Enhancement of Power Quality in Transmission and Distribution System Using UPQC : A Review

Rojin R.K

P.G Scholar,
Department of Electrical and Electronics, Maria college of Engineering and Technology, Attoor, Kanyakumari, India

Ajay Amrit Raj

Assistant Professor,
Department of Electrical and Electronics, Maria College of Engineering and Technology, Attoor, Kanyakumari, India

Abstract

Power quality is an important measure of the performance of an electrical power system. Unified Power Quality Conditioner (UPQC) is a versatile custom power device used to enhance power quality. This paper presents a literature review on the broad overview of the structure of UPQC, operation strategy, control strategies using conventional and intelligent controllers and the performance of UPQC for power quality improvement. UPQC is an integration of shunt and series compensation to limit the harmonic contamination within 5 %, the limit imposed by IEEE-519 standard. By controlling the switching of voltage source inverters (VSI) of UPQC, better compensation performance can be achieved. Therefore in this paper the controlling operation of UPQC is explained in detail.

Keywords- *Distribution Static Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR), power quality, reactive power compensation, Unified Power Quality Conditioner (UPQC), voltage sag and swell compensation.*

1. Introduction

As more sensitive loads have come into wide use, power quality is a big issue of customers and utilities. Poor power quality in power system could be due to many factors such as voltage sag, voltage swell, harmonics and inter harmonics in current and voltages, voltage outage, poor power factor, overcorrection of power factor and unbalanced loads. Different devices such as rectifiers, inverters, adjustable speed drives, computer power supplies, furnaces and traction drives lead to non-linear current waveforms. These nonlinear loads with semiconductor devices degrade electric power quality, the quality degradation leads to low power-factor, low efficiency, overheating of transformers and so on. It is well known that the reactive power demand causes a drop in the feeder voltage and increases the losses. The presence of harmonic currents can cause additional losses and voltage waveform distortions, and so cause poor power quality. Also, the number of sensitive loads that require ideal sinusoidal supply voltages for their proper operation has increased. The increasing use of electronic equipment sensitive to power variations drives the interest in power conditioning technologies. So, in order to keep the power quality within limits proposed by standards, it is necessary to include some sort of compensation.

The power electronic based power conditioning devices can be effectively utilized to improve the quality of power supplied to customers. The unified power-quality conditioner (UPQC) has been widely studied by many researchers as an ultimate device to improve power quality [1]. Such a solution can compensate for different power quality phenomena, such as: sags, swells, voltage imbalance, flicker, harmonics and reactive currents [2].

2. Unified Power Quality Conditioner (UPQC)

To provide a balance, distortion-free, and constant magnitude power to sensitive load and, at the same time, to restrict the harmonic, unbalance, and reactive power demanded by the load and hence to make the overall power distribution system more healthy, the unified power quality conditioner (UPQC) is one of the best solutions. Custom power devices have been proposed for enhancing the quality and reliability of electrical power. Unified PQ conditioner (UPQC) is a versatile custom power device which consists of two inverters connected back-to-back through a common dc-link capacitor and deals with both load current and supply voltage imperfections. UPQC can simultaneously act as shunt and series active power filters. The series part of the UPQC is known as dynamic voltage restorer (DVR). It is used to maintain balanced, distortion free nominal voltage at the load. The shunt part of the UPQC is known as distribution static compensator (DSTATCOM), and it is used to compensate load reactive power, harmonics and balance the load currents thereby making the source current balanced and distortion free with unity power factor. Voltage rating of dc-link capacitor largely influences the compensation performance of an active filter [3].

Unified Power Quality Conditioner (UPQC) consists of two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus. Unified PQ conditioner (UPQC) is a versatile custom power device which consists of two voltage source converters (VSC) connected back-to-back through a common dc-link capacitor. UPQC 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 end 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. The system configuration of a single-phase UPQC is shown in Fig. 1.1

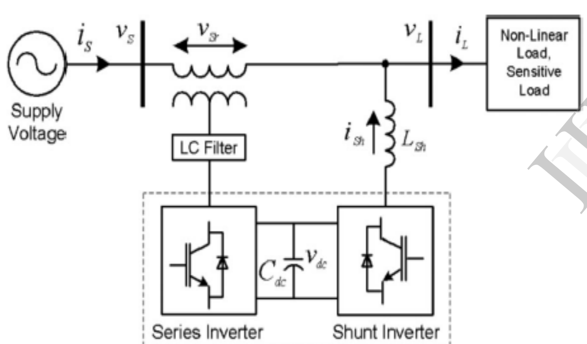

Fig. 1.1 UPQC general block diagram

Whenever the supply voltage undergoes sag then series converter injects suitable voltage with supply. Thus UPQC improves the power quality by preventing load current harmonics and by correcting the input power factor. 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 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.

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. 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 [4]. In the case of a voltage sag condition, actual source voltage 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 except in which the operation of series and shunt inverters is interchanged.

3. Structure of UPQC

The shunt active filter is responsible for power factor correction and compensation of load current harmonics and unbalances. Also, it maintains constant average voltage across the DC storage capacitor. The shunt part of the UPQC consists of a VSI (voltage source inverter) connected to the common DC storage capacitor on the dc side and on the ac side it is connected in parallel with the load through the shunt interface inductor and shunt coupling transformer. The shunt interface inductor, together with the shunt filter capacitor are used to filter out the switching frequency harmonics produced by the shunt VSI. The shunt coupling transformer is used for matching the network and VSI voltages. The series active filter compensation goals are achieved by injecting voltages in series with the supply voltages such that the load voltages are balanced and undistorted, and their magnitudes are maintained at the desired level. This voltage injection is provided by the dc storage capacitor and the series VSI. Based on measured supply and/or load voltages the control scheme generates the appropriate switching signals for the series VSI switches. The output voltages of the series VSI do not have the shape of the desired signals, but contain switching harmonics, which are filtered out by the series low pass filter. The amplitude, phase shift, frequency and harmonic content of injected voltages are controllable.

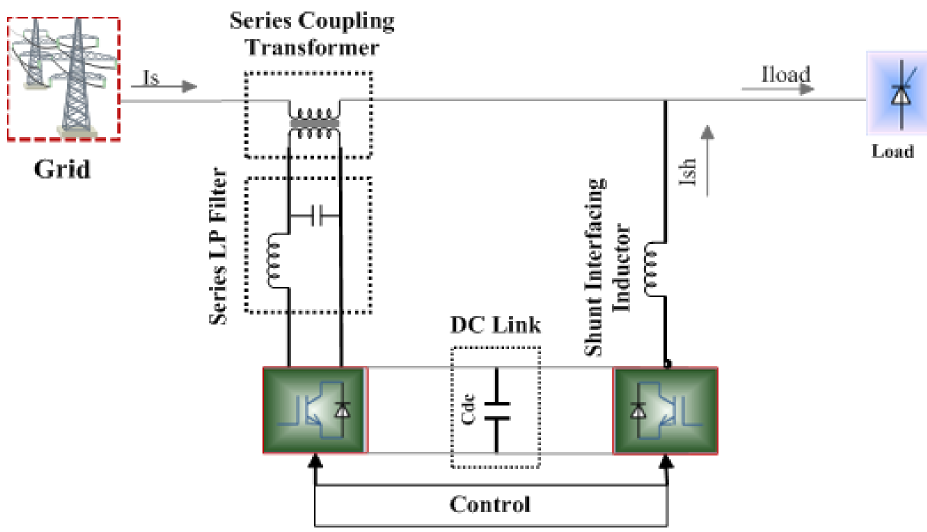

Fig. 2 Basic UPQC system configuration

The design of UPQC power circuit includes the selection of the following three main parameters:
a. shunt interface inductors
b. dc link reference voltage
c. dc link capacitor

4. Components of UPQC

The power circuit of UPQC generally consists of common energy storage unit, DC/AC converter, LC filter and injection transformer.

4.1. Energy Storage

DC link (energy storage) supplies required power for compensation of load voltage during voltage sag/swell or current harmonics. UPQC generally consists of two voltage sourced inverters (series and shunt) using IGBT which operate from a common DC link storage capacitor. DC link (DC-DC converter) connected to the battery energy storage system is also used. Voltage interruption can also be eliminated by the use of a UPQC with distributed generation. Split capacitor topology is used in the existing conventional method.

4.2. DC/AC Inverter

Inverter circuits convert DC power to AC power. Types of inverter are voltage source (fed) inverter (VSI) and current source (fed) inverter. VSIs are preferred for both shunt and series sides. The series converters are generally composed of 6 bridge VSI. Shunt converters are generally composed of 6 bridge VSIs for three phase. There are also some studies using 6 bridge inverters for series converter and three single phase H bridge inverters for shunt converter. Current source inverters are preferred for both shunt and series sides in.

4.3. LC Filter

The effect of harmonics generated by the inverter can be minimized using inverter side and line side filtering. Inverter side filtering scheme has the advantage of being closer to harmonic source thus high order harmonic currents are prevented to penetrate in to series injection transformer but this scheme has the disadvantages of causing voltage drop and phase angle shift in the fundamental component of the inverter output. In line side filtering scheme, harmonic currents penetrate into series injection transformer but voltage drops and phase shift problems do not disturb the system. Inverter side LC filtering is generally preferred for both series sides and inverter side L filtering is generally preferred for shunt side. Inverter side C filtering is preferred for shunt side in.

4.4. Injection Transformer

Series converter of UPQC is most of time in standby mode and conduction losses will account for the bulk of converter losses during the operation. In this mode, the series injection transformer works like a secondary shorted current transformer using bypass switches delivering utility power directly to the load.

5. Operation Strategy

Loads, such as, diode bridge rectifier or a thyristor bridge feeding a highly inductive load, presenting themselves as current source at point of common coupling (PCC), can be effectively compensated by connecting an APF in shunt with the load. On the other hand, there are loads, such as Diode Bridge having a high dc link capacitive filter. These types of loads are gaining more and more importance mainly in forms of AC to DC power supplies and front end AC to DC converters for AC motor drives. For these types of loads APF has to be connected in series with the load. The voltage injected in series with the load by series APF is made to follow a control law such that the sum of this injected voltage and the input voltage is sinusoidal [5]. Thus, if utility voltages are non-sinusoidal or unbalanced, due to the presence of other clients on the same grid, proper selection of magnitude and phase for the injected voltages will make the voltages at load end to be balanced and sinusoidal. The shunt APF acts as a current source and inject a compensating harmonic current in order to have sinusoidal, in phase input current and the series APF acts as a voltage source and inject a compensating voltage in order to have sinusoidal load voltage. The developments in the digital electronics, communications and in process control system have increased the number of sensitive loads that require ideal sinusoidal supply voltage for their proper operation. In order to meet limits proposed by standards it is necessary to include some sort of compensation. In the last few years, solutions based on combination of series active and shunt active filter have appeared [6]. Its main purpose is to compensate for supply voltage and load current imperfections, such as sags, swells, interruptions, imbalance, flicker, voltage imbalance, harmonics, reactive currents, and current unbalance.

6. Capacity Enhancement of UPQC

In high power applications, the filtering task cannot be performed for the whole spectrum of harmonics by using a single converter due to the limitations on switching frequency and power rating of the semiconductor devices. Therefore, compensating the reactive harmonic components to improve the power quality of the DG integrated system as well as to avoid the large capacity centralized APF, parallel operation of multiple low power APF units are increasing. Like APF, UPQC can also be placed at the PCC or at a high voltage distribution line as a part of DG integrated network or in micro grid system to work both in interconnected or islanded mode. At this place, capacity enhancement is achieved by using multilevel topologies to reach the higher power levels. These options are as follows:

i. Multi-level converter based UPQC
ii. Multi-module converter based UPQC
iii. Multi-module (power cell) unit based UPQC

A multi-level converter is proposed to increase the converter operation voltage, avoiding the series connection of switching elements. However, the multilevel converter is complex to form the output voltage and requires an excessive number of back-connection diodes or flying capacitors [7] or cascade converters [8]. A multi-module H-bridge UPQC can also be connected to the distribution system without series injection transformers. It has the flexibility in expanding the operation voltage by increasing the number of H-bridge modules. Here each phase consists of several pairs of H-bridge modules isolated through a single-phase multi-winding transformer. These Multi-module techniques allow the symmetrical distribution of the load power among the components of the topology, but the classical design procedure must be modified or refined to ensure the power cell components should be within its maximum ratings. Therefore, a new design procedure of UPQC with a feature of extending capacity based on a modular approach is presented in [9], where H-bridge power cells are added in each single phase arrangement depending on the required compensating power [10].

7. Controllers

Voltage source inverters are used for shunt and series compensation. One may note that both voltage source inverters are supplied from a common dc link capacitor. For the successful operation of the UPQC, the dc capacitor voltage should be at least 150 % of maximum line-line supply voltage. To regulate the capacitor voltage constant, and for achieving load compensation or harmonic current compensation either a conventional controller or a fuzzy controller could be used. These controllers are used to trigger the semiconductor switches used in both voltage source inverters. Controllers give firing pulses in order to turn on the switches at proper intervals of time for achieving power quality enhancement. When the capacitor voltage falls below a particular value switches are turned on to energize the capacitor, so that the voltage required for achieving load compensation and voltage regulation has to maintained at all periods of time.

7.1. Conventional Controllers

The P controller or PI controller can be used effectively to control the operation of UPQC over a long period. The PI controllers, because of their simple structures, are still the most commonly used control techniques in power systems. Thus the control structure of UPQC has been divided into shunt compensator and series compensator control circuits.

7.1.1. Shunt Compensation Control Circuit

The shunt compensation control circuit is used to control the operation of shunt active filter of UPQC. The shunt active filter (DSTATCOM) is used to compensate current related problems. The shunt converter is responsible for regulating the common DC-link voltage and it is used to compensate load reactive power, harmonics and balance the load currents thereby making the source current balanced and distortion free with unity power factor. Compensation performance of shunt active filter depends on the turning on and turning off of semiconductor switches used in shunt active filter. The control circuit for shunt active filter is shown in fig 3. The switching commands for the VSI switches are generated using hysteresis band current control method. In a hysteresis controller the reference compensation current is compared with the actual current that is being injected by the compensation circuit. Hysteresis current controller scheme is based on a feedback loop, generally with two-level comparators. The switching commands are issued whenever the error limit exceeds a specified tolerance band "$\pm h$."The hysteresis controller has the advantage of peak current limiting capacity, extremely good dynamic performance, simplicity in implementation and independence from load parameter variations [11].

The PI controller is used to maintain voltage across dc-link capacitor. The conventional PI controllers, because of their simple structures, are still the most commonly used control techniques in power systems. When PI based controller is used, the dc link voltage is sensed at regular intervals and is compared with a reference value. Here dc input voltage and reference voltage is compared and the error signal thus processed is fed to PI controller. Thus when the voltage across the dc link capacitor falls below a sufficient value, the PI controller turns on the semiconductor switches so as to maintain the voltage constant.

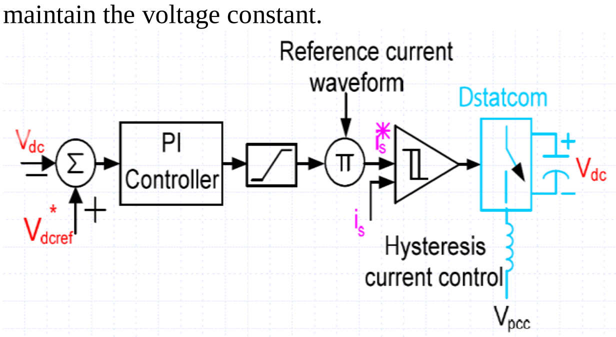

Fig 3: Control block diagram of shunt active filter

7.1.2. Series Compensation Control Circuit

The series compensation control circuit is used to control the operation of series active filter (DVR) of UPQC. Shunt active filter maintains balanced, sinusoidal, distortion free nominal voltage at the load. The control circuit of series active filter is shown in fig 4. Shunt active filter injects voltage through series transformer when a voltage drop occurs.

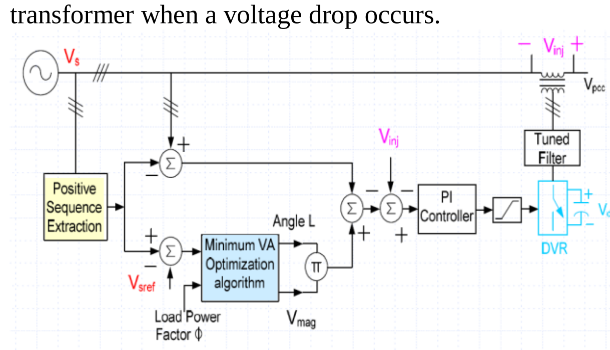

Fig 4: Control block diagram of series active filter

7.2. Fuzzy Logic Controller

The control of UPQC based on the conventional PI control is prone to severe dynamic interaction between active and reactive power flows. The Fuzzy Controller is basically nonlinear and adaptive in nature. The results obtained through FC are superior in some cases. The inherent characteristics of the changing loads, complexity and multi-variable conditions of the power system limits the conventional control methods giving satisfactory solutions. Artificial intelligence based gain scheduling is an alternative technique commonly used in designing controllers for non-linear systems. Fuzzy system transforms a human knowledge into mathematical formula [12-14]. Therefore, fuzzy set theory based approach has emerged as a complement tool to mathematical approaches for solving power system problems. Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping. Fuzzy control is based on a logical system called fuzzy logic which is much closer in spirit to human thinking and natural language than classical logical systems. Nowadays fuzzy logic is used in almost all sectors of industry and science. One of them is using fuzzy logic controller with UPQC. The main goal of UPQC in interconnected power systems is to enhance the power quality of the system. The balance between production and consumption. Control algorithms based on fuzzy logic have been implemented in many processes [15, 16]. The application of such control techniques has been motivated by the following reasons:

1) Improved robustness over the conventional linear control algorithms;

2) Simplified control design for difficult system models;
3) Simplified implementation

To improve the performance of UPQC, numerous techniques have been proposed for their design, such us using intelligent optimization methods (genetic algorithms, neural networks, fuzzy and many other nonlinear control techniques). In recent years, fuzzy logic control has emerged as a powerful tool and is starting to be used in various power system applications .The application of fuzzy logic control techniques appears to be most suitable one whenever a well-defined control objective cannot specified, the system to be controlled is a complex one, or its exact mathematical model is not available [17]. The fuzzy logic controller designed can be of the form shown in Fig. 5.

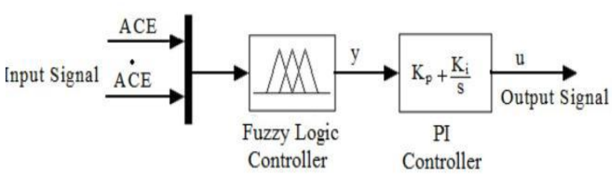

Fig 5: Fuzzy Logic Controller

The fuzzy logic controller is comprised of four main components: the fuzzification, the inference engine, the rule base, and the defuzzification [13]. The fuzzifier transforms the numeric/crisp value into fuzzy sets; therefore this operation is called fuzzification. The main component of the fuzzy logic controller is the inference engine, which performs all logic manipulations in a fuzzy logic controller. The rule base consists of membership functions and control rules. Lastly, the results of the inference process is an output represented by a fuzzy set, however, the output of the fuzzy logic controller should be a numeric/crisp value. Therefore, fuzzy set is transformed into a numeric value by using the defuzzifier. This operation is called defuzzification [18].

8. Conclusion

In distribution system power Quality problem is a major issue. Out of the custom power devices UPQC is the most effective device for mitigating these issues. This paper presented review on the UPQC to enhance the electric power quality at transmission and distribution level. The paper discussed about the structure, components, operation strategy and applications of UPQC. Mitigation of power quality problems are also explained in detail. The controllers play an important role in the performance enhancement of UPQC. 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.

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