1. Introduction

It has been always a challenge to maintain the quality of electric power within the acceptable limits. The adverse effects of poor power quality are well discussed. In general, poor power quality may result into increased power losses, abnormal and undesirable behaviour of equipments, interference with nearby communication lines, and so forth. The widespread use of power electronic based systems has further put the burden on power system by generating harmonics in voltages and currents along with increased reactive current. The term active power filter (APF) is a widely used terminology in the area of electric power quality improvement. APFs have made it possible to mitigate some of the major power quality problems effectively. Extensive and well-documented surveys on the APF technologies covering several aspects are provided in. This paper focuses on a unified power quality condition (UPQC). The UPQC is one of the APF family members where shunt and series APF functionalities are integrated together to achieve superior control over several power quality problems simultaneously. This thesis is intended to provide a comprehensive review on the topic of UPQC.

It is noticed that more than half of the papers on UPQC have been reported in the last five years, which indeed suggest the rapid interest in utilizing UPQC to improve the quality of power at the distribution level. These research papers are broadly classified into two major groups based on:

1) Physical structure of the UPQC
2) Method used to compensate sag/dip in the source voltage.

It is noticed that several interesting topologies/configurations can be realized to form a UPQC system. The UPQC is then categorized based on:

1) Type of converter (current or voltage source)
2) Supply system (single phase two-wire, three-phase three-wire and four-wire)
3) Recently developed new system configurations for single-phase and/or three-phase system.

Furthermore, it is found that there are several acronyms, such as, UPQC-P, UPQC-Q, UPQC-L, and UPQC-R that are typically addressed by researchers. These acronyms are very useful to give a broad overview on the research aspect under consideration. Therefore, this thesis also aims at It has been always a challenge to maintain the quality of electric power within the acceptable limits. The adverse effects of poor power quality are well discussed. In general, poor power quality may result into increased power losses, abnormal and undesirable behaviour of equipments, interference with nearby communication lines, and so forth. The widespread use of power electronic based systems has further put the burden on power system by generating harmonics in voltages and currents along with increased reactive current. The term active power filter (APF) is a widely used terminology in the area of electric power quality improvement. APFs have made it possible to mitigate some of the major power quality problems effectively. Extensive and well-documented surveys on the APF technologies covering several aspects are provided in. This paper focuses on a unified power quality condition (UPQC). The UPQC is one of the APF family members where shunt and series APF functionalities are integrated together to achieve superior control over several power quality problems simultaneously. This thesis is intended to provide a comprehensive review on the topic of UPQC.

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1.2. literature review

In my thesis work, we can compensate for different power quality phenomena, such as: voltage imbalance, flicker, harmonics and reactive currents by developing a simulink model of Left Shunt UPQC (UPQC-L). UPQC-L is a combination of series and shunt active filters connected in cascade via a common dc link capacitor. The series active filter inserts a voltage, which is added at the point of the common coupling (PCC) such that the load ends voltage remains unaffected by any voltage disturbance. The main objectives of the shunt active filter are: to compensate for the load reactive power demand and unbalance, to eliminate the harmonics from the supply current, and to regulate the common dc link voltage.

There are two important types of APF, namely, shunt APF and series APF. The shunt APF is the most promising to tackle the current-related problems, whereas, the series APF is the most suitable to overcome the voltage-related problems. Since the modern distribution system demands a better quality of voltage being supplied and current drawn, installation of these APFs has great scope in actual practical implementation.

However, installing two separate devices to compensate voltage- and current-related power quality problems, independently, may not be a cost effective solution. That described a system configuration in which both series and shunt APFs were connected back to back with a common dc reactor. They named this device as unified power quality conditioner (UPQC), and since then the name UPQC has been popularly used by majority of the researchers.

The back-to-back inverter topology has been also addressed as series–parallel converter, unified APF (UAPF), universal active power line conditioner universal power quality conditioning system (UPQS), load compensation active conditioner, universal active filter and so forth. In construction, a UPQC is similar to a unified power flow source inverters (VSIs) that are connected to a common dc energy storage element. A UPFC is employed in power transmission system whereas UPQC is employed in a power distribution system, to perform the shunt and series compensation simultaneously. However, a UPFC only needs to provide balance shunt and/or series compensation, since a power transmission system generally operates under a balanced and distortion free environment. On the other hand, a power distribution system may contain dc components, distortion, and unbalance both in voltages and currents. Therefore, a UPQC should operate under this environment while performing shunt and/or series compensation.

The main purpose of a UPQC is to compensate for 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. Fig.5.1 shows a single-line representation of the UPQC system configuration. 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 \( L_{SH} \) is used to interface the shunt inverter to the network. It
Also helps in smoothing the current wave shape. Sometimes an isolation transformer is utilized to electrically isolate the inverter from the network.

3) A common dc link that can be formed by using a capacitor or an inductor. In Fig.1.1, the dc link is realized using a capacitor which interconnects the two inverters and also maintains a constant self-supporting dc bus voltage across it.

4) An LC filter that serves as a passive low-pass filter (LPF) 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 current or voltage rating of the series inverter.

In principle, UPQC is an integration of shunt and series APFs with a common self-supporting dc bus. The shunt inverter in UPQC is controlled in current control mode such that it delivers a current which is equal to the set value of the reference current as governed by the UPQC control algorithm. Additionally, the shunt inverter plays an important role in achieving required performance from a UPQC system by maintaining the dc bus voltage at a set reference value. In order to cancel the harmonics generated by a nonlinear load, the shunt inverter should inject a current as governed by following equation:

\[ ISH(\omega t) = IS^*(\omega t) - IL(\omega t) \]

where \( ISH(\omega t) \), \( IS^*(\omega t) \) and \( IL(\omega t) \) represent the shunt inverter current, reference source current, and load current, respectively. Similarly, the series inverter of UPQC is controlled in voltage control mode such that it generates a voltage and injects in series with line to achieve a sinusoidal, free from distortion and at the desired magnitude voltage at the load terminal. The basic operation of a series inverter of UPQC can be represented by the following equation:

\[ VSR(\omega t) = V^*L(\omega t) - VS(\omega t) \]

where \( VSR(\omega t) \), \( V^*L(\omega t) \) and \( VS(\omega t) \) represent the series inverter injected voltage, reference load voltage, and actual source voltage, respectively. In the case of a voltage sag condition, \( VSR \) will represent the difference between the reference load voltage and reduced supply voltage, i.e., the injected voltage by the series inverter to maintain voltage at the load terminal at reference value. In all the reference papers on UPQC, the shunt inverter is operated as controlled current source and the series inverter as controlled voltage source.

The three-phase system in abc frame is transferred into synchronous dqo frame. The system is then represented in state-space formulation. It is observed that the system is nonlinear on its states as well as on its outputs. However, to realize the model, it is first transformed as an equivalent discrete system model and then to a linear equivalent discrete system model by states reconstruction and linearization. Furthermore, the output feedback periodical switched controller is designed to stabilize the closed-loop system. During the system dynamic conditions, for example, sudden load change, voltage sag, the dc-link feedback controller should respond as fast as possible to restore the dc-link voltage at set reference value, with minimum delay as well as lower overshoot. The proportional–integral (PI)-regulator-based dc-link voltage controller is simple to implement and hence widely used by the researches. To overcome the slow response time of PI-controller-based approach, researchers have developed several alternative ways, for example, a fuzzylogic-based PI controller, fuzzy-PID controller, artificial-neural-network (ANN)-based controller, linear quadratic regulator with an integral action controller, optimized controller, PL\(D\|\mu \) controller, unified dc voltage compensator and so on.

1.3. UPQC Classification

In this section, the classification of UPQC is given. Fig.1.2 shows a pictorial view for the classification of UPQC. The UPQC is classified in two main groups: 1) based on the physical structure and 2) on the voltage sag compensation approach used. Former type is considered as voltage sag compensation is one of the important functionalities of UPQC.

A. Physical Structure

The UPQC can be classified based on the physical structure used to tackle the power quality problems in a system under consideration. The key parameters that attribute to these classifications are: 1) type of energy storage device used; 2) number of phases; and 3) physical location of shunt and series inverters. Recently developed new topologies and/or system configurations for UPQC have been also discussed in this section.

1.3.1 Classification Based on the Converter Topology:

In a UPQC, both shunt and series inverters share a common dc link. The shunt inverter is responsible to regulate this self-supporting dc link at a set reference value. The UPQC may be developed using a pulse width modulated (PWM) or hysteresis controller based current source inverter(CSI) that shares a common energy storage device used; 2) number of phases; and 3) physical location of shunt and series inverters. Recently developed new topologies and/or system configurations for UPQC have been also discussed in this section.

The dc current in the inductor is regulated such that the average input power is equal to the average output power plus the power losses in the UPQC. The CSI-based UPQC topology is not popular because of higher losses, cost, and the fact that it cannot be used in multilevel configurations.
The second topology, a most common and popular converter topology for UPQC, consists of PWM VSI that shares a common energy storage capacitor $CDC$. Fig.1.1 depicts single-line representation of a VSI-based UPQC system configuration. Almost all the reported work on the UPQC dominantly uses the VSI-based topology. The advantages offered by VSI topology over CSI include lighter in weight, no need of blocking diodes, cheaper, capability of multilevel operation, and flexible overall control.

1.3.2 Classification Based on the Supply System: The ac loads or equipments on the power system can be broadly divided into single-phase and three-phase, supplied by single-phase (two wire) or three-phase (three-wire or four-wire) source of power. To mitigate the power quality problems in these systems, different UPQC configurations are possible and are classified based on the type of the supply system. The voltage-related power quality problems are similar for both single- and three-phase systems except an additional voltage unbalance compensation needed in the case of a three-phase system. For a single-phase system, the load reactive current and current harmonics are the major issues. In the case of three-phase three-wire (3P3W) system, one needs to consider current unbalance apart from reactive and harmonics current. Furthermore, the three-phase four-wire (3P4W) system requires an additional neutral current compensation loop. Fig.2.4 shows the most popular UPQC system configuration to compensate the power quality problems in single-phase two wire (1P2W) supply system consisting of two H-bridge inverters (total eight semiconductor switches. It represents the VSI-based 1P2W UPQC topology.
A CSI-based topology can also be realized for 1P2W UPQC. Nasiri and Emadi introduced two additional reduced part configurations for single phase UPQC, namely, three-leg single-phase UPQC (total six semiconductor switches) shown in Fig.2.5 and half-bridge single-phase UPQC (total four semiconductor switches) shown in Fig.2.6. These topologies can be considered for low-cost low-power applications.

In a three-leg topology, the series inverter consists of switches S1 and S2 (leg one), whereas, switches S3 and S4 are for shunt inverter (leg two). The third leg, switches S5 and S6, is common for both the series and shunt inverters. The half-bridge topology consists of one leg each for shunt and series inverters. The reduced switching devices may affect the compensation performance of UPQC. The half-bridge topology-based UPQC systems have considered a bidirectional two H-bridge dc/dc-isolated converter topology to isolate UPQC shunt and series inverters from each other. The two inverters can be connected with each other using a high-frequency transformer. Like bidirectional-isolated dc/dc converter, the power transfer between two inverters can be controlled by adjusting voltage phase shift between them.

Several nonlinear loads, such as, adjustable speed drives fed from 3P3W, current regulator, frequency converters, arc welding machines, and arc furnace, impose combinations of previously listed power quality problems. A 3P3W VSI-based UPQC is depicted in Fig.1.7. It is the most widely studied UPQC system configuration. Apart from the three phase loads, many industrial plants often consist of combined loads, such as, a variety of single-phase loads and three-phase loads, supplied by 3P4W source. The presence of fourth wire, the neutral conductor, causes an excessive neutral current flow and, thus, demands additional compensation requirement. To mitigate the neutral current in 3P4W system, various shunt inverter configurations have been attempted, namely, two split and three H-bridge. Figs.1.8 – 1.10 show the 3P4W UPQC configurations based on 2C, 4L, and 3HB topologies. The 2C topology consists of two split capacitors on the dc side. The midpoint of the capacitor, expected to be at zero potential, is used as connection point for the fourth wire. In 2C topology, it is important to maintain equal voltages across both the capacitors to avoid the flow of circulating current. This requires an additional control loop for dc bus capacitor voltage regulation in 2C topology. In 4L topology, as depicted in Fig.1.9, an additional leg (two semiconductor switches) is used to compensate the load neutral current. The 4L topology may offer better control over neutral current due to the dedicated fourth leg. The 3HB topology uses three units of single phase H-bridge inverters connected to the same dc bus of the UPQC. Fig.1.10 shows a UPQC system configuration where the shunt inverter consists of 3H-bridges. In the series inverter is configured as 3HB while the shunt inverter is realized as 2C to compensate the neutral current. Similarly, 3HB configuration for series inverter for 3P3W UPQC system. Furthermore, a configuration where both shunt and series inverters are realized as 3HB units (total 24 semiconductor switches) is also possible. A comparative study, using 2C, 4L., and 3HB topologies for shunt active filters is equally applicable for the shunt part of UPQC system. For high-voltage applications, for the reduction in UPQC system
Voltage requirement by a factor of 1.732, the 3HB topology may be considered. However, such a configuration would increase the total number of semiconductor devices, UPQC system losses, overall size, and the cost of the system. As we know, the neutral current compensation topology consisting of 3P3W UPQC and an additional star–hexagon/T-connected transformer to circulate the zero sequence current components may also be considered.

![Fig.1.10 3P4W UPQC based on 3HB shunt inverter topology](image)

**Table 1.1 Key UPQC ACRONYMS**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>UPQC-D</td>
<td>3P3W to 3P4W distributed UPQC</td>
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<tr>
<td>UPQC-DG</td>
<td>Distributed Generator Integrated with UPQC</td>
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<tr>
<td>UPQC-I</td>
<td>Interline UPQC</td>
</tr>
<tr>
<td>UPQC-L</td>
<td>Left Shunt UPQC</td>
</tr>
<tr>
<td>UPQC-MC</td>
<td>Multi-Converter UPQC</td>
</tr>
<tr>
<td>UPQC-MD</td>
<td>Modular UPQC</td>
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<tr>
<td>UPQC-ML</td>
<td>Multi-Level UPQC</td>
</tr>
<tr>
<td>UPQC-P</td>
<td>UPQC mitigates Sag by Controlling Active Power</td>
</tr>
<tr>
<td>UPQC-Q</td>
<td>UPQC mitigates Sag by Controlling Reactive Power</td>
</tr>
<tr>
<td>UPQC-R</td>
<td>Right Shunt UPQC</td>
</tr>
<tr>
<td>UPQC-S</td>
<td>UPQC mitigates Sag by controlling both Active and Reactive Power</td>
</tr>
<tr>
<td>UPQC-VA&lt;sub&gt;min&lt;/sub&gt;</td>
<td>Minimum VA loading in UPQC</td>
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**2. Conclusion**

This paper resents a review of UPQC for improving the quality of electric power. Now after overall review of UPQC, the Distributed generation integrated with UPQC is main concern. In this the solar and wind i.e. renewable sources can be used, by keeping quality of power in acceptable limits. UPQC is one of the devices, which eliminates the voltage and current harmonics.
simultaneously. Different configurations of UPQC are briefly discussed in this paper.

**REFERENCES**


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