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A Survey on Unified Power Quality Conditioner for Power Quality Improvement

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Abstract: *This paper presents a review on the unified power quality conditioner. Power system consists of complex networks, where many generating stations are interconnected to load center via long power transmission and distribution networks. Outages and interruptions in utility networks, critical commercial operations lead to financial loss, production loss, idle manpower etc. Thus, a new concept is introduced in distribution system for improvement in performance called as custom power. Performance comparison of various custom power devices is done and we can see that for the enhancement of power quality Unified power quality conditioner (UPQC) is better due to its fast response, nominal cost and high reliability. A UPQC usually compensate distortion, unbalanced conditions of voltage and current. It can efficiently protect sensitive loads against the voltage variations or disturbances. UPQC consists of two converters which are connected to a common DC link with an energy storage. UPQC has various configurations based on its application.*
Keywords: *UPQC, DVR, D-STATCOM, Power Quality, Distribution System, and APF.*

I. Introduction

Power quality is a very important issue in distribution system. Power quality is simply defined as a quality of electricity i.e. it is a concept that is use to describe the purity of the transferred energy. As per IEEE Std. 1100 Power quality is defined as concept of powering and grounding sensitive equipment in a manner that it is suitable for the satisfactory operation of that equipment. But, the power quality is disturbed or destroyed due to several problems occurring in the electrical network for e.g. voltage sag, Voltage swell, unbalance of voltage and current, harmonics produced in voltage and current flickers transient over voltage supply interruption etc. The allowable source voltage and load current distortion (THD) limit as per IEEE standards must be strictly maintained. Harmonic current components create several problems like:

- Increase in power system losses,
- Overheating and insulation failures in rotating machinery,
- Overheating and insulation failures of conductor, transformers, and cables,
- Reactive power burden,
- Low system efficiency,
- Poor power factor,
- System unbalances and causes excessive neutral currents,
- Malfunctioning of the protective relays and untimely tripping.

In these mentioned issues regarding power quality are reduced by using filters. There are two types of filters one is passive filter and second is active filter. Now a day's Active power filter is more popular because it's a more attractive compared with passive ones due to its smaller size, fast response and higher performance. The Active Power Filter (APF) have solve the problem regarding current, voltage and the power factor improvement.

The modern power distribution system is becoming highly vulnerable to the different power quality problems stated above [2], [3] The extensive use of nonlinear loads is further contributing to increased current and voltage harmonics issues. Furthermore, the penetration level of small/large-scale renewable energy systems based on, fuel cell, solar energy, wind energy etc. installations at distribution and transmission networks is increasing significantly. This integration of distributed generation in a power system is introducing new challenges to the electrical power industry to accommodate these systems [4]. For distribution system, UPQC is a most attractive solution for compensating power quality problems.

Research is continued for use of UPQC to solve problems such as voltage sag, voltage swell, voltage, correction of power factor and unacceptable levels of harmonics in the current and voltage. The swells are more destructive in nature than sag, UPQC is being studied for mitigation of voltage sag and swell [5], [6]. For example, breakdown of components or equipment due to excessive over voltage during swell condition [7]. In

[8] hysteresis current control method is used to construct APF. A simple Proportional-Integral(PI) controller is brought in use in order regulating the average dc bus voltage which thereby make the reference supply current peak value and supply voltage in phase and the model is tested with different linear and nonlinear loads to remove the harmonics and reduce reactive power. In [9] the technology based on unit vector template generation from distorted input supply is used for solving problems related with voltage and current harmonics in a basic UPQC model. H. Akagi et al. [10] proposed the instantaneous active and reactive power concept. It describes a instantaneous reactive power compensators, here switching devices are used instead of energy storage device. It is proved that both harmonic currents and fundamental reactive power in transient states can be removed. We understand the advanced control strategy i.e. d−q−o method for compensating the voltage harmonics and hence the voltage signal at series active filter is utilized to find the reference signal for the parallel active filter using p − q theory. Metin Kesler [11] proposed an advanced control method(SRF) to overcome the problems of power quality through a three-phase UPQC under unbalanced load conditions. Its performance was analyzed. The proposed control system helps in improving the power quality at the point of common coupling (PCC) on power distribution sys- tem under unbalanced load conditions and non- ideal mains voltage by compensating the current and voltage harmonics and the reactive power. In [12] we see control strategy is dealing with the series inverter controller where amplitude modulation ratio of series inverter sinusoidal PWM voltage controller is regularly adjusted to follow the actual dc link voltage and not the reference dc link voltage. Yash Pal [13], presents a control strategy for a three-phase four-wire Unified Power Quality (UPQC). A three-phase, four leg VSI is used for shunt APF and a three-phase, three legs VSI used for the series APF. Unit vector template control technique is used to get the for controlling the series APF, while Icosφ control is used for control of shunt APF. This method ensures, mitigation of voltage and current harmonics, load balancing, voltage swell and sag and voltage dips. This method helps effectively in reduction of computational time and number of sensors. The organization of the paper is as follows: Section 2 explores the different types of custom power devices. Structure of UPQC is described in Section 3, Section 4 describe the topologies and Section 5 describes the control techniques for UPQC. Finally, the conclusion is given.

II. Different Types Of Custom Power Devices

The different custom power devices are SVC, dynamic voltage restorer (DVR), which improves the supply power quality, distribution static compensator (DSTATCOM), compensate for current unbalance and harmonics of non-linear loads, and UPQC combination of DVR and D-STATCOM [16] - [18].

Distribution Static Compensator: - is connected in shunt with distribution feeder with the help of coupling transformer. It is a Voltage Source Inverter (VSI) based Static Compensator Device (STATCOM) used to maintain bus voltage sags at the required level by supplying or receiving of reactive power in the distribution system. The single line diag. of D-STATCOM is shown in Figure 1. The coupling of D- STATCOM is three phase, in parallel to network and load. The purpose of the D-STATCOM is to cancel load harmonics fed to the supply. It works as current sources, connected in parallel with the nonlinear load, it generates the harmonic currents the load requires, balance them, and provide reactive power.

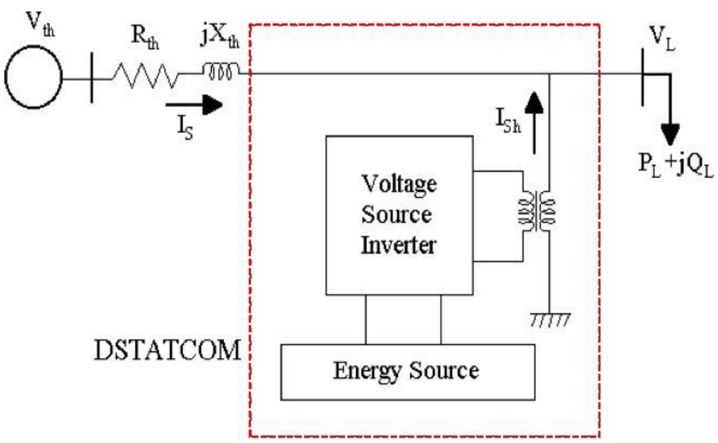


Fig.1: The single line diag. of D-STATCOM.

Dynamic Voltage Restorer (DVR): - It is a controlled, high-speed switching power electronic device. DVR is connected in series, designed to inject a dynamically controlled voltage in magnitude and phase in to distribution line through coupling transformer to correct load voltage. A basic DVR is shown in the Figure 2. It consists of a dc-dc boost-converter, voltage source inverter(VSI), energy storing device, ac filter and a coupling transformer, connected in series. We can use dc capacitor bank, fuel cell, pv-array, flywheel, supercapacitor, etc. as energy storage device, interfaced to boost converter. Generally dc capacitor bank is used. The dc link capacitor voltage is regulated by boost converter. It is used as a common voltage source for the inverters. The compensating voltage is generated by boost converter, which is injected into distribution system through series matching transformer. The ac filter is used to overcome the switching losses due to control signal generating techniques for VSI and the effects on winding of coupling transformer. The function of a dynamic voltage restorer is to reduce voltage sags which cause damage to the sensitive loads like semiconductor manufacturing plant or IT industry.

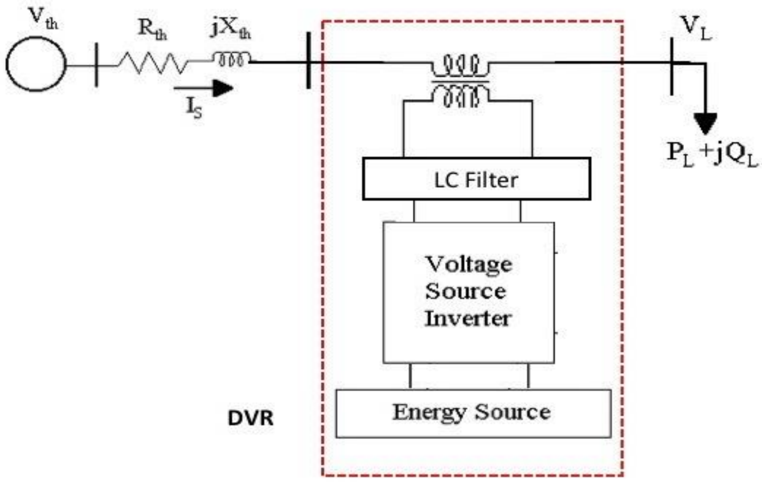


Fig.2. The single line diagram of Dynamic Voltage Restorer.

There are different types of power quality problems in distribution system and to each problem, there is a solution. Table I, shows the overall comparison of three custom devices. It has been shown that a DVR is superior to DSTATCOM. Unified PQ Conditioner (UPQC) is the best protection for sensitive loads from sources with poor quality. It is combination of DVR and DSTATCOM.

Table I: COMPARISON OF VARIOUS CUSTOM POWER DEVICES

S. No	**Factors**	**DSTATCOM**	**DVR**	**UPQC**
1	Rating	low rating	high rating	higher ratings are available
2	Speed of operation	Less than DVR	Fast	Faster
3	Compensation Method	Shunt Compensation	Series Compensation	Both series & shunt
4	Active /reactive Power	Reactive	Active/ Reactive	Both
5	Harmonics	Less	Very less	Lesser
6	Problems addressed	Sag/ Swell	Sag/ Swell/ Harmonics	Sag/ Swell/ Harmonics/ Flicker/ Transients/ unbalance in 3 phase system
7	Cost	Nominal	High	Higher

III. Unified Power Quality Conditioner

The schematic diagram of a single-phase Unified Power Quality Conditioner is shown in Figure 3. UPQC consists of two IGBT based Voltage source converters (VSC), one shunt and other series which are connected to a common DC link. The shunt converter is connected in parallel to the load. It provides VAR compensation to the load and supply harmonic currents. Whenever there is sag in supply voltage then series converter injects suitable voltage to overcome sag in supply. Thus, UPQC improves the power quality by mitigating problems due to load current harmonics and by power factor correction.

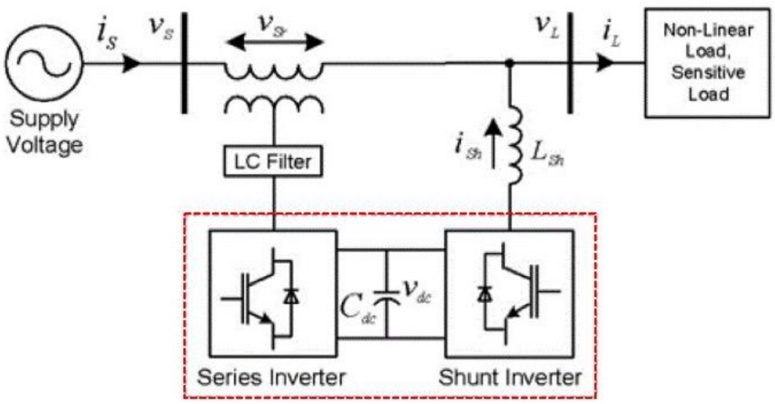


Fig.3: UPQC basic Structure.

The key components of the system are as follows:

a) **Series converter** is a VSC connected in series with the AC supply line. It acts as a line voltage source to compensate voltage disruptions. It is used to minimize line voltage fluctuations from the load supply voltage and feeds to shunt branch of the device to consume current harmonics produced by unbalance load.

b) **Shunt converter** is a VSC which is connected in parallel with the AC supply line. It acts as a current source to eliminate current disruptions and eliminates the reactive current in the load circuit. It improves the power factor of load and acts as DC-link voltage regulator for the reduction of the DC capacitor rating.

c) **Energy storage** The DC capacitor bank is generally used. it is connected between Midpoint-to-ground is divided into two parts, which are arranged in series together. The neutral point's secondary transformer is connected to the DC link midpoint directly. Since both three-phase transformers are connected in Y/Yo form, the zero- sequence voltage will appear in primary winding of transformer which is connected in series to mitigate the zero-sequence voltage of the supply power system. There would not be any zero- sequence current flow in the primary side of both transformers. When the voltage disturbance occurs the system current is balanced. Various other energy storage devices can be used such as batteries, superconducting coils, supercapacitors, flywheels, etc.

d) **The Low-pass filter (LPF)** Due to high-frequency switching mode high frequency components are produced at the output side of series converter to attenuate these LPF is used.

e) **High-pass filter (HPF)** In current switching mode ripples produced can be consumed by applying HPF at the output of shunt converter.

f) **Series and shunt transformers** are used to inject the compensating voltages and currents for electrically separation of UPQC converters.

IV. UPQC Topologies

Power electronics device has many advantages and disadvantages. But the UPQC is the most powerful power electronics device for heavy loads and have high sensitivity towards disruption in line voltage and load current. UPQC is more flexible than any single Converter/inverter based device. It can correct the imbalance and disturbances in the supply voltage and current where as other devices perform any one function. The basic topologies of UPQC are shown in Figure 4.

Right Shunt (UPQC-R) & Left Shunt (UPQC-L) UPQC: This configuration is based on the position of series and shunt inverter connections, as UPQC consist of two back-to-back converters. UPQC-R: If the shunt inverter is connected on the right side of the series inverter [19], [20], [21], [22], [23]. UPQC-L: If the shunt inverter is connected on the left side of the series inverter [19], [24], [25], [26], [27], [28].

Open UPQC: It is a power-electronic unit having steady state performance installed in series with the medium-voltage/low-voltage (LV) substation, along with several power-electronic shunt units connected close to the end users. Dc common link is not present in this configuration, so different control techniques are employed. This device can improve power quality by using only the series unit, all customers connected/supplied by the mains are supplied with custom power [31].

Interline UPQC (UPQC-I): Fig.4(D) depicts an interesting UPQC system configuration, suggested by Jindal et al. [29], in Interline UPQC (UPQC-I) the two inverters of the UPQC are connected between two distribution feeders. One of the inverters is connected in series with one feeder while the second inverter in shunt with second feeder. This configuration can regulate the voltages of both the feeders simultaneously.

Multilevel UPQC (UPQC-ML): Rubilar et al. designed a multilevel UPQC based on a three-level neutral point clamped (NPC) topology [30]. Fig.4(E) shows a Multilevel-UPQC system configuration. A three-level topology requires double semiconductor devices (24) as that of the two-level UPQC system. Based on the requirements, the UPQC-ML can be designed for several levels such as 3-level, 5-level, 7-level and so on.

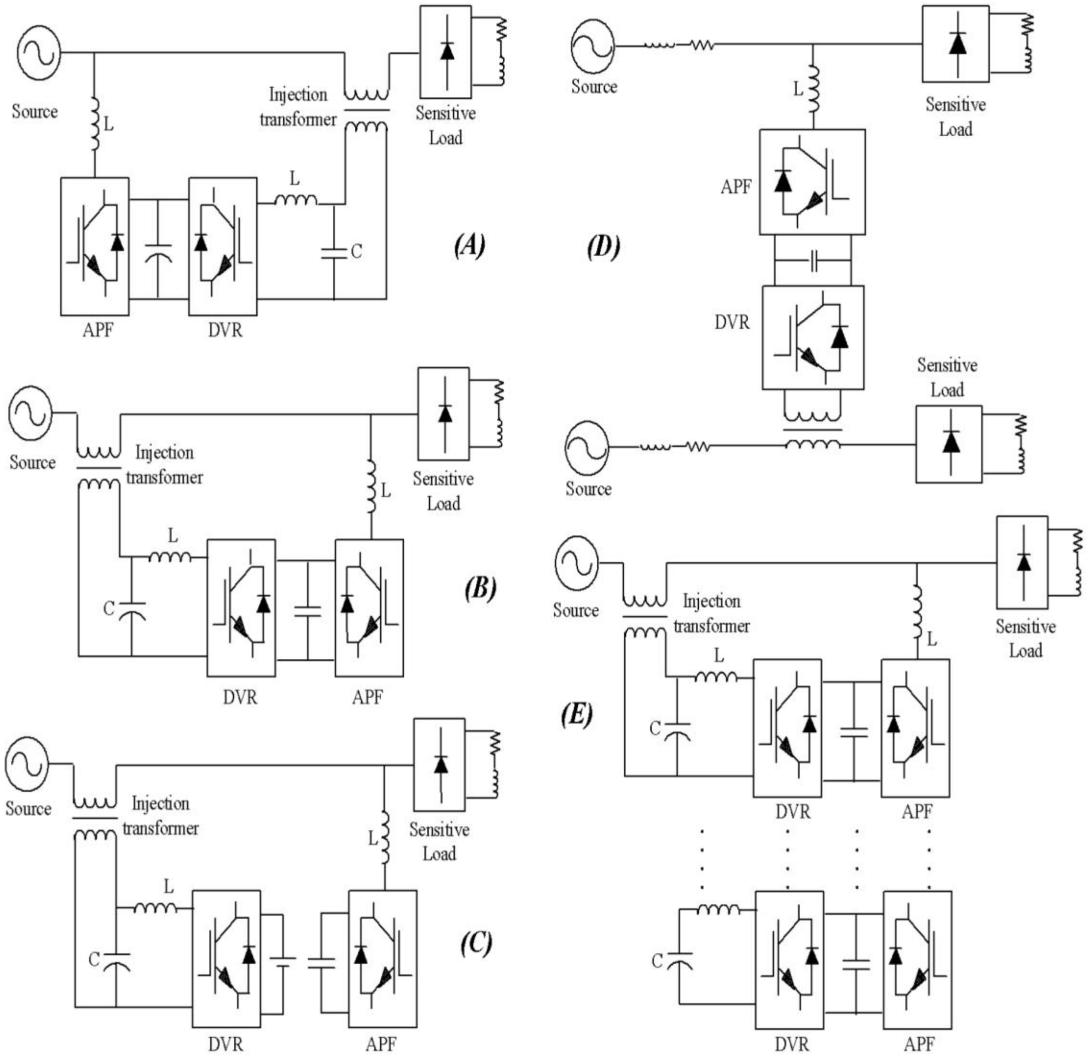


Fig. 4. Power circuit topologies. (A) Left shunt-UPQC, (B) Right shunt-UPQC, (C) Open-UPQC, (D) Interline-UPQC, (E) Multilevel-UPQC [32].

Classification of active power filter is shown in Figure 5. VSI refers to Voltage Source Inverter and CSI refers to Current Source Inverter. UPQC-MC refers to Multi-converter topology. The system is extended by adding a series-VSC in an adjacent feeder. The proposed topology can be used for simultaneous compensation of voltage and current in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected, UPQC-MD refers to Modular topology in which H-bridge module are used for capacity enhancement, UPQC-D refers to distributed, and UPQC-DG refers to UPQC for distributed generation integrated UPQC. DG sources are connected to a DC link instead of energy storage device in the UPQC as an energy source.

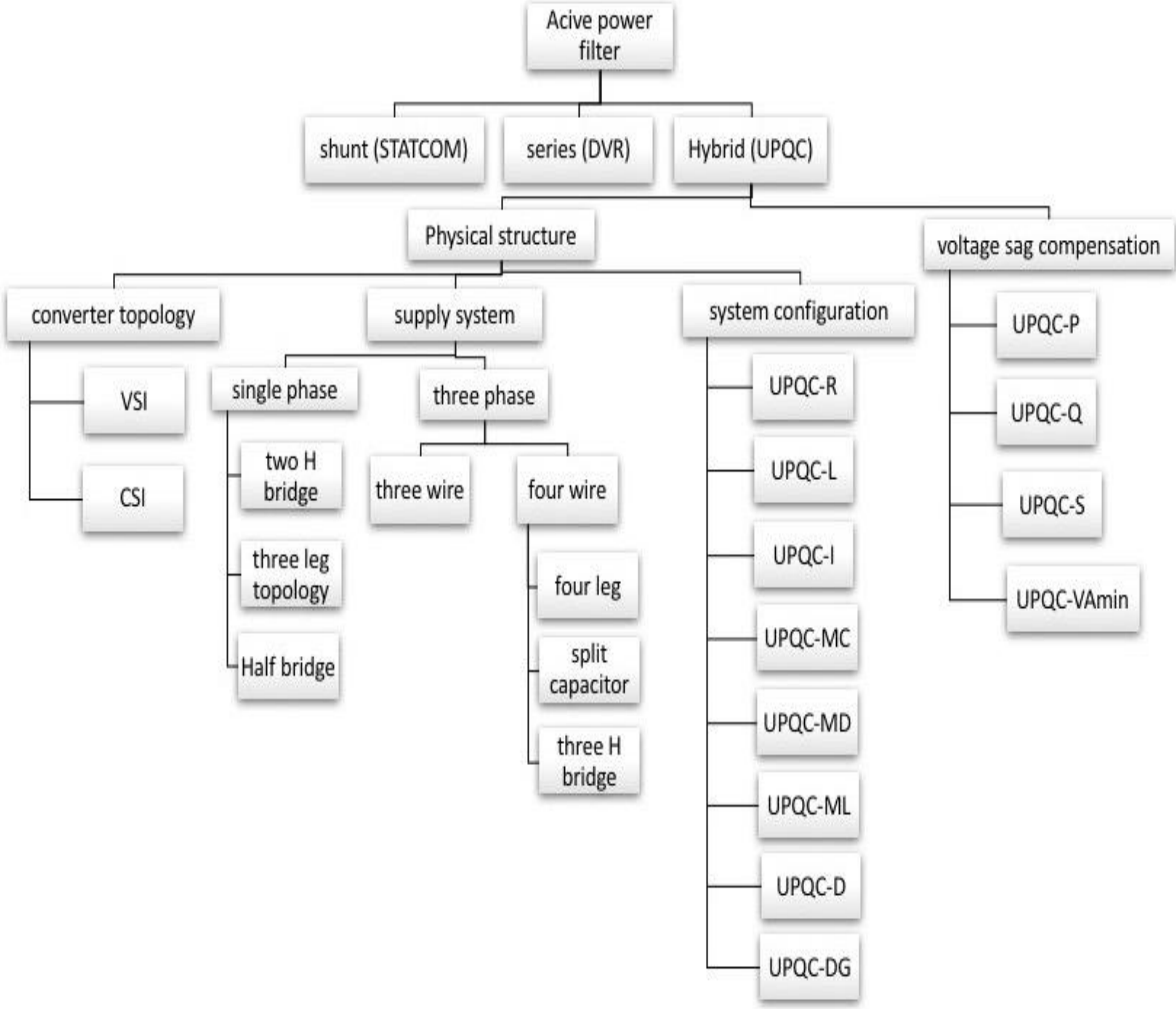
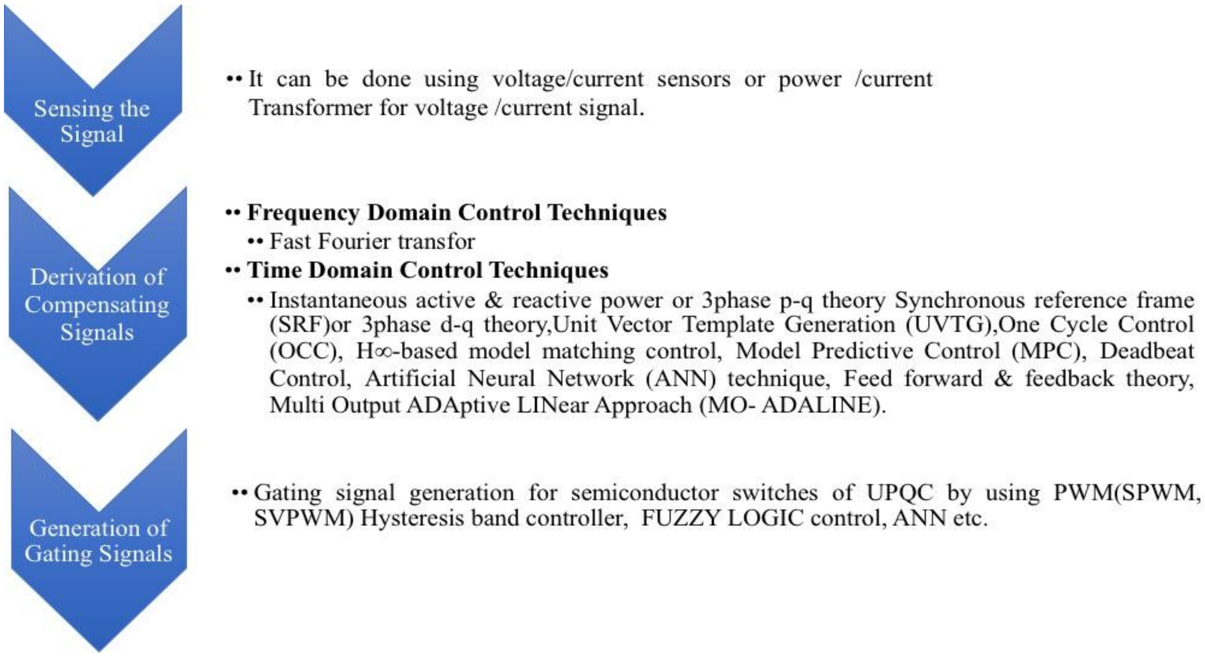


Fig. 5. Classification of UPQC.

Now a day's, due to increase in energy supplied by renewable energy sources, the most interesting topology is UPQC it is being studied for challenges in integrating distributed generation to Micro-grid.

V. Control Of UPQC

Control strategy play very important role in system's performance. The control strategy of UPQC follow three steps. Firstly, sensing the voltage signals by using power transformer or voltage sensor and current signals by using current transformer or current. In second step derivation of compensating commands in terms of voltage and current levels. The instantaneous active and reactive power (p-q theory), and Synchronous reference frame method (d-q theory) are the most widely used time domain control techniques for deriving compensating commands. The third step is, the generation of gating signals for semiconductor switches of UPQC using PWM, hysteresis or fuzzy logic based control techniques.



VI. Conclusion

With a fast-increasing number of applications of industry electronics connected to the distribution systems today, including non-linear, switching, reactive, single-phase and unbalanced three-phase loads, a complex problem of power quality evolved characterized by the voltage and current harmonics, unbalances, low Power Factor (PF). UPQC can deal with both load current and supply voltage disruptions. This paper presents a review on custom power devices, topologies of UPQC and control techniques used to enhance the power quality. The UPQC can mitigate voltage related 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. UPQC can improve power quality in Distributed Generation & Micro-grid.

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