).The control algorithm based on synchronous reference frame (SRF) theory for the series APF and shunt APF of UPQC is also modeled in MATLAB as shown in Fig. 11(a & b) that have been implemented from block diagram representation of Fig. 5&6. Simulations are carried out in discrete mode at a maximum step size of 1×10^{-3} with ode 45 (Domand-Prince) solvers. The total simulation period is 1s. The main purpose of the simulation is to study two different performances of control aspects: 1) harmonic compensation and power factor correction by indirect PI control; 2) harmonic compensation and power factor correction by synchronous reference frame control. The total harmonic distortion (THD) of the source current and load voltage are measured under the condition of without UPQC and with UPQC by considering indirect PI and synchronous reference frame control strategies.The THD measurement is compared for without UPQC and with UPQC that is presented in Table 2 and Table 3 for both control strategies. The system parameters used in these simulations are given in Table1.



(a) (b)

Fig.11. SRF theory for (a) Series compensator control scheme (b) Shunt compensator control scheme

A. *Harmonic compensation and power factor correction by Indirect PI control*

The dynamic performance of the UPQC under a load of three phase half bridge diode rectifier in parallel with a Y connected unbalanced R - L impedances is shown in Fig. 12. The source currents (i_{Sa},i_{Sb},i_{Sc}), terminal voltages (V_{ta},V_{tb},V_{tc}) and dc voltage (V_{dc}) are depicted in Fig. 12 and Fig. 13 respectively. It is also observed that the waveforms of source currents (i_{Sa},i_{Sb},i_{Sc}) and terminal voltages (V_{ta},V_{tb},V_{tc}) are in same phase hence power factor correction (unity power factor) occurs when UPQC is connected with the distribution line. The dc link voltage $V_{dc\ is}$ in pulsating nature.

Figs 14 & 15 show the harmonic spectrum of source current and load voltage under the condition of without UPQC and with UPQC. The total harmonic distortion (THD) level in source current has been reduced from 19.73% without UPQC to 0.06 % with UPQC as shown in Fig. 14. The THD value of load voltage is also reduced from 17.71% without UPQC to 4.58% with UPQC which has been clearly depicted in Fig. 15. The FFT analysis of the UPQC confirms that total harmonic distortion (THD) of the source current and load voltage are less than 5% for the Indirect PI control strategy that are in compliance with IEEE-519 and IEC 61000-3 harmonic standards (Christopher and Ray 1989; Karuppanan and Mahapatra 2012).

B. Harmonic compensation and power factor correction by synchronous reference frame (SRF) control

The dynamic performance of UPQC in three phase four wire system for the compensation of harmonics and power factor correction by synchronous reference frame control have been explained. The waveforms of source currents (i_{Sa},i_{Sb},i_{Sc}), terminal voltages (V_{ta},V_{tb},V_{tc}) and dc voltage (V_{dc}) are presented to demonstrate the filtering performance of the UPQC. It is observed from Fig. 16 that the waveforms of source currents (i_{Sa},i_{Sb},i_{Sc}) and terminal voltages (V_{ta},V_{tb},V_{tc}) are in same phase hence power factor correction (unity power factor) occurs in the distribution system by UPQC. The DC link voltage V_{dc} starts gradually increasing and maintained a constant value of 9.8 V from t = 0.4 s onwards as shown in Fig. 17.

The total harmonic distortion (THD) level in source current and load voltage of three phase four wire system are measured under the situation of without UPQC and with UPQC. It is observed from Fig. 18 that total harmonic distortion (THD) level in source current has been reduced from 19.73% without UPQC to 0.05 % with UPQC. The THD value of load voltage is alsoreduced from 17.71% without UPQC to 1.49 % with UPQC which has been clearly depicted in Fig. 19.The FFT analysis of the UPQC confirms that total harmonic distortion (THD) of the source current and load voltage are less than 5% for the Synchronous Reference Frame control strategy that are in compliance with IEEE-519 and IEC 61000-3 harmonic standards.

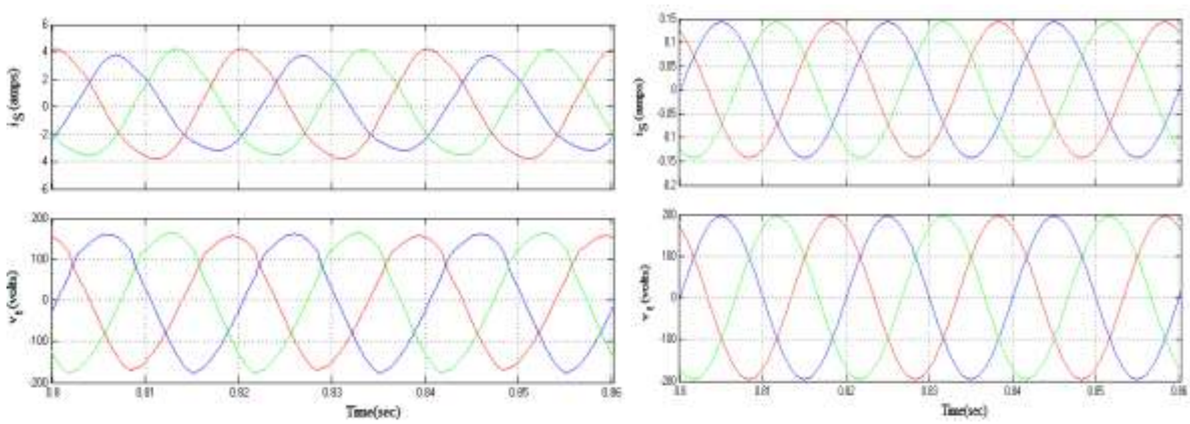
From Table 2 it is observed that when the UPQC is in operation with distribution system, the THD of source current is 0.06 % for the case of indirect PI control (IPIC), but in case of synchronous reference frame control (SRFC), THD of source current is 0.05%. Moreover in Table 3 also the THD of Load voltage is 4.58 % for the case of indirect PI control (IPIC), but in case of synchronous reference frame control (SRFC), THD of Load voltage is 1.49 %. Thus the synchronous reference frame control based UPQC gives lesser THD value as compared to indirect PI control based UPQC and hence proposed synchronous reference frame controller represents better performance in terms of harmonic mitigation in the source current as well as load voltage.

Table II:Measured THD of Source current under various Control strategies

Control strategy	Without UPQC (%)	With UPQC (%)
Indirect PI	19.73	0.06
Synchronous reference frame	19.73	0.05

Table III:Measured THD of Load voltage under various Control strategies

Control strategy	Without UPQC (%)	With UPQC (%)
Indirect PI	17.71	4.58
Synchronous reference frame	17.71	1.49



(a) (b)

Fig. 12. Power factor correction of distribution system in PI controller (a) without UPQC (b) with UPQC

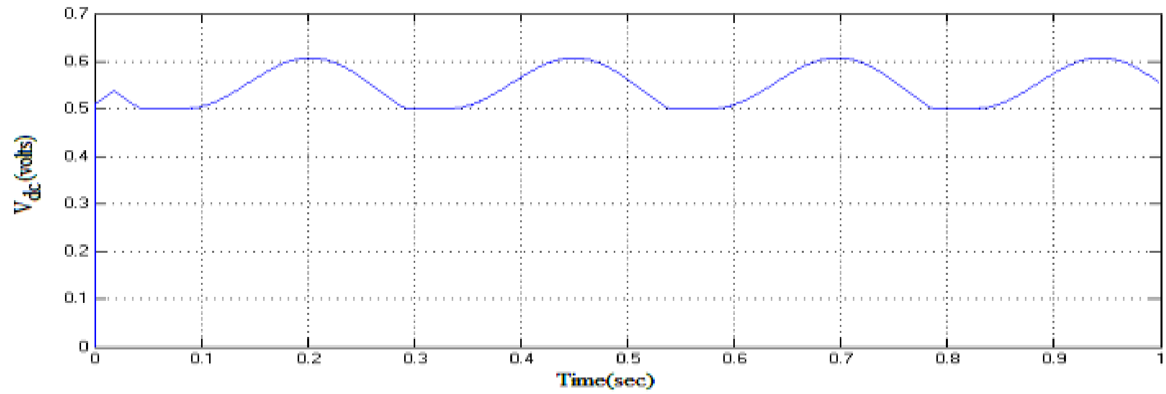
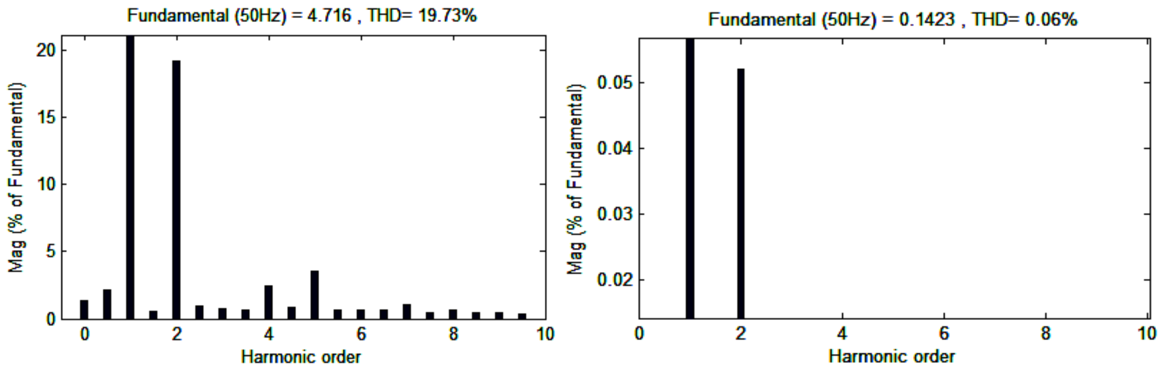
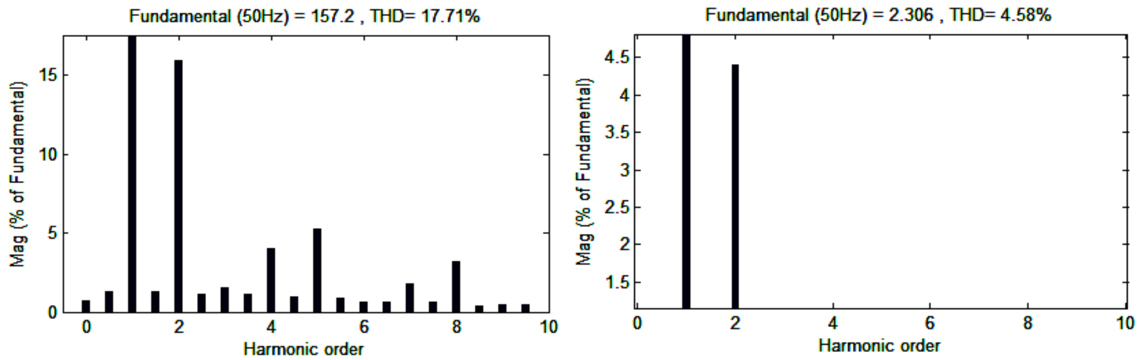


Fig. 13. DC link voltage



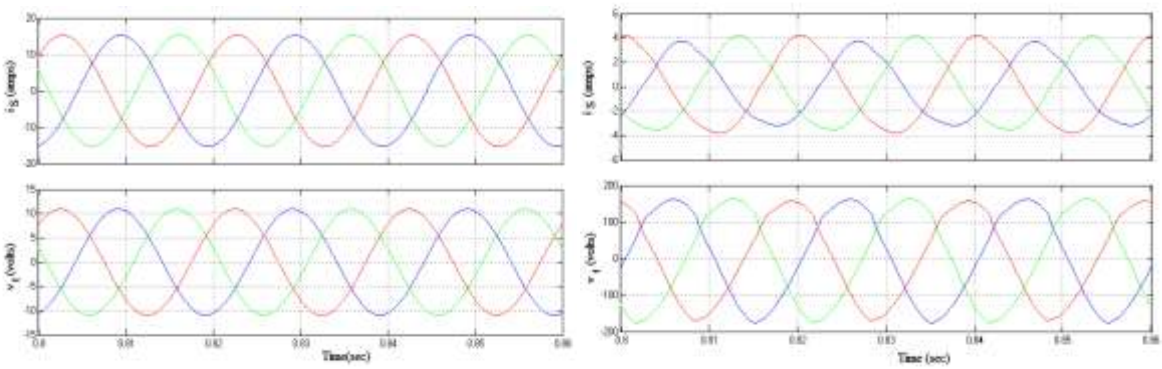
(a) (b)

Fig. 14 Spectrum of the source current in phase 1 for PI Control (a) Without UPQC (b) With UPQC



(a) (b)

Fig. 15 Spectrum of the load voltage in phase 1 for PI Control (a) Without UPQC (b) With UPQC



(a) (b)

Fig. 16. Power factor correction of distribution system in SRF controller (a) without UPQC (b) with UPQC

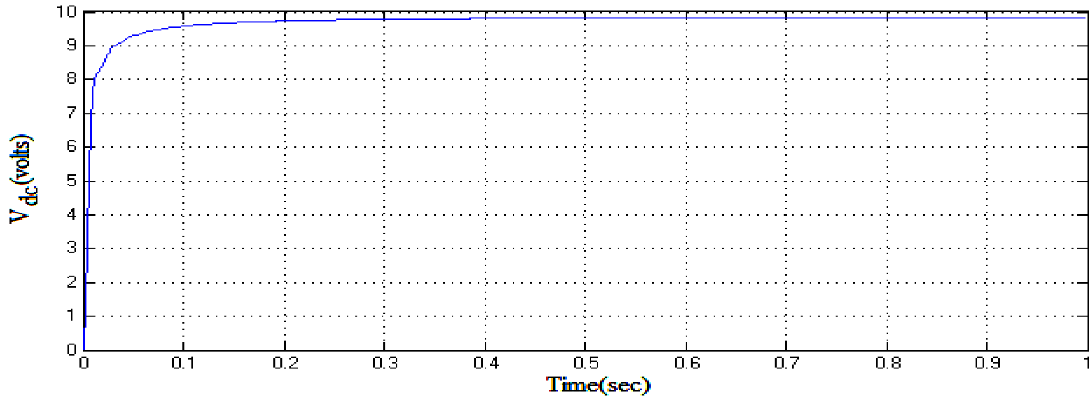
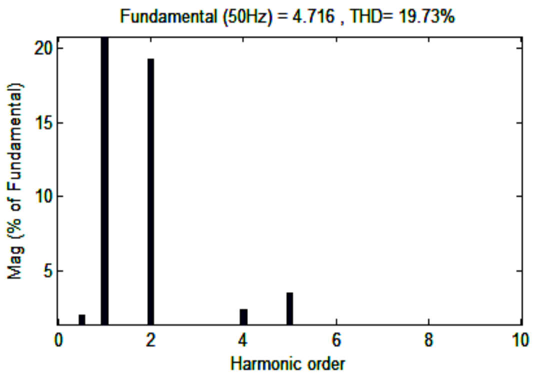
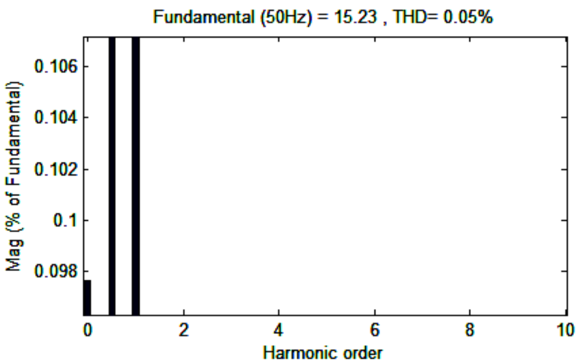


Fig. 17 DC link voltage

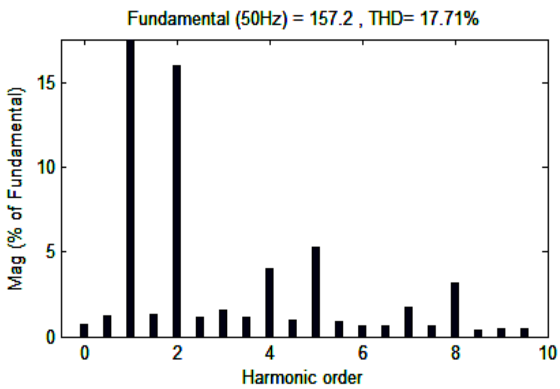


(a)

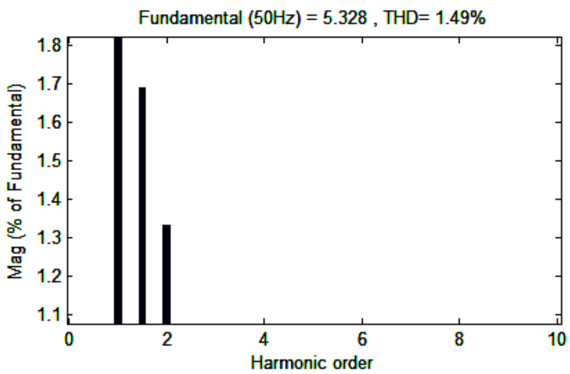


(b)

Fig.18 Spectrum of the source current in phase 1 for SRF Control (a) Without UPQC (b) With UPQC



(a)



(b)

Fig.19 Spectrum of the load voltage in phase 1 for SRF Control (a) Without UPQC (b) With UPQC

VI. Conclusion

The new three phase four wire topologies for distribution system utilizing unified power quality conditioner(UPQC) have been proposed in this paper. These proposed topologies would be very useful to compensate the different power quality problems. The modeling and simulation of UPQC integrated with three phase transformer have been carried out and the performances have been demonstrated for power factor correction and harmonic mitigation. The unified power quality conditioneris implemented with pulse width modulated controlled back to back connected voltage source converter. The converter switching patterns are generated from Indirect PI and synchronous reference frame controller. It has been observed that the system has a fast dynamic response and is able to keep the total harmonic distortion of the source current and load voltage below the limits specified by the IEEE 519 and IEC 61000-3 harmonic standards.

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