Enhancement of Power Quality by UPQC: A Review

Sukhjinder Singh, Mukul Chankaya

***Abstract*— As the power electronic based loads are increasing the power quality issues are becoming more and more significant in these days. Due to decrease in cost of power electronic devices, fast switching characteristics and increased efficiency of power converters and energy storage devices the use of Custom Power devices and Flexible AC Transmission Systems is increased for solution of power quality problems. Unified Power Quality Conditioner (UPQC) is a custom power device. UPQC can be used for solution of both voltage and current related problems. In this paper, a review on circuit topologies of Unified Power Quality Conditioner is presented. This study helps the researchers to select the power circuit configuration according to requirement.**

***Index Terms*— Unified Power Quality Conditioner (UPQC), Active Power Filter (APF), Dynamic Voltage Restorer (DVR), Reactive Power Compensation.**

I. INTRODUCTION

The main challenge in power industry these days is power quality problems due to increase in nonlinear loads. Any problem with quality of voltage, current or frequency which causes undesired operation of equipment is treated as power quality problem. Also the increase in power from renewable energy resources is making the distribution system more susceptible to (PQ) problems [1]. These power quality problems can cause undesired operation of equipment like flickering, overheating, poor efficiency and interference with communication circuits. So the need is to improve power quality. The major problems of power quality are voltage sags/swells, flickers, interruptions, transients, variable frequency and harmonics [2]. Voltage related problems are due to variable loads and sudden switching of loads etc. Harmonics are induced in to system by non-linear loads, power electronics devices, rectifiers and inverters etc. Harmonics can affect the performance of equipment by reducing efficiency and also heating of equipment will be more and these can disturb the performance of nearby communication circuits [3]. Transients occur mainly during the starting and shut down of the generation, sudden switching of transformers and loads, by lightning surges etc. Frequency of the system is always fluctuating due to variation of load. These power quality problems can affect the performance of sensitive loads and if the variation is large then poor power quality can damage the equipment [4]. Therefore the need is to improve Power quality by minimizing these problems. Unified Power quality conditioner (UPQC) is very effective in minimizing the power quality problems as it can provide both series and shunt compensations. Therefore due to its ability to compensate both voltage and current related problems it is called unified power quality conditioner.

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II. POWER QUALITY

Power quality in electric network is the major concern in today's time. As power system is becoming more complex day by day therefore power quality emerges as major issue. Poor power quality causes malfunctioning of equipments, therefore power with proper power quality should be supplied to user [4]. Power quality problem can be detected from symptoms like flickering of lamps, communication interface, overheated elements of devices, frequent dropouts of sensitive equipments and frequent blackouts etc [5]. Therefore to protect equipment from damage and to avoid malfunctioning of equipment all the parameters of power quality should be in prescribed limits. The quality of power must fulfill the national and international standards [6]. The main power quality problems are given below.

A. Voltage variations

Voltage variations can be of two types like short duration voltage variation and long duration voltage variation. Short duration voltage variations occur for time period of less than 1min [6]. And long duration voltage variations are for more than 1min. Short duration voltage variations are due to switching on of loads which need high starting current. Short duration voltage variations can be of three types like voltage sag, voltage swell and interruption [7]. The range of short voltage variations can be from few seconds to 1min. These can be due to any fault, sudden switching on or shutting down of load and intermittent loose connections wiring. These types of voltage variations include voltage sags, voltage swells and interruptions. Voltage sag is a small decrease in line voltage from 10 to 90 percent of nominal line voltage [8]. Duration of sag can be half cycle to 1min.it can be due to starting of large inductive loads like induction motors etc. A swell is a small increase in line voltage (1.1 to 1.8 percent) of nominal line voltage [9]. Duration of swell can be half cycle to 1min. The main reason behind voltage swell can be switching in a large capacitor bank or switching off a large load. The time period for interruption is always less than 1 min [7].

In this line current or voltage reduces to less than 0.1 PU of nominal value [6]. These can be due to equipment failure or power system faults. An over voltage comes under long duration voltage variation. In this voltage increases for more than 110 percent at power frequency, and the duration is longer than 1 min [8]. These can be due to incorrect transformer tap settings and switching off load [6]. An under voltage can be define as decrease in voltage to less than 90

percent at power frequency, And the duration is more than 1min [8]. This can be due to switching off a capacitor bank or due to switching on large load [9]. If the supply voltage is not available for more than 1 min, then it is called sustained interruption [7]. We can say that the unavailability of supply for the time duration more than 1 min is called sustained interruption. It can be due to any fault or failure of any generating unit etc.

B. *Harmonics*

Harmonics can be defined as sinusoidal voltages or currents with a frequency that is integer multiple of the fundamental frequency [8]. Like if the fundamental frequency is f then the harmonics will be 2f, 3f, 4f, 5f……..etc. harmonics can be a major reason for distorted wave, and are harmful for the sensitive equipments, these can lead to undesired operation of electrical devices, heating of appliances and interference with communication circuits [3].Harmonics also leads to unwanted tripping of relays.

C. *Transients*

Transients can be divided in to two parts first one is impulsive transient, and second is oscillatory transient. Impulsive transient is a brief unidirectional variation in voltage or current on power line [9]. The main reasons behind these types of transients are lightning surges, switching phenomenon switching in of distribution system [10]. Effect of this type of transients can be reduced by transient voltage suppressors like zener diode etc. oscillatory transient is a brief bidirectional variation in current or voltage on a power line, the major reason behind these types of transients is switching of capacitor banks [11]. These can be harm full to the equipment, because these will lead to undesired operation of equipment. Transients are major cause of heating of apparatus and interference to communication circuit [12].

III. Unified Power Quality Conditioner (UPQC)

Unified power quality conditioner (UPQC) can be used to manage power quality by reducing voltage sag, voltage swell, and harmonics and provide reactive power to system. UPQC consists of a shunt Active Power Filter, and a series active power filter [2]. Both shunt and series active power filters are connected via a common dc link. A shunt active power filter is used for current-based compensation. It compensates current harmonics and reactive power. The series active power filter is used for voltage compensation [12]. It is used to compensate voltage related problems like voltage sag/swell, interruption etc. The UPQC system consists of two main sections: The control unit and the power circuit [13]. Control unit is used to detect disturbance, reference signal generation and gate signal generation etc. Power circuit consists of two voltage source converters, system protection system, injection transformers and harmonic filters [9]. In this study power circuit configuration and control unit of UPQC are given and after that field applications are discussed. The basic representation of UPQC is shown in Fig.1. The literature survey summarizes the available study related to power circuit and control unit of UPQC. The basic structure of UPQC is shown with the help of fig.1.

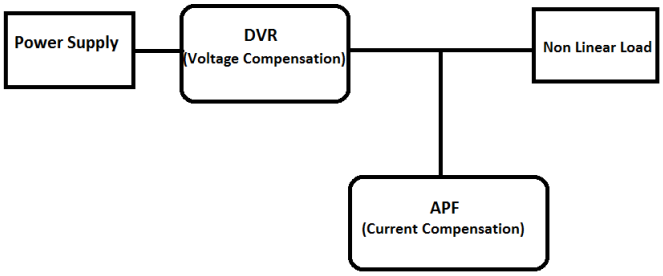


Fig.1. Basic Representation of UPQC

IV. Power Circuit

UPQC is a combination of series and shunt compensators connected through a common DC link. In this system two fully controlled dc/ac converters are used which makes the system more versatile as power conditioner. In this system the converters can have different functions of compensation depending on controller design. In this shunt active power filter can be used for current based compensations like current harmonics and reactive power compensation. It can also balance unbalancing currents [3], [4]. The series active power filter used for voltage compensations, which includes voltage harmonics and voltage sags, voltage swells etc. Both series and shunt active power filters are connected through a common dc link [3]. The UPQC system consists of two main sections: The control unit and the power circuit. Control unit is used to detect disturbance, reference signal generation and gate signal generation etc. Power circuit consists of two voltage source converters, system protection system, injection transformers and harmonic filters etc.

The paper has been mainly focused on circuit topologies and control algorithms of Unified power quality conditioner. UPQC can be used for low and medium voltage applications. Two commonly used types UPQC are 3-phase 3-wire (3P3W) and 3- phase 4-wire (3P4W) systems [5]. The second one is mainly used in secondary distribution system and first one is used in transmission and primary distribution system [6], [7]. Single phase UPQC systems are also used distributed generation systems [8]. Some other commonly used topologies are H bridge topology, multilevel topology [9], single phase UPQC with two half bridge converters, [10] are also used these days. Some topologies which are used more commonly are left-shunt UPQC [11], right- shunt UPQC [12], open UPQC [13], and interline UPQC [16] and multilevel UPQC [14]. These are some commonly used topologies of UPQC. The power circuit mainly consists of energy storage unit, DC/AC converters injection transformer and LC filters. The protection to UPQC against voltage surges and short circuit conditions is also provided [15]. Some important topologies are shown below with the help of simplified diagrams. So the power circuit basically includes AC/DC inverters, which are used to convert AC power to DC. It also includes battery energy storage system which is used to store DC power. The other main part is injection transformer which is connected in series with the line. LC filters are used to filter out high frequency components called harmonics produced by inverter circuits. These components are included in power circuit of UPQC. Different power circuit topologies are shown in fig.2. Which include left shunt UPQC, right shunt UPQC, open UPQC and interline UPQC [14]. Most

commonly UPQCs are used in distributed generation and low voltage and medium voltage operations [15].

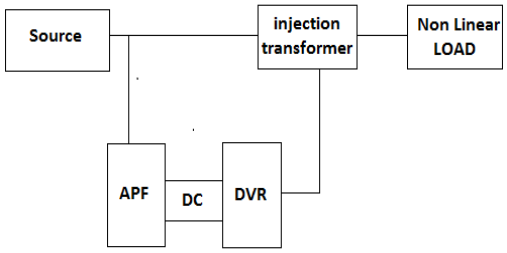
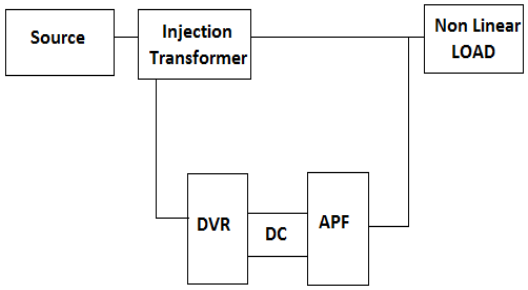
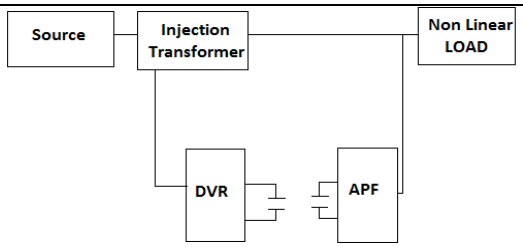
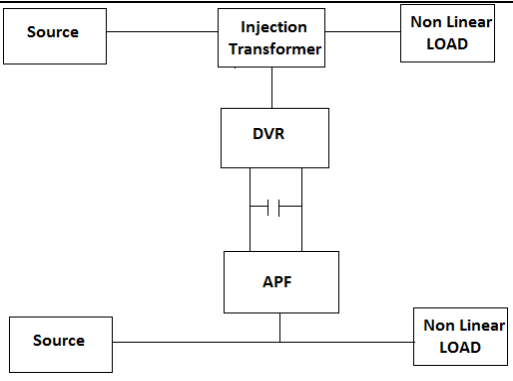
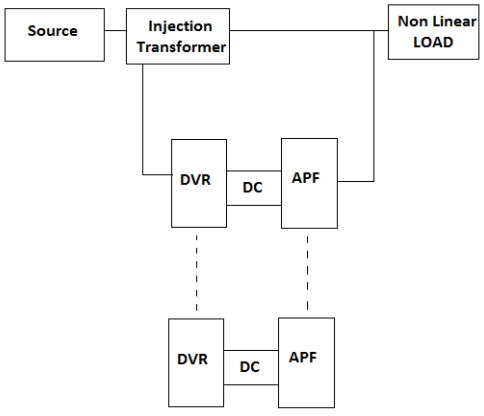
Power Circuit topology	Figure
Left Shunt UPQC	
Right Shunt UPQC	
Open UPQC	
Interline UPQC	
Multilevel UPQC	

Fig.2. Power Circuit Topologies

- Two inverter circuits are used in UPQC, one is for series compensation and other is for shunt compensation [16]. Inverter circuits convert DC power in to AC. Types of inverters are voltage source inverters and current source inverters [17]. In UPQC voltage source inverters (VSI) are preferred.
- Energy storage unit is basically a common DC link between series and shunt active power filters. It supplies required power for compensation of load voltage during voltage unbalance and current harmonics [18]. These days distributed generation is for providing DC power to Inverters, for that use of solar photovoltaic system is increasing day by day [7]. Photovoltaic generation as well as the functions of unified power quality conditioner is used simultaneously in distributed generation system [19].
- An injection transformer is used with series active power filter to inject voltage at the time of voltage variations [14]. At the time when series converter is on standby mode at that time this transformer behaves like secondary shorted current transformer and the power is delivered directly to load through by bypass switching. A novel configuration of UPQC can be connected to the distribution system without series injection transformer is presented in [20].
- Inverters generate harmonics [21], the effect of these harmonics should be minimized and for this filtering can be done on line side and on inverter side [6]. Inverter side filtering scheme can prevent higher order harmonics currents to penetrate into system because it is very close to source which is generating harmonics, but this scheme can cause phase shift of fundamental components [9]. Inverter side filtering is preferred because of the advantage of being closer to source of harmonics therefore the higher order harmonic currents are prevented to penetrate into series injection transformer [21]. There are two main disadvantage of this scheme, first one is phase angle shift in fundamental component of inverter output and second one is voltage drop [22].

V. Control Unit

The control unit plays most important role in functioning of UPQC. It is used to detect disturbance with accuracy and then generate reference signal [11]. Control should be fast and the response should be highly dynamic. The main considerations are series and shunt inverter controls [15]. Series inverter control is used to provide voltage compensations which include sag/swell detection, voltage reference generation, and generating gate signals for injection of voltage according to requirement. Shunt inverter control is used to provide current compensation [23], it includes current reference generation, generation of gating signals and DC link voltage control [24]. Voltage sag/swell must be detected fast so that reference and gate signals can be generated fast and compensation can be provided as fast as possible. The sag/swell detection methods for series inverter side are root mean square method [25], fast Fourier transforms method (FFT), peak sequence analysis

method (PSA), synchronous reference frame method (SRF) for generation of reference signal [26]. The synchronous reference frame theory can be used to extract the harmonics from supply voltage and currents. For this these days modified PLL circuit is used with SRF theory, it can operate satisfactorily under highly distorted and unbalanced system voltages. So the SRF theory can be used in control strategy to compensate the reactive power along with voltage and current harmonics under unbalanced voltage and current conditions. To generate reference signals for shunt converter instantaneous reactive power theory (IRTP) is generally preferred for calculation of reference current [27].

To generate switching signals of inverter the output signals of controller process are used. To generate gating signals for series inverter sinusoidal pulse width modulation and hysteresis controllers are employed [27]. To generate gating signals for shunt inverter hysteresis controller and predictive current regulation controller are employed [28]. The overall power balance of UPQC is maintained through the DC-link capacitor [13]. Traditional DC voltage feedback control can be used to control the DC voltage [29].

VI. CONCLUSION

The unified power quality conditioner can be used to compensate both voltage and current related problems. As Disturbances can cause unwanted operation of power equipment, it can lead to malfunction of sensitive loads. Therefore power quality should be maintained in prescribed limits, for this purpose Unified Power Quality Conditioner can be used as effective tool. So the UPQC can be used to compensate the reactive power along with voltage and current harmonics under unbalanced voltage and current conditions. It provides both series and shunt compensations. It can stabilize the voltage by reducing voltage sag/swells and interruptions and it can compensate current harmonics and improve quality of wave. There are different power circuit topologies which are used according to the requirement. By reducing power quality problems it provides balanced power to load. This paper has been mainly focused on power quality issues and converter topologies of UPQC.A number of UPQC topologies have been reviewed.

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