POWER QUALITY: PROBLEMS AND MITIGATION TECHNIQUE

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Abstract : This paper deals with the Power Quality of the system, their problems due to non-linear sensitive loads and improvement in power quality by using a FACTs device Unified Power Quality Conditioner(UPQC). The UPQC mentioned in this paper consists of thyristor controlled capacitors banks, back to back connected series and shunt active filter. In this paper Synchronous Reference Frame (SRF) control technique is used to mitigate the power quality problems by using UPQC. Hysteresis Current Controller is used for generation of switching pulses to series and shunt APF's. MATLAB/Simulink based simulation results are presented, which support the functionality of the UPQC.

Index Terms **- Power Quality, Unified Power Quality Conditioner (UPQC), Active power filters (APF), Synchronous Reference Frame (SRF)**

I. INTRODUCTION

The present power distribution system is usually configured as a three-phase three-wire or four-wire structure featuring a power-limit voltage source with significant source impedance and various types of loads. Ideally, the system should provide a balanced and pure sinusoidal three-phase voltage of constant magnitude to the loads; and the loads should ideally draw a current from the line with unity power factor, zero harmonics, and balanced phases [1]. However, this is becoming tedious day by day because of the increased applications of power electronics based appliances at domestic and industrial purposes. "These nonlinear burdens draw non-straight present and corrupt electric power quality. The quality debasement prompts low power factor, low proficiency, overheating of transformers et cetera. [2]. Apart from this, on a distribution side the net load is hardly found balanced. Because of increased applications of sophisticated and more advanced software and hardware for the control systems, the power quality has figured out the most important issue for power engineers.

With the help of FACTS device and custom power device we are capable to reduce the power quality problems. Among the custom power gadget UPQC is a successful gadget for tackling the power quality issues. The main function of UPQC is to mitigate the disturbance that affects the performance of load. [23]

In this paper, the problems associated with poor power quality, the performance of UPQC is investigated using synchronous-reference-frame (SRF) based control method under unbalanced and non-linear load conditions. In order to verify the working condition of UPQC, supply voltage is polluted with fifth order and seventh order harmonics. In the proposed control method, source voltage, source current, load voltage and load currents are measured. THD without and with UPQC is also evaluated under unbalanced and non-linear load conditions using MATLAB/Simulink software.

II. PROBLEMS OF POOR POWER QUALITY

Poor power quality in a framework could be because of various factors, for example, voltage list, voltage swells, voltage blackout and over amendment of energy factor and unsatisfactory levels of music in the current and voltage [3].

The issues related with poor power quality are as per the following:

1. VOLTAGE SAGS

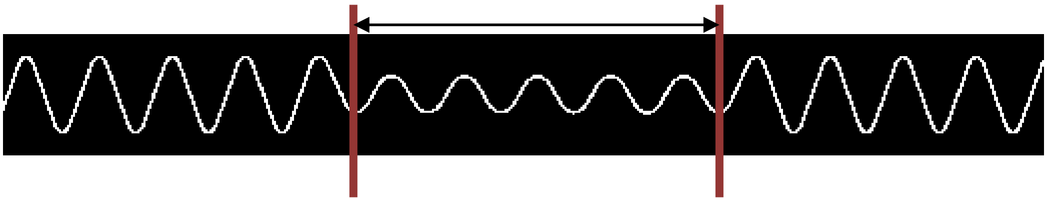

Fig. 1 Voltage Sag

Voltage sagss are the most widely recognized power issue experienced. Sags are a fleeting diminishment in voltage (that are 80-85% of ordinary voltage), and can make intrusions delicate gear, for example, flexible speed drives, transfers, and robots. Sags are frequently caused by wire or breaker task, engine beginning, or capacitor exchanging. Voltage sags ordinarily are non-dreary, or rehash just a couple of times due to recloser activity. Lists can happen on numerous stages or on a solitary stage and can be joined by voltage swells on different stages. [4,5]

2. POWER INTERRUPTION

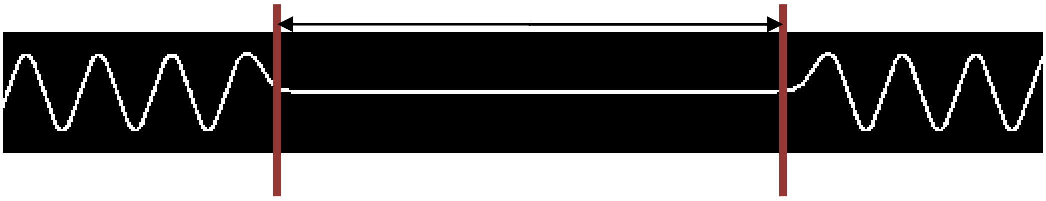

Fig. 2 Power Interruption

Power interruptions are zero-voltage events that can be caused by weather, equipment malfunction, recloser operations, or transmission outages. Interruptions can occur on one or more phases and are typically short duration events, the vast majority of power interruptions are less than 30 seconds. [4,5]

3. VOLTAGE FLICKER

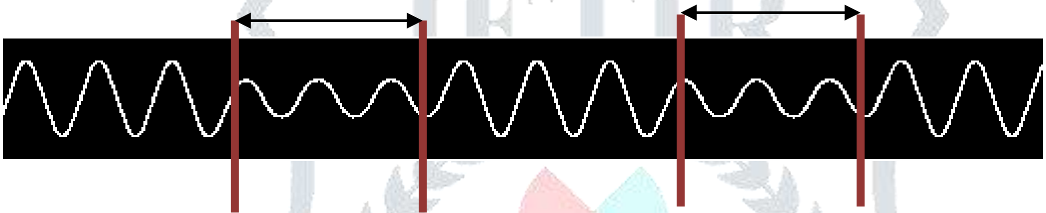

Fig. 3 Voltage Flicker

Voltage flicker is quickly happening voltage sags caused by sudden and huge increments in output current**.** Voltage gleam is most ordinarily caused by rapidly changing loads that require a lot of reactive power, for example, welders, rock crushers, sawmills, wood chippers, metal shredders, and entertainment rides. It can cause obvious glint in lights and make different procedures close down or glitch. **[4,5]**

4. POWER SURGES

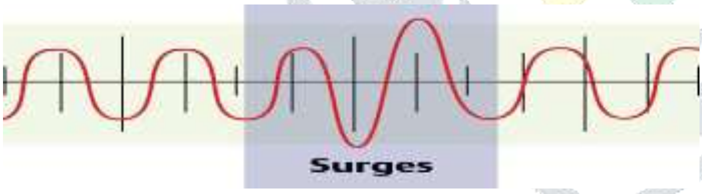

Fig. 4 Power Surges

A power surge takes place when the voltage is 110% or more above normal. The most widely recognized reason is substantial electrical appliance being switched off. Under these conditions, PC frameworks and other state-of-art devices can encounter gleaming lights, hardware shutoff, errors or data loss. **[4,5]**

5. HIGH-VOLTAGE SPIKES

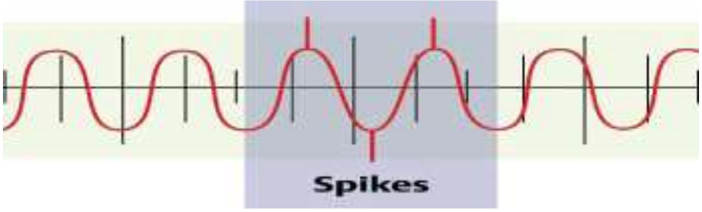

Fig. 5 High-Voltage Spikes

High-voltage spikes happen when there is a sudden voltage pinnacle of up to 6,000 volts. These spikes are normally the aftereffect of close-by lightning strikes, yet there can be different causes too. The effects on electronic systems can include loss of data and burned circuit boards. [4,5]

6. SWITCHING TRANSIENTS

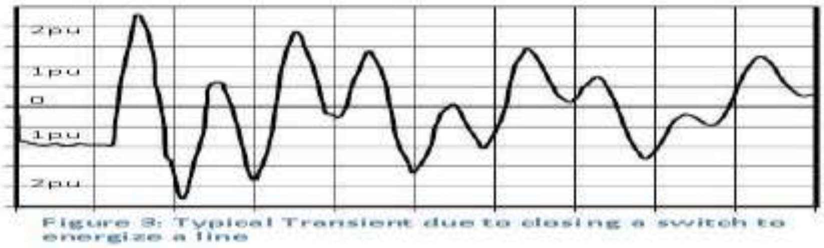

Fig. 6 Switching Transients

Switching transients happen when there is an amazingly quick voltage pinnacle of up to 20,000 volts with length of 10 microseconds to 100 microseconds. Switching transients take place in such a short duration that they often do not show up on normal electrical test equipment. They are normally caused by apparatus beginning and ceasing, arcing issues and static release In addition, switching disturbances initiated by utilities to correct line problems may happen several times a day. Effects can include data errors, memory loss and component stress that can lead to breakdown. [4,5]

7. FREQUENCY VARIATION

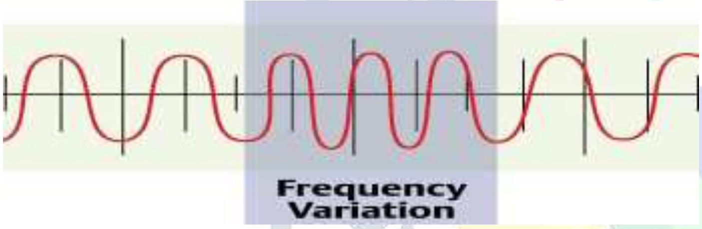

Fig. 7 Frequency Variation

A frequency variation includes an alteration in frequency from the ordinarily stable utility frequency of 50Hz. This might be caused by turbulent operation of emergency generators or unstable frequency power sources. For sensitive equipment, the results can be data loss, program failure, equipment lock-up or complete shutdown. [4,5]

8. ELECTRICAL LINE NOISE

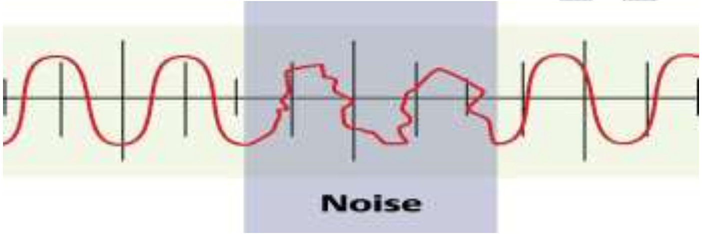

Fig. 8 Electrical Line Noise

Electrical line noise is characterized as Radio Frequency Interference (RFI) and Electromagnetic Interference (EMI) and causes undesirable impacts in the circuits of PC frameworks. Sources of the problems include motors, relays, motor control devices, broadcast transmissions, microwave radiation, and distant electrical storms. RFI, EMI and other frequency problems can cause equipment to lock-up, and data error or loss. [4,5]

9. BROWNOUTS

A brownout is a steady lower voltage state. An example of a brownout is what happens during peak electrical demand in the summer, when utilities can't always meet the requirements and must lower the voltage to limit maximum power. When this happens, systems can experience glitches, data loss and equipment failure. [4,5]

10. BLACKOUTS

A power failure or blackout is a zero-voltage condition that lasts for more than two cycles. It might be caused by shutting off of an electrical switch and utility power outage. A power outage can cause data loss or corruption and equipment damage. [4,5]

III. POWER QUALITY SOLUTION

In the past, passive filters were used to mitigate these identified power quality problems. Conventionally passive *L-C* filters were used to reduce harmonics and capacitors were employed to improve the power factor of the ac loads. However, passive filter have the limitations such as, fixed compensation, large size, resonance with the source impedance and the difficulty in tuning, time dependence of filter parameters. The increased severity of harmonic pollution in power networks has attracted the attention of power electronics and power system engineers to develop dynamic and adjustable solutions to the power quality problems. Such equipment, generally known as active filters (AF's) [6-13].

For the mitigation of different power quality problems faced by today's power distribution systems, a new technology called custom power (CP) emerged [14]. The CP devices are applicable to distribution systems for enhancing the reliability and quality of the power supply. The compensating type custom power devices mainly covers the shunt connected device (called DSTATCOM [15]), series connected device (called DVR [16]) and combination of series and shunt connected device (called UPQC [17-19]) . Generally, the DSTATCOM takes care of the current based distortions, while DVR is used for the mitigation of voltage based distortions.

The Unified Power Quality Conditioner (UPQC) is one of the key CP gadget, which remunerate both current and voltage related issues, at the same time. As the UPQC is a combination of back to back connected series and shunt APFs to a common DC link voltage, two APFs have different functions. The series APF vanquishes and isolates voltage-based distortions, while the shunt APF neutralizes current-based distortions. At the same time, it improves the power factor by compensating reactive component load current [20].

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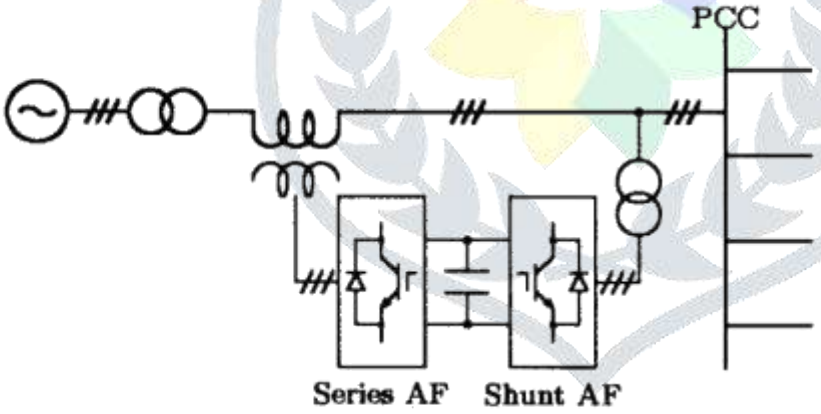

Fig. 9 General Configuration of UPQC

Fig. 9 demonstrates a fundamental system design of a general UPQC comprising of the mix of an arrangement of a series-active and shunt-active filter [21]. The general UPQC will be installed at substations by electric power utilities in the near future. The main purpose of the series-active filter is harmonic isolation between a subtransmission system and a distribution system. In addition, the series-active filter has the capability of voltage-flicker/imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC). The main objective of the shunt-active power filter is to absorb current harmonics, compensate for reactive power and negative-sequence current, and regulate the dc-link voltage between both active filters. In this paper, the integration of the series-active and shunt-active filters is called the UPQC, associated with the unified power flow controller which has been proposed by Gyugyi [22].

IV. CONTROL STRATEGY OF UPQC

The suggested control tactics intended the generation of reference signals for both shunt and series APFs of UPQC. In this segment an advent based on synchronous reference frame (SRF) theory is used to obtain reference signals for series and shunt APFs. The pedestrian SRF hypothesis, additionally called as d-q procedure, and it is engaged around a-b-c to d-q-0 transformation (park transformation).

A. CONTROL SCHEME FOR SERIES APFs

The control strategy for series APF using SRF theory is shown in the fig. 10

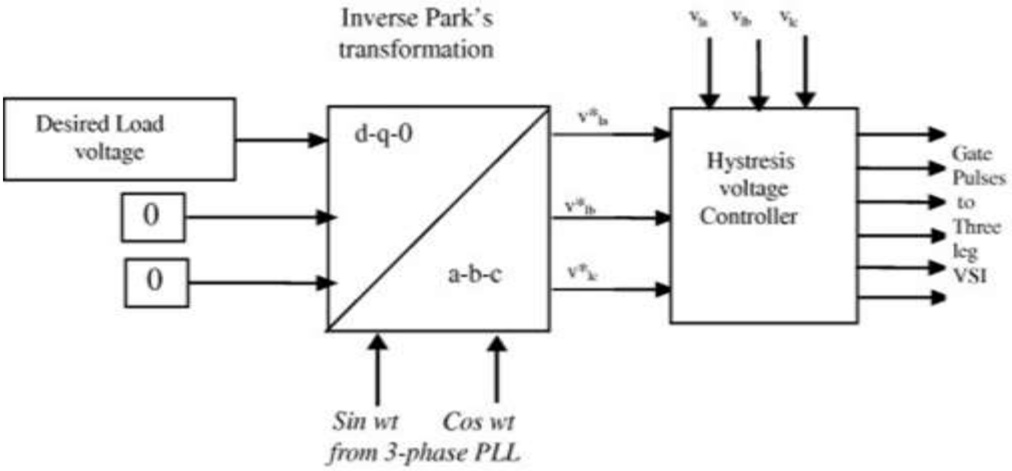

Fig. 10 Control Scheme of Series APF using SRF Theory

In series compensation, the supply voltage is distorted and is transformed to d-q-0 coordinates using phase locked loop (PLL) in accordance with equation (1)

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(wt) & \cos(wt-120^\circ) & \cos(wt+120^\circ) \\ -\sin(wt) & -\sin(wt-120^\circ) & -\sin(wt+120^\circ) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{1}$$

A phase locked loop (PLL) is used to achieve synchronization with the supply voltage [24]. The transformed coordinates (Vd and Vq) are oscillatory in nature, can be easily eliminated using low pass filters in d-q-0 coordinates; results averaged output waveforms which are stable in nature. In this controller the reference voltages have been generated considering and utilizing only active component and reactive, zero components are set to zero so as to compensate the load voltage harmonics [25]. Now these d-q-0 coordinates again transferred back to a-b-c coordinates by using equation (2) which now give a waveform without the harmonic components and set as reference voltages for the series inverter to generate pulses according to the situation to compensate the distortion in the voltage.

$$\begin{bmatrix} V_{a\_ref} \\ V_{b\_ref} \\ V_{c\_ref} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \sin wt & \cos wt \\ \frac{1}{\sqrt{2}} & \sin(wt-120^\circ) & \cos(wt-120^\circ) \\ \frac{1}{\sqrt{2}} & \sin(wt+120^\circ) & \cos(wt+120^\circ) \end{bmatrix} \begin{bmatrix} V_0 \\ V_d \\ V_q \end{bmatrix} \tag{2}$$

The generated reference voltages and actual load voltages are compared in the Hysteresis Current Controller to produce accurate switching signals which compensate voltage harmonics.

B. CONTROL SCHEME FOR SHUNT APFs

The control scheme to get the reference source (i_a^*, i_b^*, i_c^*) using SRF theory is shown in the fig. 11

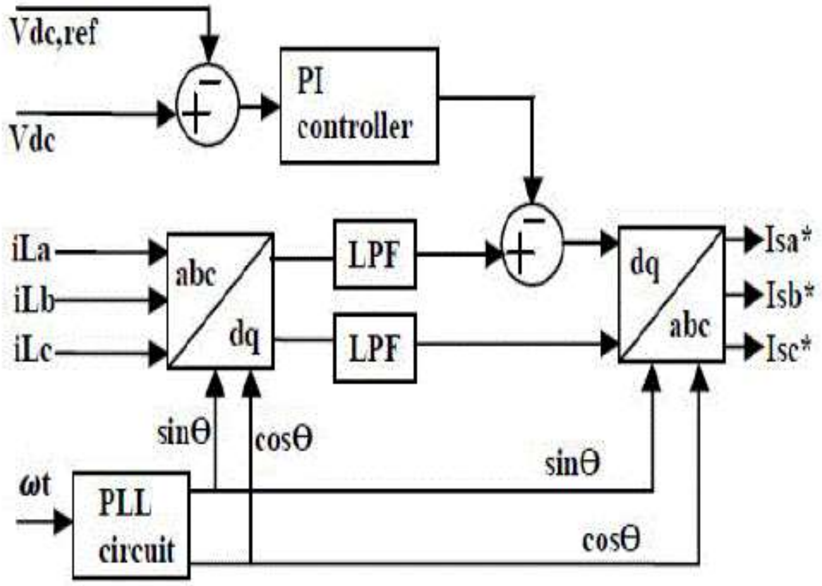

Fig. 11 Control Scheme of Shunt APF using SRF Theory

The Shunt APF is used to compensate the current harmonics produced due to non-linear loads. With the help of the unit vectors (sin wt, cos wt) the load currents (a-b-c coordinates) are transformed into d-q-0 coordinates, using Park's transformation as per the equation no. (3)

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(wt) & \cos(wt-120^\circ) & \cos(wt+120^\circ) \\ -\sin(wt) & -\sin(wt-120^\circ) & -\sin(wt+120^\circ) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{3}$$

In unbalanced three phase system and nonlinear load conditions, the instantaneous source currents incorporate both oscillating components and average components. Subsequent to figuring the d-q-0 part of the load current, the'd' component is gone through a low pass filter to separate dc part of load current. A SRF controller extracts dc quantities by a low pass filter and hence non-dc quantities (harmonics) are separated from the reference signal. In SRF control strategy, the zero and negative sequence components of the source current references (I*0 and I*q) in the 0-axes and q-axes are set to zero in order to compensate the harmonics, unbalance and distortion in the source current. The source current references are calculated as given in equation (4)

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \sin(wt) & \cos(wt) \\ \frac{1}{\sqrt{2}} & \sin(wt-120^\circ) & \cos(wt-120^\circ) \\ \frac{1}{\sqrt{2}} & \sin(wt+120^\circ) & \cos(wt+120^\circ) \end{bmatrix} \begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} \tag{4}$$

In this suggested control algorithm, the detected ($i_{a,} i_b, i_c$) and reference source currents (i_a^*, i_b^*, i_c^*) are contrasted in a hysteresis current controller with to originate the switching signals to the switches of the shunt APF which makes the supply currents sinusoidal, balanced in- phase with the voltage at PCC. Hence the supply current contains no harmonics or reactive power component.

V. SIMULATION RESULTS

The proposed control procedure has been simulated using MATLAB/Simulink and its Sim-Power System toolkit. The execution of UPQC is assessed in terms of voltage and current harmonics mitigation. The parameters used for the simulation model are shown in appendix.

The waveform of source voltage, with a range before and after compensation is shown in three sub figures of figure 12. Second waveform is steady state response of source voltage after time t = .015s and third fig shows the distorted waveform before t = 0.15s.

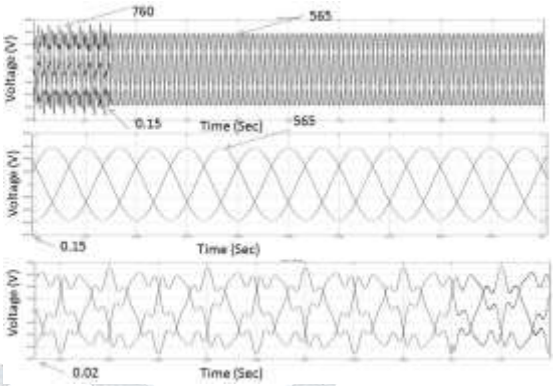

Fig.12 Source voltage waveform

Source current waveform, which shows the complete behavior of source current before and after compensation is shown in figure. 13

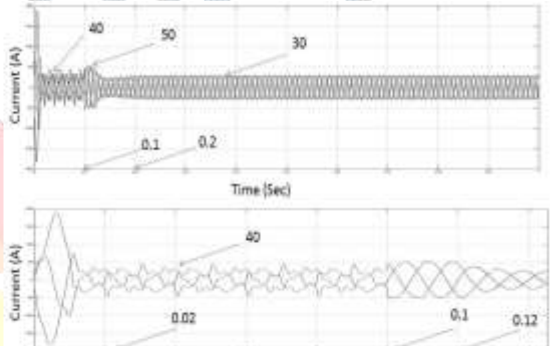

Fig. 13 Source current waveform

Load current waveform, which shows the complete waveform of load current before and after compensation is shown in figure 14.

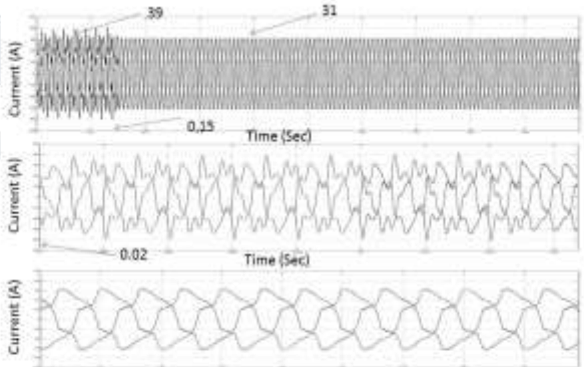

Fig. 14 Load current waveform

The variation of DC link capacitor voltage, which shows that capacitor start charging at the instant of 0.1 sec when shunt APF starts working and settled to 700 V which is reference dc voltage is shown in figure 15.

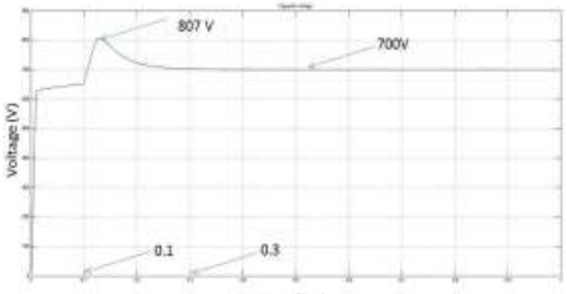

Fig. 15 DC link capacitor voltage

The variation of current injected by the shunt APF is shown in figure 16.

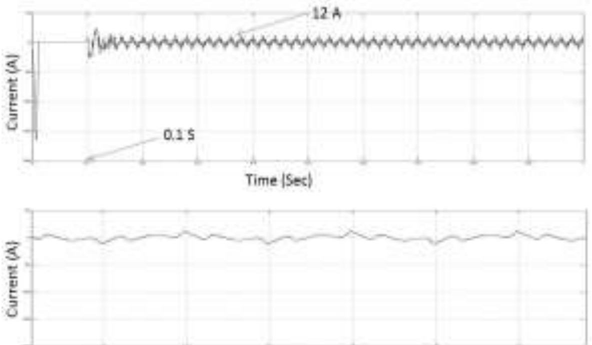

Fig. 16 Injected current

Figure. 17 shows the voltage and current waveforms of full wave rectifier fed R-L load. The full wave rectifier is used to create the effect of non-linear load.

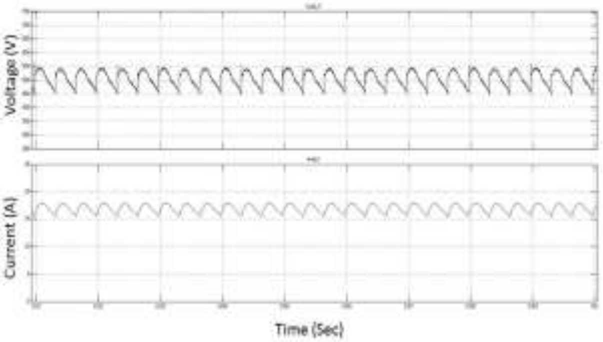

Fig.17 Rectified voltage and current waveform of non-linear load

The series voltage injected by series APF to compensate the change in supply voltage due to the nonlinear load is shown in figure 18.

Fig.18 Series voltage injected by series APF through series transformer

The FFT analysis of the source current, source voltage, without and with compensations working with nonlinear load are shown in figure 19, figure 20, figure 21 and figure 22 respectively, to get the total harmonic distortion and Figure 23 shows the THD (total harmonic distortion) analysis or FFT for load current waveform.

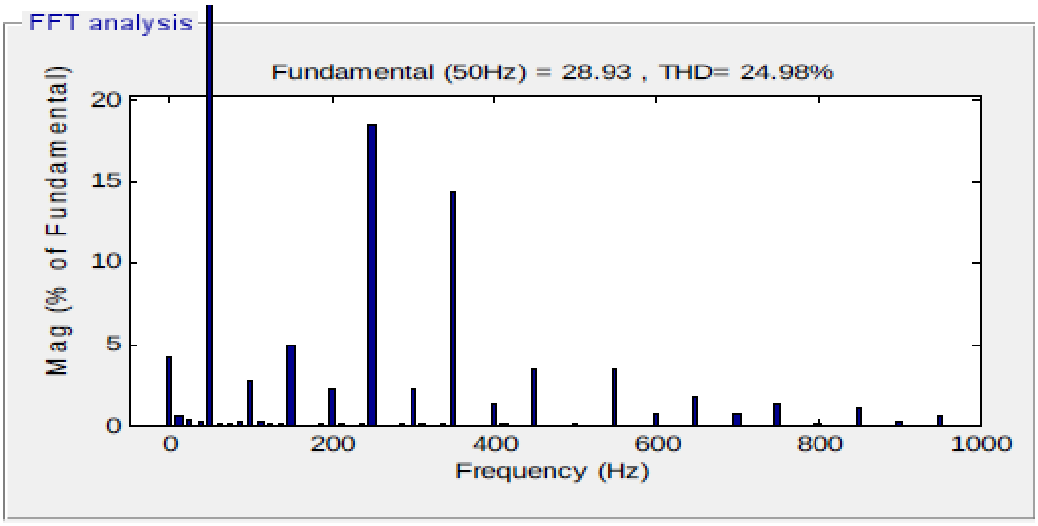

Fig. 19 FFT analysis of source current without compensation

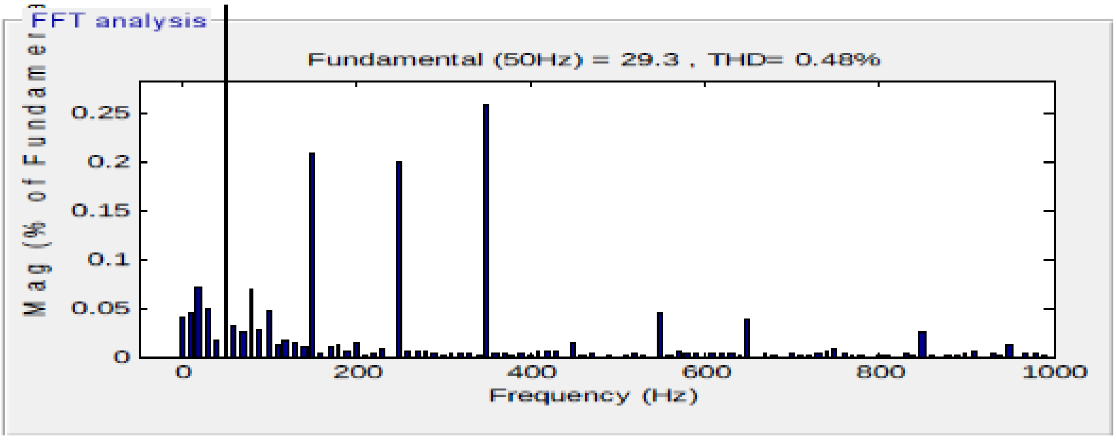

Fig. 20 FFT analysis of source current with compensation

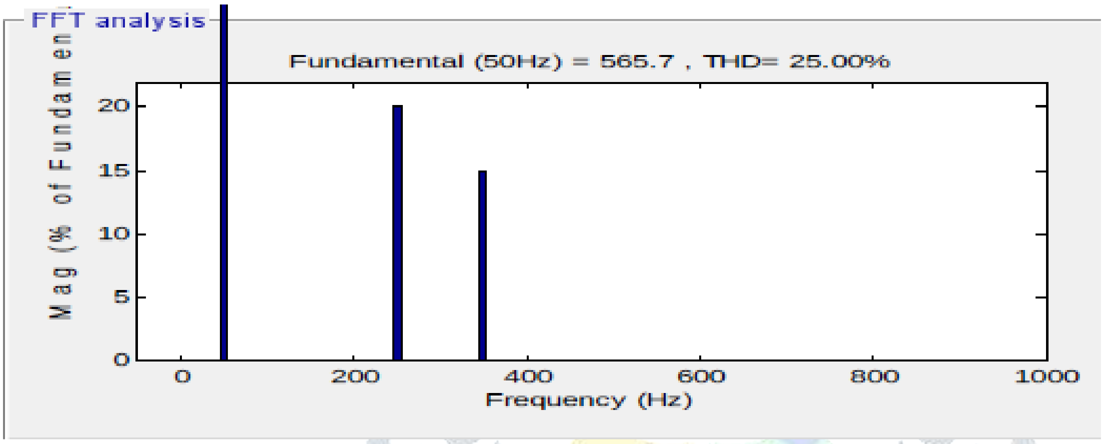

Fig. 21 FFT analysis of source voltage waveform without compensation

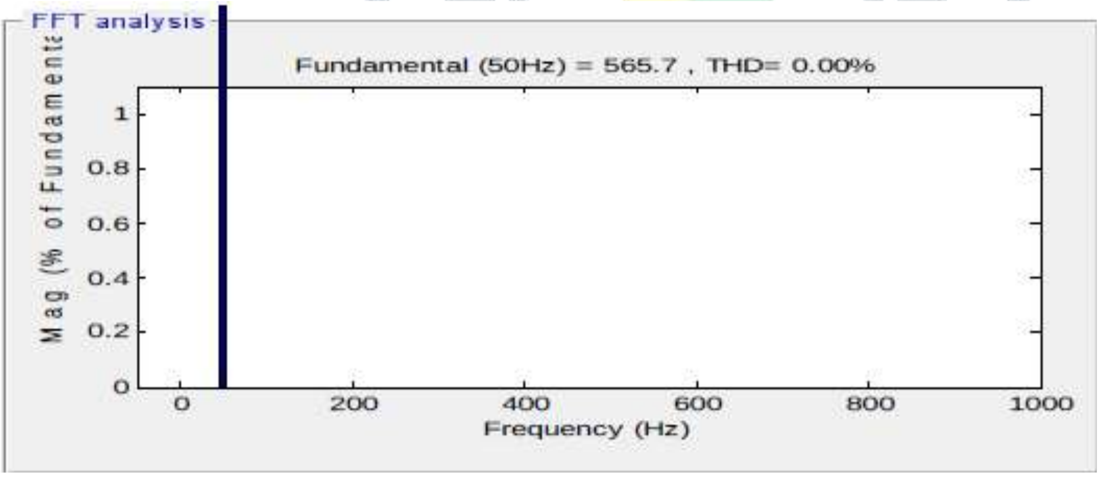

Fig. 22 FFT analysis of source voltage waveform with compensation

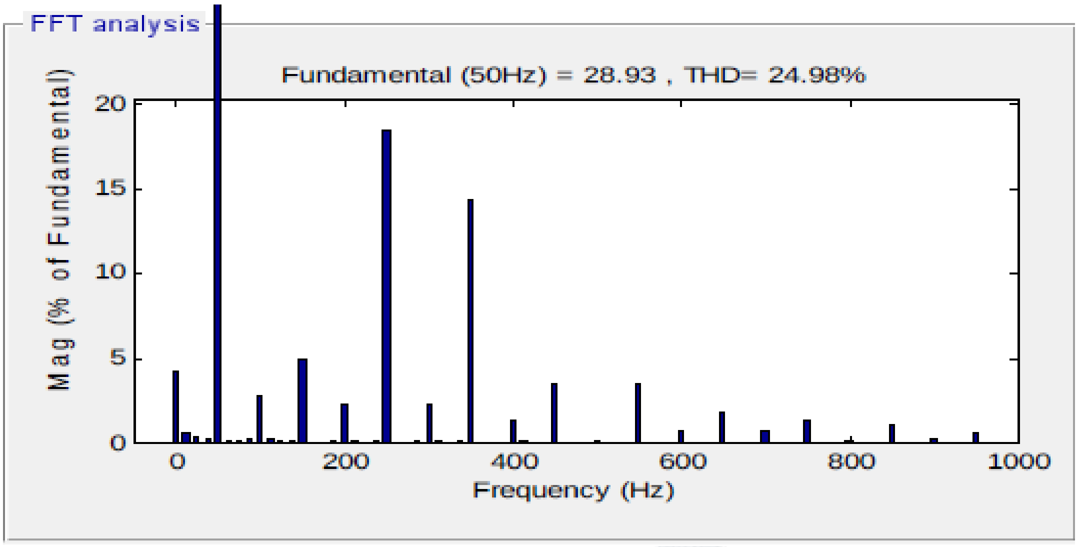

Fig. 23 FFT analysis of load current waveform

VI. CONCLUSION

A MATLAB based model of the UPQC has been simulated for RL and DC machine load using the hysteresis control technique. The simulation results show that the input voltage harmonics and the current harmonics caused by non-linear load are compensated very effectively by using the UPQC.

VII.FUTURE SCOPE

In this paper the hysteresis control technique has been used. There are several other techniques like Pulse Width Modulation (PWM) which can improve the performances of these active power filters. Artificial Intelligence techniques are developing for implementation of control techniques in power electronics. Fuzzy logic controller can be used to control the dc link capacitor voltage for compensation. Another AI technique which is gaining more popularity now-a-days in power electronics field is Artificial Neural Networks. In hardware modules the embedded controllers can be used to improve the performance of these filters. Also, DSP/DSpace techniques can be used to further improve the performance of active power filters. In series filters the low pass interfacing circuits can be used in place of series transformers which reduce the THD further.

VIII. APPENDIX

S. NO.	The values of the different parameters used for shunt active power filter
1	Source Voltage: 3phase, 100V, 50 Hz
2	Proportional gain Kp: 0.5
3	Integral gain Ki: 10
4	Capacitor reference voltage: 300V
5	RL load parameters: 10Ω, 100mH
6	DC machine load: 240V field voltage, Rf = 240Ω, Ra = 0.5Ω
7	Line parameters: 0.2Ω, 1.5mH
8	Filter Inductor: 5Mh
9	Hysteresis band gap: -0.01 to 0.01

S.NO.	The values of the different parameters used for series active power filter
1	Source Voltage: 3phase, 100V, 50 Hz
2	Harmonics in the supply voltage: 5th, 0.2pu and 7th, 0.15pu.
3	Series transformer rating: 1kV, 50Hz, 240/24V
4	RL load parameters: 10Ω, 100mH
5	DC machine load: 240V field voltage, Rf = 240Ω, Ra = 0.5Ω
6	Line parameters: 0.2Ω, 1.5mH
7	RC filter parameters : 16 Ω, 199.04μF
8	Hysteresis band gap : -0.01 to 0.01
S. NO.	**The values of the different parameters used for UPQC**
1	Source voltage: 3-phase, 100V, 50Hz.

2	Harmonics in the supply voltage: 5th, 0.2pu and 7th, 0.15pu.
3	Proportional gain Kp: 0.5
4	Integral gain Ki : 10
5	Capacitor reference voltage: 300V
6	Series transformer rating: 1kV, 50Hz, 240/24V
7	RL load parameters = 10 Ω, 100mH
8	DC machine load: 240V field voltage, Rf =240 Ω, Ra = 0.5 Ω, 50Hz.
9	Line parameters : 0.2 Ω, 1.5mH
10	RC filter parameters : 16 Ω, 199.04μF
11	Hysteresis band gap : -0.01 to 0.01

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