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Evaluation of Unified Power Quality Conditioner (UPQC)For Improvement in Power Quality

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Abstract - *This paper present an analysis on the unified Power quality conditioner (UPQC) to improve the electric power quality atdistribution levels. Conventional power quality mitigation equipment is a providing to be poor for an increasing number of applications. Different approaches in compensation and recent developments in fields. Single modern and very promising solution that deal with both load current and supply voltage inadequacy is the Unified Power Quality Conditioner (UPQC). This is intended to present a broad overview on the different possible UPQC system configurations for single-phase (two-wire) and three-phase (three-wire and four-wire) networks.*

Keywords *- Active power filter (APF), Power quality, Unified Power Quality Conditioner (UPQC), Voltage sag and swell compensation.*

I. INTRODUCTION

The word "Power Quality" is the most important facts of any power delivery system. Low quality power affects electricity consumers in many ways. The lack of quality power can cause loss of damage of equipment, production or appliances, increased in power losses, interference with communication lines. The widespread use of power electronics equipment has produced a significant impact on quality of electric power supply by generating harmonics in voltages and currents. Therefore, it is a very important to maintain a high standard of power quality [1].

The word active power filter (APF) is a widely used terminology in area of a power quality improvement. Conventional power quality mitigation equipments use passive elements and do not always respond correctly as a nature of power system condition change. One modern solution that deals with both load current and supply voltage imperfections is the UPQC. The UPQC is a one of the APF family members [2, 3].

The UPQC is a combination of series and shunt active filters connected in cascade via a common DC link capacitor. The main purpose of a UPQC is to compensate for supply voltage power quality problems such as swells, sags, harmonics, unbalance, flicker, and for load current power quality problems such as, unbalance, harmonics, reactive current and neutral current [4].

II. BASIC STRUCTURE OF UPQC

UPQC consist of combined series and shunt APFs for simultaneous compensation of voltage and current. The series APF is inserts a voltage, which is added at a point of common coupling (PCC) such that the load end the voltage remains unaffected by any voltage disturbance, where as the shunt APF is most suitable to compensate for load reactive power demand and unbalance, to reduce the harmonics from regulate common DC link voltage and to supply current. [1,2].

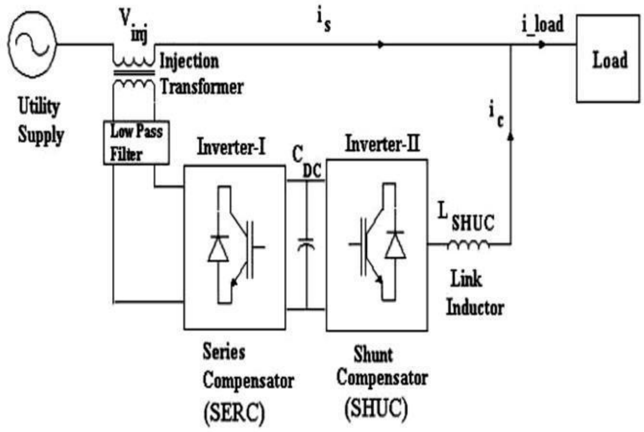

Figure 1 Right Shunt UPQC Structure

Here Figure 1 and Figure 2 shows the basic configuration of the UPQC. The UPQC has two different parts:

1. Power circuit formed by series and shunt PWM converters
2. UPQC controller

The series PWM converter of the UPQC behaves as a controlled voltage source, that it is behaves as a series APF, whereas a shunt PWM converter behaves like a controlled current source, as a shunt APF. No power supply is connected at the DC link. It contains only a relatively small DC capacitor as a smallEnergy storage element.

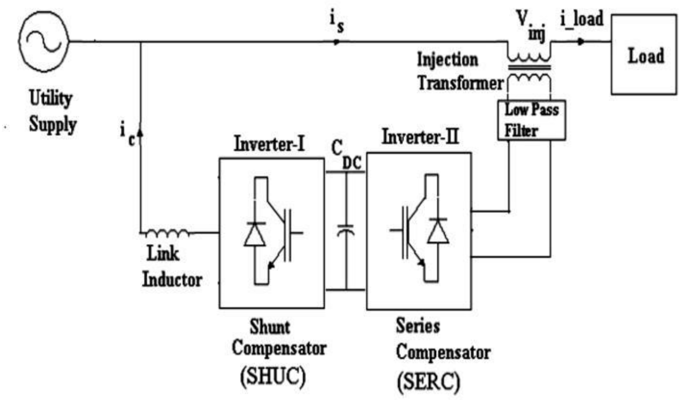

Figure 2 Left Shunt UPQC Structure

The left shunt configuration can be get by changing the place of the Shunt compensator and the series compensator in Figure-2. The majority of the work reported on UPQC is on application of right shunt UPQC, as its characteristics are more favourable than those of the left shunt UPQC in applications when the shunt compensator has tocompensate for load reactive power and harmonics and the series compensator has to compensate for voltage disturbances from the source side When the application of UPQC is considered for a distribution network as in where UPQC has two different loads, one of them is voltage sensitive and the other generates harmonics, the left shunt configuration is preffred[9,1]

III. POWER QUALITY PROBLEMS

Power quality is a very important term that embraces all aspects associated with the amplitude, phase and frequency of the voltage and current waveform existing in a power circuit. Any problem established in frequency deviation, voltage, or current that results in failure of the customer equipment is known as power quality problem.

The increasing numbers of power electronics based equipment have produced significant impact on the quality of electric power supply. Low quality power affects electricity consumers in many ways. The lack of quality power can cause loss of production, damage of equipments or appliances, increased power losses, interference with the communication lines. Therefore, it is obvious to maintain high standards of power quality [3].

The major types of power quality problems are:Interruption,Voltage-swell,Voltage-sag,Harmonics,Waveform Distortion,

(a) Interruption

Figure 3 Interruption

An interruption is defined (Fig 3) as complete loss of supply voltage or load current. Interruptions can be the result of the power system faults, control malfunction,and equipment failures, There are three types of the interruptions which are characterized by their duration:

- The temporary interruption is defined as the complete loss of supply voltage or load current having duration between 0.5 cycles & 3 sec.

- The momentary interruption is the complete loss lasting between 3 seconds and 1 minute,
- The long term interruption is an interruption which has a duration of more than 1 minute.

(a) Voltage Swells

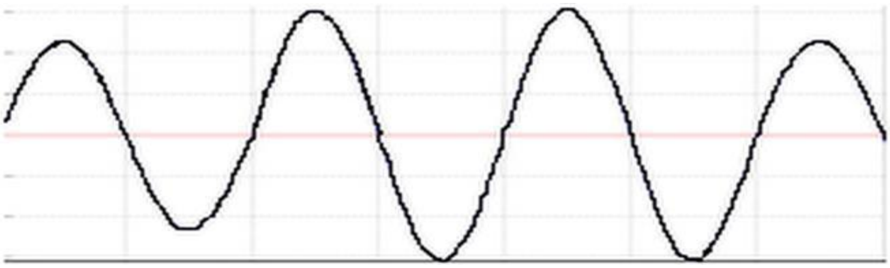

Figure 4 Voltage Swells

Voltage swell is an rms increase in the ac voltage, at related power freq. For duration from 1/2 cycle to a few seconds. As shown in Fig 4. Voltage can increase the above normal level for several cycles to few seconds. Voltage swells will normally cause
damage to lighting, motor and electronic loads and will also cause shutdown to the equipment. The severity of voltage swell during a fault condition is a function of fault place, grounding and system impedance.

(b) Voltage Sags

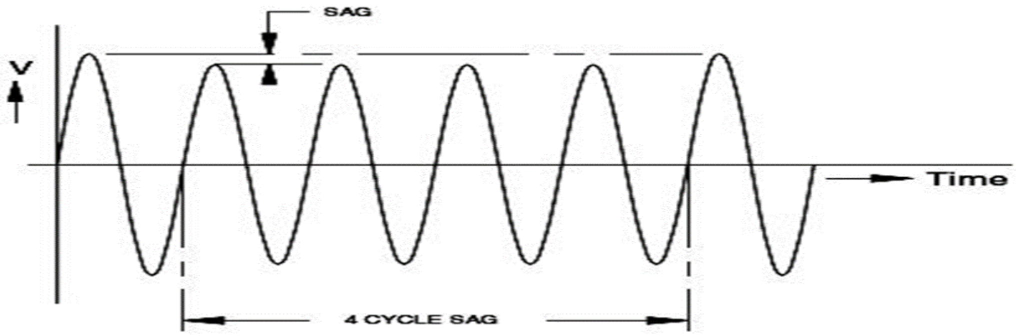

Figure 5 Voltage Sags

Voltage sags (dips) are the short-duration reductions in rms voltage caused by short-duration increases of the current. The most common causes of the overcurrents leading to voltage sags are motor starting, transformer energizing and faults. A sag is decrease in voltage at the power frequency for the duration is from 1/2 cycle to 1min. Voltage sags are usually related with system faults but can also cause by energisation of heavy loads at starting of large motors (Fig 5).

(d) Harmonics

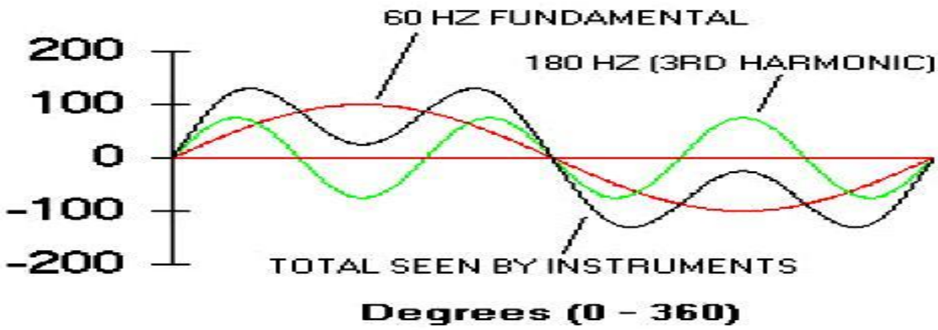

Figure 6 Waveform with 3rd Harmonic

Harmonics are sinusoidal current or voltages having frequency that are integer multiples of the fundamental frequency. Here, 3rd harmonics is show in the Figure 6.

(e) Waveform Distortion

Voltage or current waveforms assume non-sinusoidal shape called the distorted wave as shown in Fig 7. When a waveform is identical from one cycle to next and it can be selected as a sum of pure sine waves in which the frequency of each sinusoid is an integer multiple of the fundamental frequency of the distorted wave.

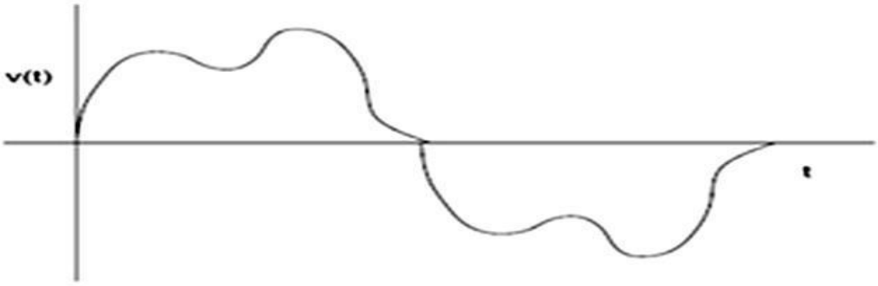

Figure 7 Distorted Waveform

It's defined as steady state deviation from an ideal sine wave, due to harmonics, which are sinusoidal voltages or currents having frequencies which are whole multiples of frequency at which supply system is designed to operate (50 HZ).

IV. CLASSIFICATION OF UPQC

The Unified Power Quality Conditioner are classified on various bases like topology, supply type and compensation method converter used, The UPQC is classified in two main groups which is based on, 1) Physical structure and 2) Voltage sag compensation [4].

(1)Physical structure:

The key parameters that aspect to these classifications are: Number of phases, Type of energy storage device used, and Physical location of shunt and series inverter.

(1a) Converter based classification

- voltage source inverter (VSI)
- current source inverter (CSI)

(1b) Supply system based classification

a) Single-Phase
  a1) Two H-bridge (total 8 switches)
  a2) 3-Leg topology (total 6 switches)
  a3) Half Bridge (total 4 switches
b) Three-Phase
  b1) Three-Wire
  b2) Four-Wire
    b2.1) Four-Leg
    b2.2) Split Capacitor
    b2.3) Three-H Bridge

(1c) UPQC Configuration based classification

a) Right Shunt (UPQC-R)
b) Left Shunt (UPQC-L)
c) Interline (UPQC-I)
d) Multi-Converter (UPQC-MC)
e) Modular (UPQC-MD)
f) Multilevel (UPQC-ML)
g) Distributed (UPQC-D)
h) Distributed Generator integrated (UPQC-DG)

(2) Voltage Sag Compensation:

The voltage sag on a system is considered as one of the important power quality problems. There are mainly four methods to compensate the voltage sag in UPQC-based applications.

(2a) UPQC-P (Active Power Control)
(2b) UPQC-Q (Reactive Power Control)
(2c) UPQC-VAmin (Minimum VA Loading)
(2d) UPQC-S (Active-Reactive Power Control)

TABLE-1.1: Comparison between Voltage Source Inverter (VSI) and Current Source Inverter (CSIs)

Voltage Source Inverter (VSI) based	Current Source Inverter (CSI) based
1. The UPQC may be developed using PWM voltagesource inverter(VSI)	1. The UPQC may be developed using PWM current source inverter(CSI)
2. VSI shares a common energy storage capacitor (C_{dc}) to form the dc-link	2. CSI shares a common energy storage inductor (L_{dc}) to form the dc-link

3. The VSI based UPQC system configuration is shown in given Figure 8	3. The CSI based UPQC system configuration is shown in given Figure 9.
4. Advantages:	4. Advantages:
- Lower cost,	- High efficiency when the load power is low
-Capability of multilevel operation	- Open loop current control is possible
- Smaller physical size,	
- Lighter in weight,	
- Cheaper,	
- Flexible overall control,	
- High efficiency near nominal operating point.	
5. Disadvantages:	5. Disadvantages:
- Low efficiency when the load power is low,	-Bulky and heavy dc inductor,
-Limited lifetime of the electrolyte capacitor.	- High dc-link losses,
	- Low efficiency near nominal operating point,
	- It cannot be used in multilevel operation.

From the comparison given in TABLE-1.1 one can find that VSI based UPQC topology is more popular than CSI based UPQC topology.

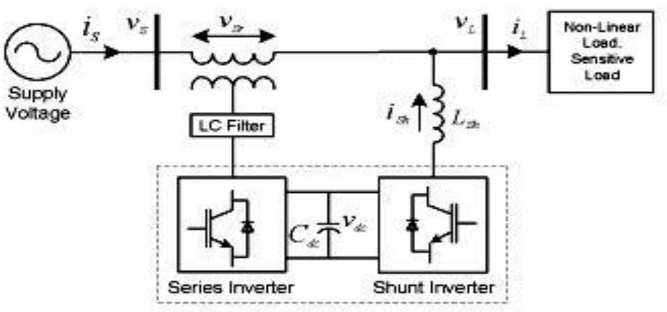

Figure 8 VSI based UPQC system configuration

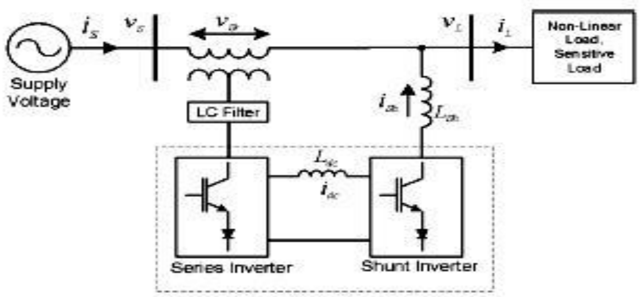

Figure 9 CSI based UPQC system configuration

To mitigate power quality problems in the UPQC's different configurations are classified based on the type of supply system. There are mainly two types of supply 1) single-phase and 2) three-phase.

Single-phase two-wire two-Hbridge UPQC configuration is shown in Figure 10. Another two topologies first is 3-leg topology (total 6 switches). Apart from total 6 switches, 4 switches are used in series inverter and 2 switch are used in shunt inverter. Second is half-bridge topology (total 4 switches). In this half-bridge topology, 2 switches are used in series inverter and 2 switches used in shunt inverter.

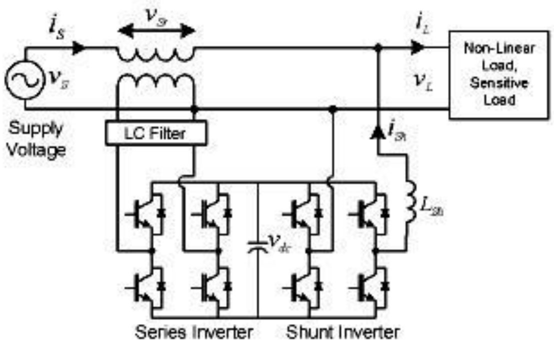

Figure 10 Single-phase Two-wire UPQC based on Two H-bridge configuration (eight switches)

Three-phase three-wire(3P3W) UPQC configuration is shown in Figure 11. Several non-linear loads, such as diode rectifier, adjustable speed drives (ASD), controlled rectifier etc. are fed from three-phase three-wire UPQC system[6].

The combination of three-phase and single-phase loads are supplied by three-phase four-wire (3P4W) UPQC configuration.For the neutral current compensation in three-phase four-wire (3P4W) system, various shunt inverter configurations are given, namely, four-leg (4L), two split-capacitor (2C) and three-H bridge (3HB).

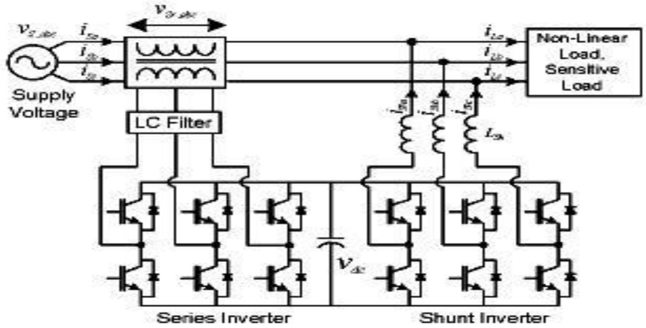

Figure 11 Three-phase Three-wire (3P3W) UPQC

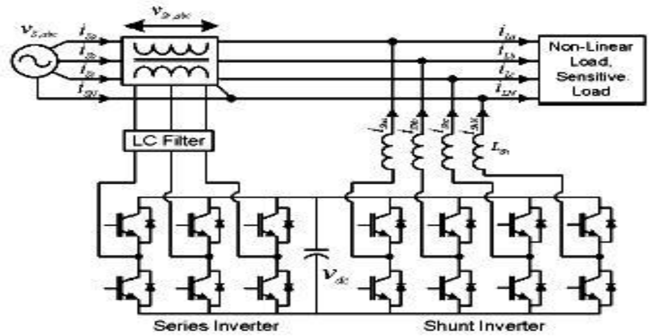

Figure 12 Three-phase Four-wire (3P4W) UPQC based on Four-leg (4L) shunt inverter topology

The 3HB topology use three single-phase H-bridge inverter connected to same dc bus of the UPQC. The 2C topology use two split-capacitor on dc side and the midpoint of two capacitor is at zero potential which is used as connection point for the fourth wire. Among all three topologies four-leg (4L) is give better control over neutral current due to four leg. So, in this paper three-phase four-wire based on four-leg (4L) shunt inverter topology is shown in Figure 12.

The comparison of single-phase UPQC and three-phase UPQC is given in TABLE-1.2 which gives detailed information about both sources.

TABLE-1.2: Comparison between Three-phase UPQC and Single-phase UPQC

Three-phase UPQC (3P UPQC)	Single-phase UPQC (1P UPQC)
1. Three-phase UPQC is possible in three-phase three-wire or three-phase four-wire (3P3W or 3P4W)	1. Single-phase UPQC is possible in single-phase two-wire (1P2W)
2.- In three-phase three-wire(3p3w) system apart from reactive current, current harmonics additional problem is current unbalance - In three-phase four-wire system additional neutral current problem	2. In single-phase system load reactive current, current harmonics are major problems
3. Voltage related power quality problems are similar for both single and three-phase system except voltage unbalance compensation is required in three-phase system	3. Voltage related power quality problems are similar for both single and three-phase system except voltage unbalance compensation is not required in single-phase system
4. Three-phase four-wire UPQC is further classified on: (a) Four-Leg (b) Split Capacitor (c) Three-H Bridge	4. Single-phase UPQC is further classified on: (a) Two H-bridge (b) 3-Leg topology (c) Half Bridge

There are various types of configurations of UPQC is given in above classification. Figure 7 to 11 all are represents right shunt UPQC (UPQC-R) and when in Figure 8 to 12 shunt inverter is located in left at that time it is called left shunt UPQC (UPQC-L). Among this two configurations UPQC-R is commonly used because current flow through series transformer is mostly sinusoidal in UPQC-R configuration. The UPQC-L is rarely used when to avoid interference between shunt inverter and passive filters.

First, the comparison between Interline UPQC (UPQC-I) and Multi-converter UPQC (UPQC-MC) is given in TABLE-1.3.

TABLE-1.3: Comparison between Interline UPQC and Multi-converter UPQC

Interline UPQC (UPQC-I)	Multi-converter UPQC (UPQC-MC)
1. In Interline UPQC two inverters are connected between two distribution feeders.	1. In UPQC-MC third converter is added to support dc bus.
2. UPQC-I can control and manage flow of real power between two feeders.	2. To improve system performance, use of storage battery or super capacitor at third converter.
3. One inverter is connected in series with one feeder while other inverter is connected in shunt with other feeder.	3. The third converter is connected either series or parallel with feeder.

Second, the comparison between Modular UPQC (UPQC-MD) and Multi-level UPQC (UPQC-ML) is given in TABLE-1.4.

TABLE-1.4: Comparison between Multi-level UPQC and Modular UPQC

Multi-level UPQC (UPQC-ML)	Modular UPQC (UPQC-MD)
1. UPQC-ML is based on 3-level neutral point clamped topology.	1. In UPQC-MD several H-bridge modules are connected in cascade in each phase.
2. UPQC-ML can also be useful to in achieve high power levels.	2. UPQC-MD can be useful to in achieve high power levels.
3. In UPQC-ML three-level topology require double semiconductor switches.	3. The H-bridge modules for shunt inverter is connected in series through multi-winding transformer, while, series inverter is connected in series without using series transformer.

Third, the comparison between Distributed UPQC (UPQC-D) and Distributed Generator Integrated UPQC (UPQC-DG) is given in TABLE-1.5

TABLE-1.5: Comparison between UPQC-D & UPQC-DG

Distributed UPQC (UPQC-D)	Distributed Generator Integrated UPQC (UPQC-DG)
1. Fourth leg is a added to 3P3W UPQC to compensate neutral current flowing towards transformer neutral point.	1. In UPQC-DG battery can be added at dc bus which is used as a stored power and used as a backup which give benefit for eliminating voltage interruption.
2. UPQC-D topology is also known as 3P3W to 3P4W Distributed UPQC because 3P4W system is a realized by using 3P3W system.	2. The UPQC can be integrated with one or several DG system Which is known as the UPQC-DG.
3. In UPQC-D system the neutral of series transformer is used as neutral of 3P4W system.	3. The output of DG system is connected to dc bus of UPQC to compensate voltage and current related problems.

The difference between Minimum VA Loading (UPQC-VAmin) and Active-Reactive Power Control (UPQC-S) is given in TABLE-2.1

TABLE-2.1: Comparison between Active & Reactive Power Control and Minimum VA loading

Active & Reactive Power Control (UPQC-S)	Minimum VA loading (UPQC-VAmin)
1. In UPQC-S the series inverter is delivered both active and reactive power.	1. This method is used which is injected certain optimal angle with respect to source current.
2. The series inverter of UPQC-S perform voltage sag and swell compensation and sharing reactive power with shunt inverter.	2. The series voltage injection and the current drawn by shunt inverter must need for determining Minimum VA loading of UPQC.

Finally, the category is based on voltage sag compensation is given in this section. There are mainly four methods to compensate voltage sag in UPQC based applications, the comparison between Active Power Control (UPQC-P) and Reactive Power Control (UPQC-Q) is given in TABLE-2.2

TABLE-2.2: Comparison between Active Power Control and Reactive Power Control

Active Power Control (UPQC-P)	Reactive Power Control (UPQC-Q)
1. voltage sag is mitigated by injecting active power through series inverter of UPQC.	1. In this voltage sag is mitigated by injecting reactive power through series inverter of UPQC.
2. To compensate equal percentage of sag UPQC-P requires	2. To compensate equal percentage of sag UPQC-Q requires

smaller magnitude of series injection voltage compared to UPQC-Q.	smaller magnitude of series injection voltage compared to UPQC-P.
3. Active Power Control P is referred as active power.	3. Reactive Power Control Q is referred as reactive power.

V. CONTROL PROCEDURE OF UPQC

Control Procedure play very important role in system's performance. The control procedure of UPQC may be implemented in three stages:

1) First sensed Voltage and current signals
2) The Compensating commands regarding voltage and current levels are obtain
3) The gating signals for semiconductor switches of UPQC are generated using fuzzy logic, PWM, or hysteresis based control techniques

- In the first stage voltage signals are sensed using power transformer (PT) or current signals and voltage sensor are sensed using current sensor or current transformer [7].
- In second stage deduction of compensating commands are mainly based on two types of domain methods: (1) Frequency domain methods, and (2) Time domain method. Frequency domain methods, which, are based on the current signals to extract compensating commands or Fast Fourier Transform (FFT) of distorted voltage. This FFT are not popular because of large computation, time and delay.

Control methods of UPQC in time-domain are based on instantaneous derivation of compensating commands in form of either current signals or voltage. Mainly two widely used time domain control techniques of UPQC are:

1. p-q theory or The instantaneous active and reactive power and
2. d-q theory or Synchronous reference frame method.

In *p-q* method instantaneous active and reactive powers are calculate, while, the *d-q* method deals with the current independent of the supply voltage. Both methods modify voltages and currents from abc frame to stationary reference frame (p-q theory) or synchronously rotating frame (d-q theory) to unconnected the fundamental and harmonic quantities [8].

In third and final stage stage of the gating signals for semiconductor switches of UPQC based on derive compensating commands in terms of voltage or current. Then, these recompense commands are given to PWM, hysteresis or fuzzy logic based control techniques.

VI. CONCLUSION

Problems in The power quality at distribution systems are old but customer recognition of these problems increased recently. AMain evaluation of UPQC for improvement in Power Standard at distribution level has been reported in this paper. It's very tough to maintain electric power quality at acceptable limits. One modern and very favourable solution that deals with both load current and supply voltage imperfection is the Unified Power Quality Conditioner (UPQC). This paper presented evaluation on the UPQC to improve the electric power quality at distribution level. The UPQC is able to compensate supply voltage power quality problems such as harmonics, voltage sags, voltage swells,voltage unbalance, voltageflicker and for load current power quality problems such as, unbalance, harmonics, reactive current and neutral current. In this paper some UPQC layout have been discussed. Among all these arrangement, UPQC-DG could be the most interesting topology for a renewable energy based power system.

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