A Review on Power Quality Improvement by UPQC

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Abstract: ***The introduction of power electronic based equipment has produced a great impact on the quality of electrical power supply. Modern day equipments are highly sensitive to variation from ideal sinusoidal voltages. Conventional power quality improvement equipments are providing solution but not sufficient. A very promising solution for supply voltage imperfection is UPQC (Unified Power Quality Conditioner), which allow the mitigation of voltage and current disturbances that could affect sensitive electrical loads while compensating the load reactive power. This paper presents a review on the unified power quality conditioner (UPQC) to improve electric power quality. Connection methodologies with their advantages and disadvantages are also described***.

Keywords: Power Quality, UPQC, voltage sag, voltage swell, FACTS, DVR, STATCOM**.**

1. Introduction

As the use of nonlinear loads in modern power distribution system is increased. This lead to electrical power quality problems such as voltage sag, swell, harmonics, very short interruptions, long interruptions, voltage spike, noise, voltage unbalance. For the mitigation of current as well as voltage based distortions, various Custom Power devices can be used. Different CPD such as DVR and distribution STATCOM, UPQC are also reported for the effective mitigation of voltage sag/swell, while compensation capability of UPQC is better.

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. Controlling methods has the most significant role in any power electronics based system. It is the control strategy which decides the efficiency of a particular system. The efficiency of a good UPQC system solely depends upon its various used controlling algorithm. This review paper will deals with physical structure, method used to compensate sag, recently developed new system.

2. Power Quality Problems

"Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy." Any problem which occur in voltage, current or frequency deviation that results in failure of customer equipment is known as power quality problem. Any problem manifested in voltage, current or frequency deviation that results in failure of customer equipment is known as power quality problem. The major types of power quality problems are, Voltage Sag, Voltage swell, Interruption, Voltage unbalance, Harmonics.

2.1 Voltage Sag

RMS reduction in the AC voltage at power frequency from half of a cycle to a few seconds' duration. Voltage sags are usually associated with heavy loads at starting of large motors.

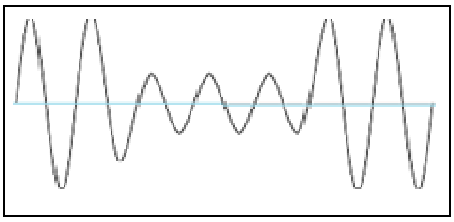

Figure.1: Voltage Sag

2.2 Voltage Swell

RMS increase in AC voltage at power frequency from half of a cycle to a few seconds' duration.The severity of voltage swell during a fault condition is a function of fault location, system impedance and grounding.

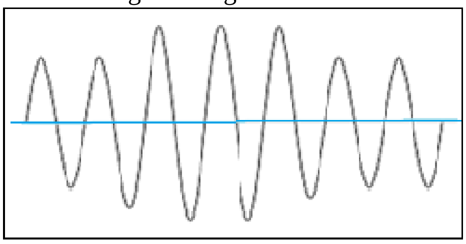

Figure 2: Voltage Swell

2.3 Interruption

Complete loss of voltage or current for a time period. Interruptions can be the result of power system faults, equipment failures, and control malfunction.

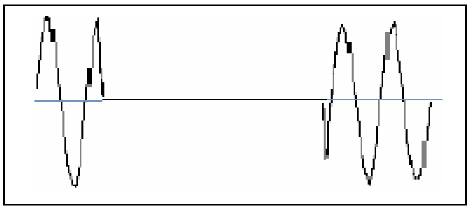

Figure 3: Interruption

2.4 Harmonics

Sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency .Harmonic distortion is Quantitative representation of the distortion from a pure sinusoidal waveform.

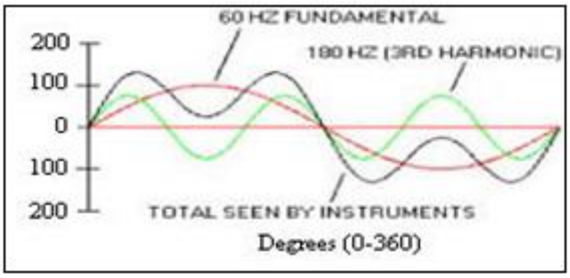

Figure 4: Harmonics

3. Unified Power Quality Conditioner

In recent years, FACTS has appeared as solution of many PQ problems. The FACTS concepts applied in distribution systems has resulted in a new generation of compensating devices. A UPQC is the extension of the UPFC concept at the distribution level.

UPQC is the integration of Series APF and shunt APF, active power filters, connected back-to-back on the dc side, sharing a common DC capacitor. The series component of the UPQC is responsible for mitigation of the supply side disturbances: voltage sags/swells, flicker, voltage unbalance and harmonics. It inserts voltages so as to maintain the load voltages at a desired level; balanced and distortion free. The shunt component is responsible for mitigating the current quality problems caused by the consumer: poor power factor, load harmonic currents, load unbalance etc. It injects currents in the ac system such that the source currents become balanced sinusoids and in phase with the source voltages. The overall function of UPQC mainly depends on the series and shunt APF controller.

3.1 Block Diagram of UPQC

The system configuration of a single-phase UPQC is shown in figure given below.

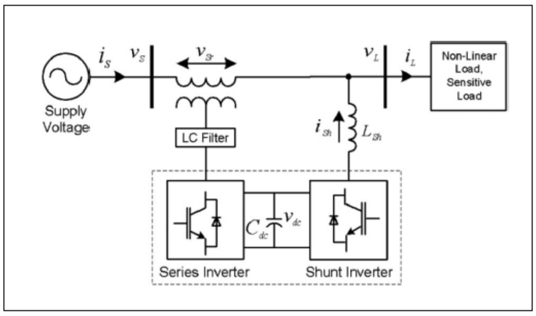

Figure 5: Block Diagram Of UPQC

UPQC consists of two IGBT based VSC, one shunt and one series cascaded by a common DC bus. The main components of a UPQC are series and shunt power converters, DC capacitors, low-pass and high-pass passive filters, and series and shunt transformers. 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.
2) Shunt coupling inductor L is used to interface the shunt inverter to the network. It also helps in smoothing the current wave shape.
3) A common dc link that can be formed by using a capacitor or an inductor.
4) An LC filter that serves as a passive low-pass filter 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 voltage and current rating of series inverter.
6) The integrated controller of the series and shunt APF of the UPQC to provide the compensating voltage reference V_c and compensating current reference I_c.

3.2 Control Objectives

Various control objectives of UPQC are stated below.

The shunt connected converter has the following control objectives.

1) To balance the source currents by injecting negative and zero sequence components required by the load.
2) The compensate for the harmonics in the load current by injecting the required harmonic currents.
3) To control the power factor by injecting the required reactive current.
4) To regulate the DC bus voltage.

The series connected converter has the following control objectives

1) To balance the voltages at the load bus by injecting negative and zero sequence voltages to compensate for those present in the source.
2) To isolate the load bus from harmonics present in the source voltages, by injecting the harmonic voltages.
3) To regulate the magnitude of the load bus voltage by injecting the required active and reactive components.
4) To control the power factor at the input port of the UPQC.

4. Classification of UPQC

The UPQC is classified in two main groups which are based on, Physical structure and Voltage sag compensation.

4.1 Physical Structure

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

4.1.1. Converter based classification

1) VSI (voltage source inverter)
2) CSI (current source inverter)

VSI based UPQC topology is more popular than CSI based UPQC topology due to following reasons given in Table 1.

Table 1: Comparison of VSI and CSI based UPQC

Voltage Source Inverter (VSI)based	**Current Source Inverter (CSI)based**
1.The UPQC may be developed using PWM Voltage source inverter	1.The UPQC may be Developed using PWM Current source inverter
2. VSI shares a common energy storage capacitor (Cdc) to form the dc-link.	2.CSI shares a common Energy storage inductor (Ldc) to form the dc-link.
3.Advantages: -Lower cost, -Small physical size, -Lighter in weight, -Cheaper, -Multilevel Operation capability, -Flexible overall control, -High efficiency near nominal operating point	3.Advantages: -Open loop current Control is possible, -High efficiency when the load power is low.
4.Disadvantages: -Low efficiency when the load power is low, -Limited life time of the Electrolyte capacitor.	4. Disadvantages: -Bulky and heavy dc inductor, -High dc-link losses, -Low efficiency near nominal operating point, -It cannot be used in multilevel operation.
5. The VSI based UPQC system configuration is shown in given Figure 6	5. The CSI based UPQC system configuration is shown in given Figure 7.

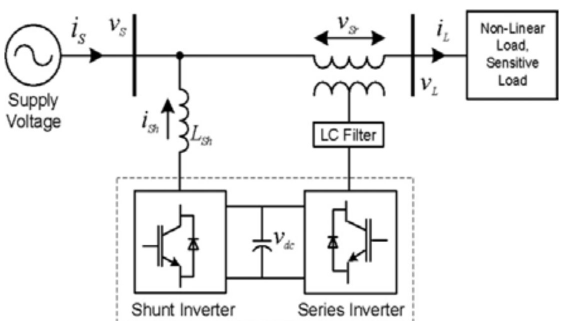

Figure 6: Voltage Source Inverter (VSI) based UPQC

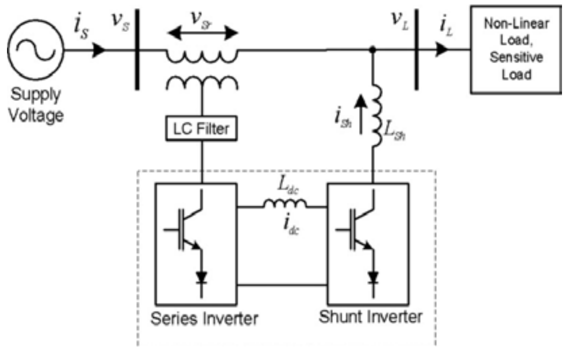

Figure 7: Current Source Inverter (CSI) based UPQC

4.1.2. Supply system based classification

1) Single-phase includes Two H-bridge (total 8 switches), 3-Leg topology (total 6 switches), Half Bridge (total 4 switches).
2) Three-Phase includes Three-wire & Four-wire.

Various types are as stated above and the comparison between single phase and three phases is given in Table 2.

Table 2: Comparison between Single & Three Phase UPQC

Single-phase UPQC	**Three-phase UPQC**
1.Single-phase UPQC is possible in single-phase two-wire (1P2W)	1.Three-phase UPQC is possible in three-phase three-wire or three-phase four-wire(3P3W)
2.Single-phase UPQC is further classified on: (i) Two H-bridge (ii) 3-Leg topology (iii) Half Bridge	2.Three-phase four-wire UPQC is classified as (i) Four-Leg (ii) Split Capacitor (iii) Three-H Bridge
3.In single-phase system Load reactive current, current harmonics are major problems	3. In three-phase three wire system apart from reactive current, current harmonics additional problem is current Unbalance. In three phase four-wire system additional neutral current problem
4. 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. Voltage related power quality problems are similar for both single and three phase system except voltage unbalance compensation is required in three-phase system

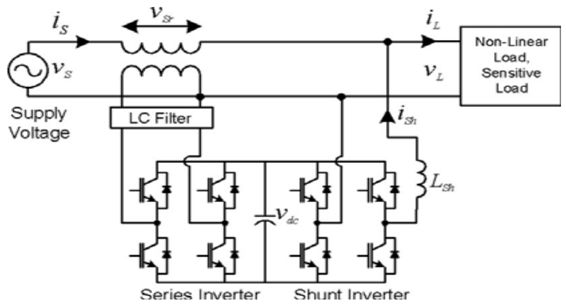

Figure 8: Single-phase Two-wire UPQC based on Two H-bridge configuration (eight switches)

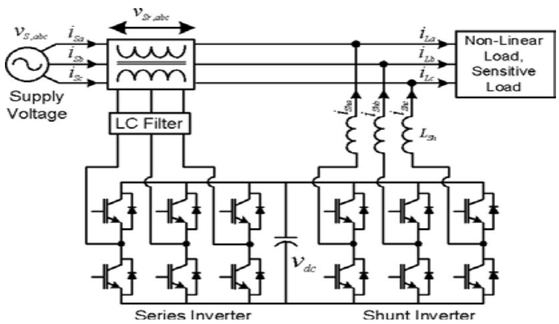

Figure 9: Three-phase Three-wire (3P3W) UPQC

4.1.3. UPQC Configuration based classification

1) UPQC-R (Right Shunt)
2) UPQC-L (Left Shunt)
3) UPQC-I (Interline)
4) UPQC-MC (Multi-Converter)

There are various types of configurations of UPQC is given in above classification. Among the two configurations UPQC-R is commonly used because current flow through series transformer is mostly sinusoidal. The UPQC-L is rarely used due to interference between shunt inverter and passive filters. First, the comparison between Interline UPQC (UPQC-I) and Multi-converter UPQC (UPQC-MC).

Table 3: Comparison between UPQC-I & UPQC-MC

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.One inverter is connected in series with one feeder while other inverter is connected in shunt with other feeder.	2.The third converter is connected either series or parallel with feeder.
3.UPQC-I can control and manage flow of real power between two feeders.	3.It can control and manage flow of real power between two feeders.

4.2 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.

1) UPQC-P (Active Power Control)
2) UPQC-Q (Reactive Power Control)
3) UPQC-VAmin (Minimum VA Loading)
4) UPQC-S (Active-Reactive Power Control)

The comparison between Active Power Control (UPQC-P) and Reactive Power Control (UPQC-Q) is given in Table 4 and the comparison between Minimum VA Loading (UPQC-VAmin) and Active-Reactive Power Control(UPQC-S) is given in Table 5.

Table 4: Comparison between UPQC-P and UPQC-Q

Active Power Control (UPQC-P)	Reactive Power Control (UPQC-Q)
1.The voltage sag is Mitigated by injecting active power through series inverter of UPQC	1.The voltage sag is mitigated by injecting reactive power through series inverter of UPQC
2.In Active Power Control P is referred as active power	2. In Reactive Power Control Q is referred as reactive power.
3.To compensate equal percentage of sag UPQC-P requires smaller magnitude of series injection voltage compared to UPQC-Q.	3.To compensate equal percentage of sag UPQC-Q requires larger magnitude of series injection voltage compared to UPQC-P.

Table 5: Comparison between UPQC-VAmin and UPQC-S

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

5. Control Strategies Of UPQC

To improve the system's performance, Control strategy plays a very important role. Control strategy of UPQC may be implemented in three stages:

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

In second stage derivation of compensating commands are mainly based on two types of domain methods:

(1) Frequency domain methods
(2)Time domain method.

Frequency domain methods,which is based on the Fast Fourier Transform (FFT) of distorted voltage or current signals to extract compensating commands. 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 the form of either voltage or current signals. There are mainly two widely used time domain control techniques of UPQC are:

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

In p-q theory instantaneous active and reactive powers are computed, while, the d-q theory deals with the current independent of the supply voltage.Both methods transforms voltages and currents from abc frame to stationary reference frame (p-q theory) or synchronously rotating frame (d-q theory) to separate the fundamental and harmonic quantities.

Different time domain control techniques used are as given below:
1) Instantaneous active & reactive power or 3phase pq theory
2) Synchronous reference frame or 3phase dq theory (SRF)
3) Unit Vector Template Generation (UVTG)
4) One Cycle Control (OCC)
5) H∞-based model matching control
6) Model Predictive Control (MPC)
7) Deadbeat Control
8) Artificial Neural Network (ANN) technique
9) Feed forward & feedback theory
10) Multi Output ADAptive LINear Approach (MO-ADALINE)

A simple controller scheme for UPQC, called as unit vector template generation (UVTG) method uses a phase-locked loop (PLL) to generate unit vector template(s) for single-/three-phase system.

6. Various Backup Storage Devices Used in UPQC

6.1 DC storage capacitors

1) Store energy in their capacitance.
2) Useful for short ride through times.
3) Require DC/DC converter between the constant voltage bus and the capacitance.
4) Cost increases with the increase in ride through time.

6.2 Batteries

1) Most common method of storing energy.
2) Do not require DC/DC converter as they are directly connected to VSC.
3) Capacitor can compete with batteries but only for short ride through times.
4) Utilize environmentally unfriendly materials.
5) Have limited life time.
6) Require regular maintenance.
7) Some new types of batteries do not have above mentioned limitations but have higher cost.

6.3 Super Capacitors

1) Energy densities comparable to batteries.
2) Improve equipment voltage tolerance.
3) Have much longer lifetime than batteries.
4) Require much less maintenance than batteries.
5) Discharge time is not less than 1 minute.
6) Faster than batteries but much slower than capacitors.
7) Only available for voltages of a few volts.

6.4 Flywheels

1) Store energy in fast-spinning flywheels.
2) Stored energy cannot be extracted fully.
3) Require an additional DC/DC converter.

6.5 Superconducting coils

1) Energy is stored in superconducting magnetic energy storage (SMES) coils.
2) Most cost attractive solution for high power short time ride through applications.
3) Fast extraction of energy as compared to batteries.
4) Have reduced size and lower maintenance cost as compared to batteries.
5) Can be quickly and easily installed with short lead times.
6) Have modular design to meet future load growth and are portable.
7) Require an additional DC/DC converter between SMES and constant voltage bus.

7. Conclusion

A comprehensive review on the UPQC to enhance the electric power quality at distribution level has been reported in this paper.UPQC in this context could be useful to compensate both voltage- and current-related power quality problems simultaneously. Different aspects of UPQC and up to date developments in this area of research have been briefly addressed. The UPQC is able to compensate supply voltage power quality issues such as, sags, swells, unbalance, flicker, harmonics, and for load current power quality problems such as, harmonics, unbalance, reactive current and neutral current. Hence, with the help of above said topologies can meet required load demand in future, increase the production in industries and increase the economy of the country.

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