Implementation of UPQC to Mitigate Voltage Sag, Swell and Harmonics in Distribution System

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Abstract

In a powers system network, there are many problems related to power quality. So, to improve power quality of a system we use different power filters. One of the most popular filters is active power filter (APF). APF may be Shunt Active Power Filter (Shunt APF), Series Active Power Filter (Series APF) or combination of both, which is known as UPQC (Unified Power Quality Conditioner). Here we have done MATLAB simulation of Unified Power Quality Conditioner as it incorporates the benefits of both series APF and shunt APF. Shunt APF is used to mitigate the problems due to current harmonics which is because of non-linear load and make source current sinusoidal and distortion free. The control scheme used is hysteresis current controller using d-q transformation. Series APF is used to mitigate problems caused due to voltage distortion and unbalance present in source voltage and make load voltage perfectly balanced and regulated. The control scheme used is Hysteresis voltage controller by using a-b-c to d-q transformations. Then Shunt APF and Series APF is combined for designing UPQC and by this current harmonic in load current and voltage unbalances in source voltage both are removed and sinusoidal source current and balanced load voltage is achieved.

Keywords: Hysteresis voltage controller; Shunt APF; Series APF; MATLAB; UPQC

1. Introduction

Today in this modern world power quality has become a great issue. For industries and domestics use we need voltage and current free from all types of harmonics and unbalances. For mitigation of different issues in power quality, there are development of different methods to improve power quality, majorly by using APF [1]. The APF are used to remove harmonics from current of load side and make supply current completely sinusoidal, and it also mitigate the problems of supply voltage imbalance i.e voltage rise/dip and make voltages at load side balanced of equal magnitude[2]. The APF can be combined together and made to remove both problems due to voltage and current harmonics. There are wide range of controlling techniques for APF [3].

In [4] three phase simulation of series APF is done for removal of voltage unbalances in supply side and make load voltage balanced and regulated.

In [5] the operation of three phase four wire shunt APF is explained which is used to suppress load current harmonics which is due to non-linear loads. As the power quality is the most important factor so to get improved power quality and removal of all type of harmonics from voltage and current we study UPQC which is a very versatile device and can be used for both mitigate the problems due to current harmonics and voltage disturbances [6]. The voltage source inverter active filters are used for removal of power quality problems. The shunt APF is used to remove all the problems related to current harmonics and reactive power compensation so that the power quality will improve.

APF are used for power quality enhancement. APF can be classified according to system configuration. APF are of two types: series and shunt. Combining both series APF & shunt APF we get a device known as UPQC. UPQC eliminates the voltage and current based distortions together. A Shunt APF eliminates all kind of current problems like current harmonic compensation, reactive power compensation, power factor enhancement. A Series APF compensates voltage dip/rise so that voltage at load side is perfectly regulated. The Shunt APF is connected in parallel with transmission line and series APF is connected in series with transmission line. UPQC is

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formed by combining both series APF and shunt APF connected back to back on DC side.

2. UPQC concept

UPQC is connected between utility side with non-sinusoidal voltage and non-linear load. It mainly consists of series APF and shunt APF [2]. Series APF is comprised of series transformer, dc voltage regulator and hysteresis voltage controller. Series APF injects a compensating voltage so that load voltage will be perfectly balanced and regulated. Shunt APF is comprised of dc capacitor, voltage source inverter, Hysteresis Current Controller. The two voltage source inverter are connected back to back through a DC capacitor. DC capacitor is provides a DC voltage for working of both the inverter.

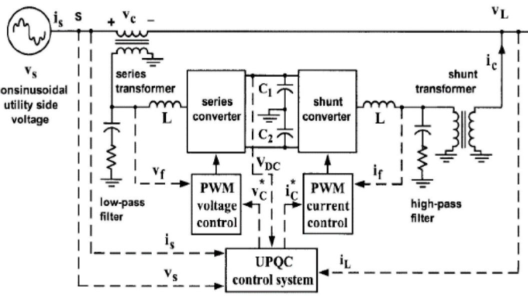

Figure 1: Basic Configuration of UPQC [5]

During normal operations when UPQC is disconnected from supply the reactive power is completely supplied from the main source [6]. But when UPQC is joined with the system than the reactive power is supplied with the Shunt APF. Shunt APF provides reactive power to the load and there is no burden on main supply. Series APF has no relation with reactive power demand of load.

In Voltage dip (sag) condition current will be higher than normal current. In this required power is taken from source at increased current so that power will be balanced in the network and DC capacitor value should be at desired level. Here series injected power will be positive. From source to Shunt APF the real power flows, first real power flow from source to shunt APF and then from shunt APF to series APF through DC link capacitor and from Series APF to load. So load will get desired power during voltage sag condition. In this case the real power absorbed by shunt APF from source is equal to real power supplied by series APF to load.

During voltage rise (swell) condition, series APF absorbs more power from source. As source voltage is increased DC link capacitor voltage increases. Shunt APF lessen the current from supply so that the DC link voltage remains constant. UPQC gives extra amount of power to system.

2.1 Control of Series APF

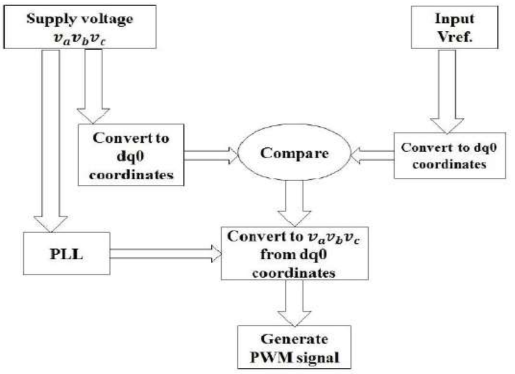

Figure 2: Flowchart of series APF control [6]

Control of shunt APF is done relying on dq0 transformation. The steps for controlling series APF are generation of reference compensating voltage and then comparing reference compensating voltage with actual compensating voltage in hysteresis voltage controller and generating Pulse Width Modulation (PWM) signal for voltage source inverter. The generation of pwm signal is shown in figure 2.

The dqo transformation to abc transformation are given below:

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} sin(wt) & sin(wt-\frac{2\pi}{3}) & sin(wt+\frac{2\pi}{3}) \\ cos(wt) & cos(wt-\frac{2\pi}{3}) & cos(wt+\frac{2\pi}{3}) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{1}$$

Inverse Park's transform i.e from abc to dqo transform

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \begin{bmatrix} sin(wt) & cos(wt) & 1 \\ sin(wt-\frac{2\pi}{3}) & cos(wt-\frac{2\pi}{3}) & 1 \\ sin(wt+\frac{2\pi}{3}) & cos(wt+\frac{2\pi}{3}) & 1 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2}$$

If the system voltages are unbalanced the park transform results in:

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} V_{sp}\,cos(\emptyset_p) \\ V_{sp}\,sin(\emptyset_p) \\ 0 \end{bmatrix} + \begin{bmatrix} V_{sn}cos(2wt + \emptyset_n \\ -V_{sn}sin(2wt + \emptyset_n \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ V_{sn}cos(2wt + \emptyset_n \end{bmatrix}$$

$$= \begin{bmatrix} V_{dp} \\ V_{qp} \\ 0 \end{bmatrix} + \begin{bmatrix} V_{dn} \\ V_{qn} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ V_{00} \end{bmatrix} \qquad (3)$$

where $\emptyset_p$ is the phase difference between the positive sequence component of reference voltage, the fundamental positive sequence component of voltage is represented by dc terms.

2.2 Control of Shunt APF

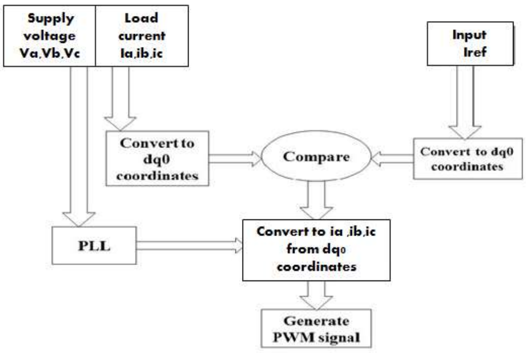

Figure 3. Flowchart of shunt APF control [6]

Control of shunt APF is done relying on dq0 transformation. The steps for controlling series APF are generation of reference compensating current and comparing reference compensating current with actual compensating current in hysteresis voltage controller and generating PWM signal for voltage source inverter.

Similar transformations as applied to voltage can be applied to current when the unbalance of source is present.

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \begin{bmatrix} I_{dp} \\ I_{qp} \\ 0 \end{bmatrix} + \begin{bmatrix} I_{dn} \\ I_{qn} \\ 0 \end{bmatrix} \qquad (4)$$

3. Digital simulation of UPQC

An UPQC in a distribution power system with non-linear load is the model described in this article. The UPQC is composed series and shunt APF. The series transformer is modeled with linear transformer with unit turns ratio to inject suitable voltage in the system. Control of series and shunt APF is done by generating pulse using hysteresis controller. For series APF reference voltage is generated using dq0 transformation of supply voltage and comparing it with compensated voltage. For shunt APF reference current is generated by dq0 transformation of load current. Then it is compared with compensated current and current hysteresis controller is used to generate gate pulse.

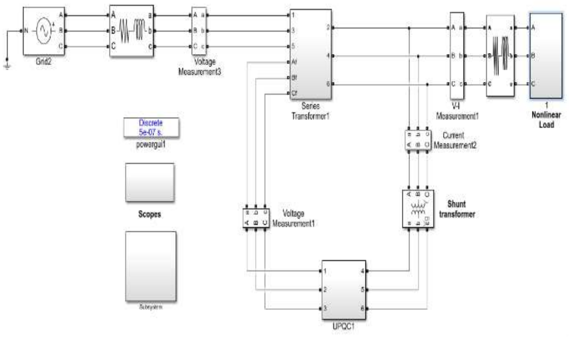

Figure 4: UPQC model in matlab

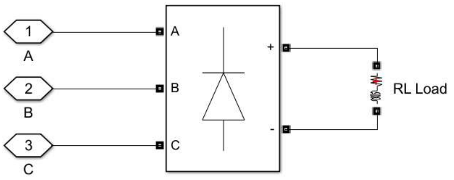

Figure 5: Three phase diode rectifier

The load is non-linear which introduces harmonics in the supply current.

The parameters of source, load, dc link, series APF, shunt APF for system modelling is shown in table 1.

Table 1: Parameters used for modeling

	Parameters	Value
Source	Voltage	380Vrms
	Frequency	50HZ
Line	3-phase AC line resistance	0.4 Ω
	3-phase AC line inductance	15e-3 H
Load	1-phase DC resistance	60 Ω
	1-phase DC inductance	0.15e-3 H
Dc-link	Voltage(dc)	700V
Series APF	Three Series transformer(S)	5.4 KVA
	Filter resistance	5Ω

	Filter Capacitor	25e-6
Shunt APF	Filter resistor	5 Ω
	Filter Capacitor	0.5e-6 F

3.1 Series APF

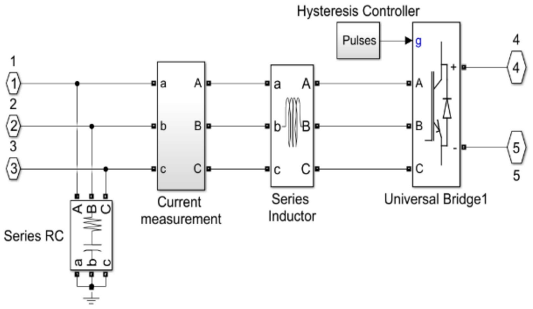

Figure 6: Series APF

Here control series APF is based on Park's transformation or $dq0$ transformation. Here we compared the reference voltage with actual output voltage of series APF. The supply voltage is first converted into $dq0$ coordinates form abc phases. Then this output voltage is compared with input reference voltage which is first converted into $dq0$ coordinates.

After comparing this two voltages they are again transformed from $dq0$ coordinates to abc phases. The wt required in converting $dq0$ to abc coordinates or vice versa we get from PLL (phase locked loop). After this the supply voltage is given to PLL and wt is generated.

Then this wt along with $dq0$ output voltages are transformed into abc phases which is the reference output voltage. Then this reference output voltage (vc*) is compared with sensed series APF output voltage (vc) in hysteresis voltage controller and PWM signal is generated which is given to VSI. The PLL is a control system that will generate an output signal whose phase is related to phase of an input signal. The load bus voltage should be maintained sinusoidal with constant amplitude even if the source voltage is distorted. Therefore, from equation (3) the expected load voltage in dq0 domain will only consist of one value:

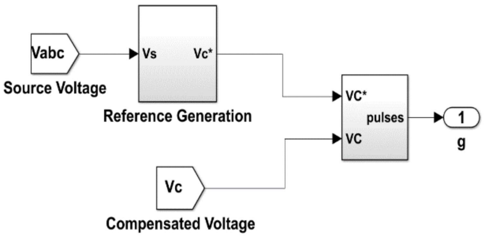

Figure 7: Pulse generation masked model

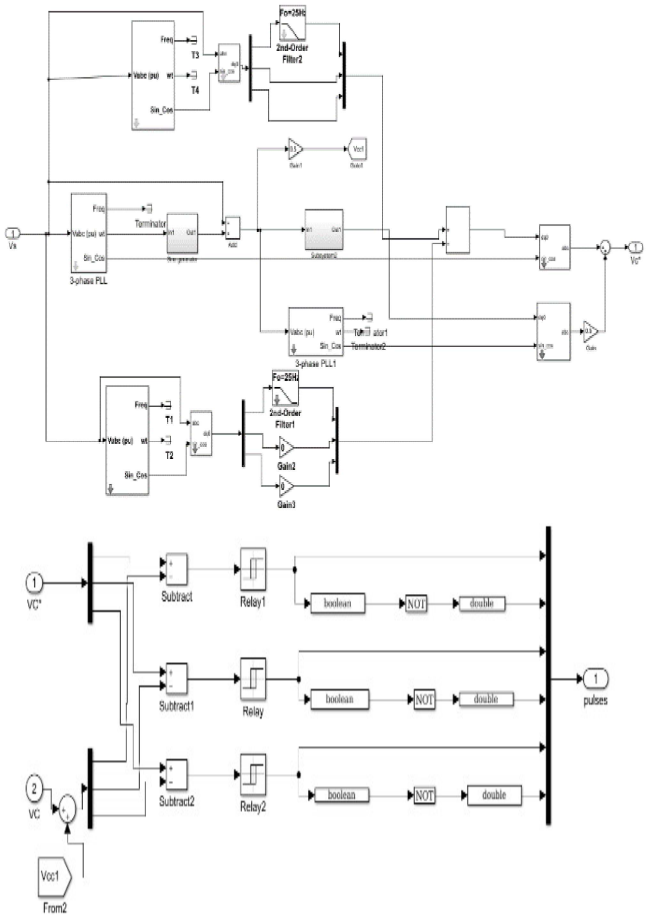

Figure 8: Pulse generation detail model

$$V_{abc}^{expected} = \begin{bmatrix} V_{dp} \\ V_{qp} \\ V_{0p} \end{bmatrix} = \begin{bmatrix} V_m \\ 0 \\ 0 \end{bmatrix} \tag{5}$$

where,

$$V_{abc}^{expected} = \begin{bmatrix} V_s\cos(wt) \\ V_s\cos(wt+120) \\ V_s\cos(wt-120) \end{bmatrix}$$ are sinusoids and compensation reference voltage is:

$$V_{dq0}^{ref} = V_{dq0}^{expected} - V_{sdq0} \tag{6}$$

where V_{dq0}^{ref} is the distorted source voltage in the dq0 frame. Therefore, V_{dp} should be maintained at V_m and all other terms must be eliminated by compensation voltage.

The compensated reference voltage is then inversely transformed into the abc reference frame. Comparing the compensation reference voltage with a actual compensating voltage in a hysteresis voltage controller, the output of the series converter is obtained by a PWM voltage control unit.

3.2 Shunt APF

The control pattern of shunt APF is based on Park's transformation or $dq0$ transformation. Here we compared the reference current with actual output current of series APF.

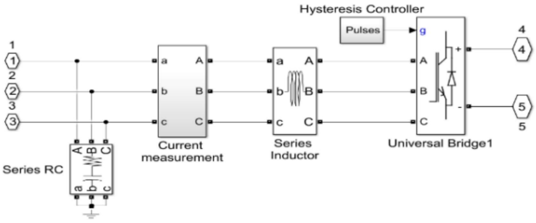

Figure 9: Shunt APF

The load current is first converted into $dq0$ coordinates form abc phases. Then this output current is compared with input reference current which is first converted into dqo coordinates. After comparing this two current they are again transformed from dqo coordinates to abc phases. The wt required in converting dqo to abc coordinates or vice versa we get from PLL (phase locked loop).

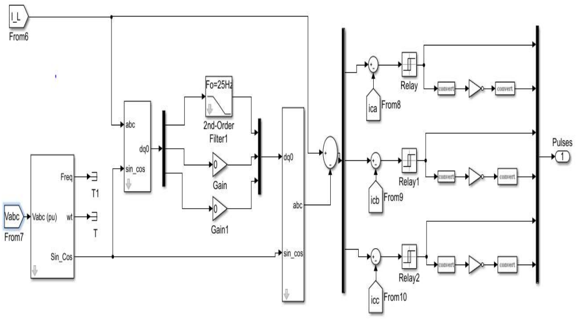

Figure 10: Shunt Pulse Generation

After this the supply load current is given to PLL and wt is generated. Then this wt along with dqo output voltages are transformed into abc phases which is the reference output cur-rent. Then this reference output current (ic*) is compared with sensed series APF output current (ic) in hysteresis voltage controller and PWM signal is generated which is given to VSI. The PLL is a control system that generates an output signal whose phase is related to phase of an input signal.

Unlike the voltage waveforms, which are maintained at their rated values, the load currents will change with load characteristics at the PCC and it will not be possible to have a fixed expected reference current value. Therefore the expected current in dq0 reference frame has only one value.

$$i_{dq0}^{expected} = \begin{bmatrix} \mathrm{I_{sp}}\cos(\emptyset_p \\ 0 \\ 0 \end{bmatrix} \tag{7}$$

$$i_{dq0}^{ref} = i_{dq0}^{expected} - i_{sdq0} \tag{8}$$

where i_{dq0}^{ref} is the distorted load current in the dq0 reference frame .

4. Results and Discussion

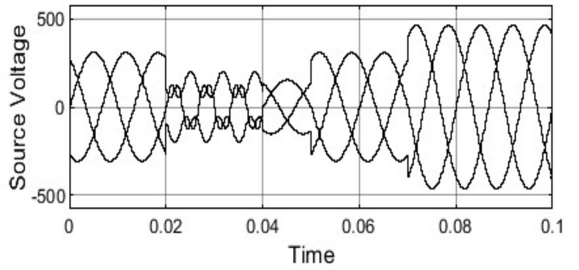

Figure 11: Supply voltage

In supply voltage shown in figure 11, sag occurs from 0.02 to 0.05 and voltage swell occurs from 0.07 to 0.1. that is the source voltage is not sinusoidal. The harmonic is generated from 0.02 to 0.04 as shown in fig 10

4.1 Without UPQC compensation

4.1.1 Load voltage

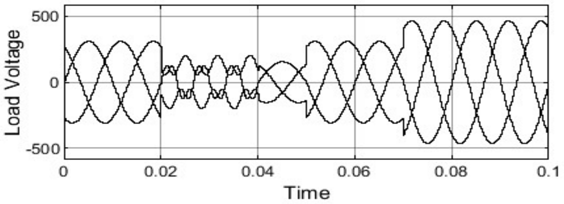

Figure 12: Load voltage before compensation

Figure 12 shows the load voltage before the compensation is applied. Because of the non-linear load and sag and swell introduced in the system voltage the load voltage also becomes distorted.

4.1.2 Source current:

The source current is distorted due to non-linear load and source voltage imbalance as shown in figure 13. The load current is also distorted due to the imbalances.

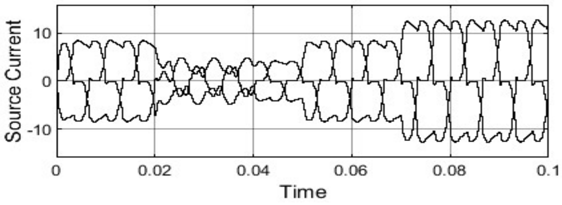

Figure 13: Source current before compensation

4.2 With UPQC Compensation

4.2.1 Load voltage

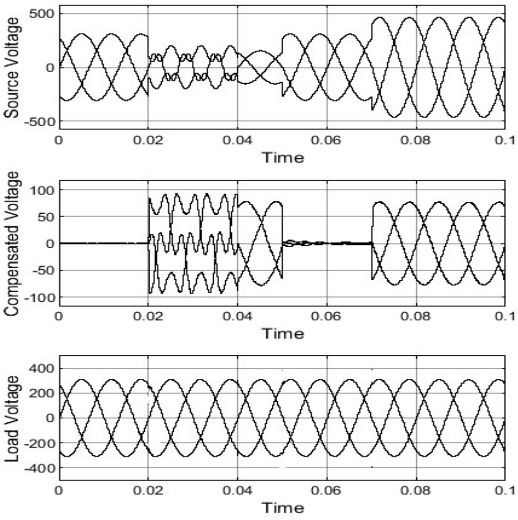

Figure 14: Load voltage with compensation

When the UPQC is connected series APF injects the compensating voltage such that the positive sequence voltage is left in the system. After the compensation the voltage swell and sag is removed and the load voltage is maintained balanced with required magnitude which is shown in figure 14.

4.2.2 Source current

The current drawn by the load is non-sinusoidal due to the presence of non-linear load in the system. So compensating current is provided by shunt compensator to get sinusoidal source current which is shown in figure 15.Table 1 shows the THD analysis of load voltage and source current before and after compensation.

Table 1: THD% of load voltage and source current before and after compensation

	Phases	Without UPQC	With UPQC
THD% of Load voltage	A	27.86	3.94
	B	34.68	2.52
	C	34.16	4.77
THD% of Source Current	A	29.41	3.69
	B	32.84	3.25
	C	35.18	2.36

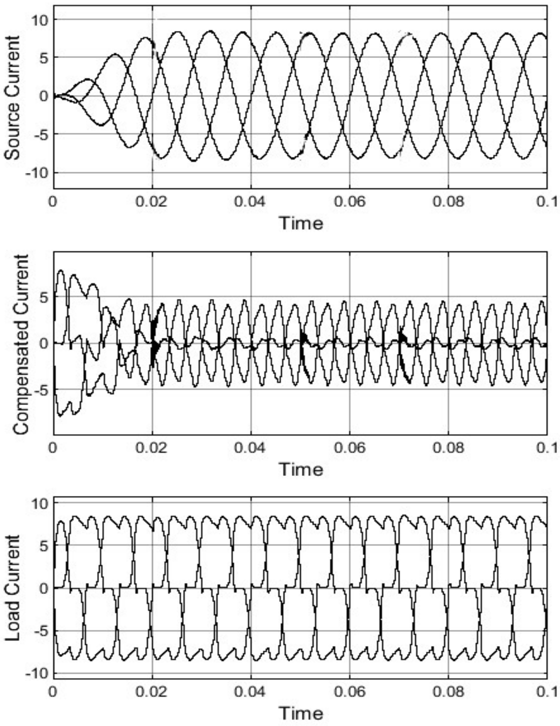

Figure 15: Source current with compensation

From THD analysis shown in table 1, we can observe that the THD% of load voltage and source current is decreased significantly even when the source voltage itself has sag and swell and load is non-linear.

5. Conclusions

From the various results obtained it is evident that UPQC can be a better choice for mitigating source voltage dip and swell conditions. Also it helps to achieve balanced load voltage .The control of shunt APF and series APF is done relying on dq0 transformation. The steps for control are generation of reference compensating values and comparing reference compensating values with actual compensating values in hysteresis voltage controller and generating PWM signal for voltage source inverter. The controlling techniques used here are hysteresis band controller. The simulation is done and current harmonics are removed and source current is sinusoidal. And the voltage dip in supply side is mitigated and load voltage is perfectly balanced. Also the THD% is significantly decreased for source current and load voltage with the introduction of UPQC.

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