A NOVEL STRUCTURE OF UPQC TO CONTROL POWER QUALITY PROBLEMS IN ELECTRIC POWER SYSTEMS

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Abstract
This paper presents a control scheme for a Unified Power Quality Conditioner and introduces a new definition for "power quality''. This paper present simulation results using PSCAD/EMTDC program for compensation of power quality problems. Also this paper shows the results of the measurement of effective parameters in power quality in a typical industrial unit in the Salimi industrial city near Tabriz, IRAN, with device ION-7330 made in Power Measurement CO., CANADA.
Keywords: Power Quality, UPQC, Active Filter

1. Introduction

The technology of power electronics has progressed rapidly during recent decades and its applications are fast expanding in industrial, commercial, residential, military and utility environments. Both electric utilities and users of electrical power are becoming increasingly concerned about the quality of electric power. The term power quality has become one of the most prolific buzzwords in the power industry since the late 1980s.

In different references different definitions have been presented for power quality. For example, utilities may define power quality as reliability and show statistics demonstrating that the system is 99.98 percent reliable [1]. The manufacturer of load equipment may define quality power as those characteristics of the power supply that enable the equipment to work properly. These can be very different for different equipment and different manufacturers.

However, the most unified definition for power quality is:

Any power problem manifested in voltage, current, or frequency deviations that result in failure or miss-operation of customer equipment.

There are four major reasons for problems concerning power quality:

1. Load equipment is becoming more sensitive to power quality variations nowadays.
2. The increased utilization of adjustable speed motor drives and shunt capacitors, etc.
3. Increased awareness of power quality issues by the users.
4. Power networks interconnection between different power systems.

Energy converters such as air conditioners, refrigeration systems and renewable energy systems are the considerable sources of power quality problems. Connection of these systems to the utility results in voltage quality problems such as voltage harmonics, voltage sag/swell and voltage fluctuation as well as current quality problems such as current harmonics and imbalance currents. On the other hand, poor power quality not only results in reduction of efficiency, malfunction, production of audible noise and reduction of life cycle of EEC, but also is an origin of electric power problems on the operation of nearby installed electric apparatuses. The Unified Power Quality Conditioner (UPQC) is expected to be one of the most important systems to overcome the power quality problems in distribution systems. The distribution systems are considered as a link between producers and consumers, so they experience the voltage and current quality problems of both producer and/or consumer. Most usual voltage quality problems of utility are voltage imbalance, sag, swell, fluctuation, harmonic and notches. On the other hand, there are well known current quality problems such as harmonics, imbalance neutral current, which affects the power quality of utility. The UPQC is used to overcome all of the above mentioned problems simultaneously. This system is usable especially in such cases that a group of harmonic sensitive loads are operating close to a (or group of) harmonic and/ or imbalance generating load(s) and on the other hand, there are some voltage quality problems in the utility too. It is important to notice that this condition is a usual case especially in industrial sites with a poor quality utility source.

2. Principle of UPQC Operation

According to the basic idea of UPQC, it consists of back-to-back connection of two three-phase active filters (AFs) with a common dc link. One of the AFs is connected in parallel with the utility and is called parallel active filter (PAF). The PAF works as current source and usually compensates for current quality problems of load and regulating of dc link. Fig.(1) shows single line diagram of PAF. With controlling of magnitude of inverter output voltage it can absorb or inject reactive power from or to AC transmission line [2].
Capabilities and specifications of PAF are:
Current harmonics and imbalance compensation, supply of requirement reactive power of load and in general compensation of all current quality problems. On the other hand, the second AF is connected in series with the utility and acts as series active filter (SAF) to compensate for voltage quality problems of utility. Fig.(2) shows single line diagram of SAF.
Capabilities and specifications of SAF are:
Compensation of all voltage quality problems such as voltage imbalance, sag, swell, fluctuation, harmonic, notch and active power flow [3].

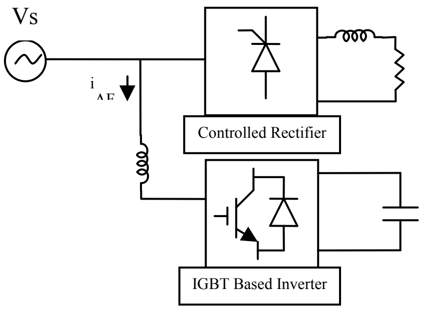

Fig (1): Single line diagram of PAF.

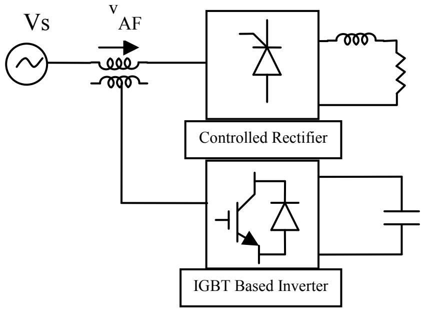

Fig (2): Single line diagram of SAF

Fig.(3) shows the general power circuit configuration of UPQC. In Fig.(3) the notations of i_a, i_b, i_c and v_a, v_b, v_c stand for instantaneous load side currents and utility side voltages, respectively. The operation of UPQC results in generation of compensation currents of PAF, i_{compa}, i_{compb}, i_{compc}, and compensation voltages of SAF, v_{compa}, v_{compb}, v_{compc}, in the phases a, b and c, respectively. The notations i_{sa}, i_{sb}, and i_{sc}, stands for source side currents and v_{La}, v_{Lb} and v_{Lc}, stands for load side voltages in the phases a, b and c, respectively. It is possible writing the following expressions easily:

$$is_{a,b,c} = i_{a,b,c} - i_{comp\ a,b,c} \qquad (1)$$

$$v_{La,b,c} = v_{a,b,c} - v_{comp\ a,b,c} \qquad (2)$$

Equation 1 shows that the waveforms of source side currents are controllable using the operation of PAF. Equation 2 shows that the waveforms of load side voltages are controllable using the operation of SAF.

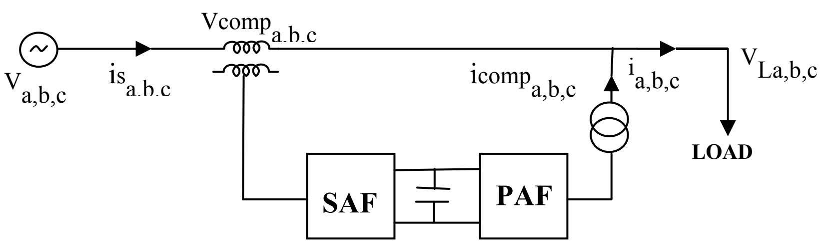

Fig (3): General configuration of UPQC.

3. Measurement of Effective Parameters in Power Quality

In this subsection the results of measurement of effective parameters in power quality in the typical industrial unit in Salimi industrial city near Tabriz, IRAN, carried out by ION 7330 made in Power Measurement co. Canada, are presented. For measured data analysis made by this device, Power View software has been used.

Electrical specifications of this unit are: P = 1000 kW & V = 20 kV

Fig.(4) shows the results of the measurements. Fig.(4-a) shows variation of total active and reactive power of industrial unit. Fig.(4-b) shows power factor of this industrial unit. Fig.(4-c) shows voltage imbalance and current imbalance. As shown from this figure, voltage imbalance is within standard band and current imbalance is nearly high. Fig.(4-d) shows currents of phases a, b, c. Fig.(4-e) shows harmonic spectra of current phases a, b, c. As shown from this figure, harmonics of 2, 3, 5, 7 orders have high percentages and them values exceed from IEEE519 standard. Therefore according to measurements, shown in this unit, problems are related to current and they could be decreased by using PAF.

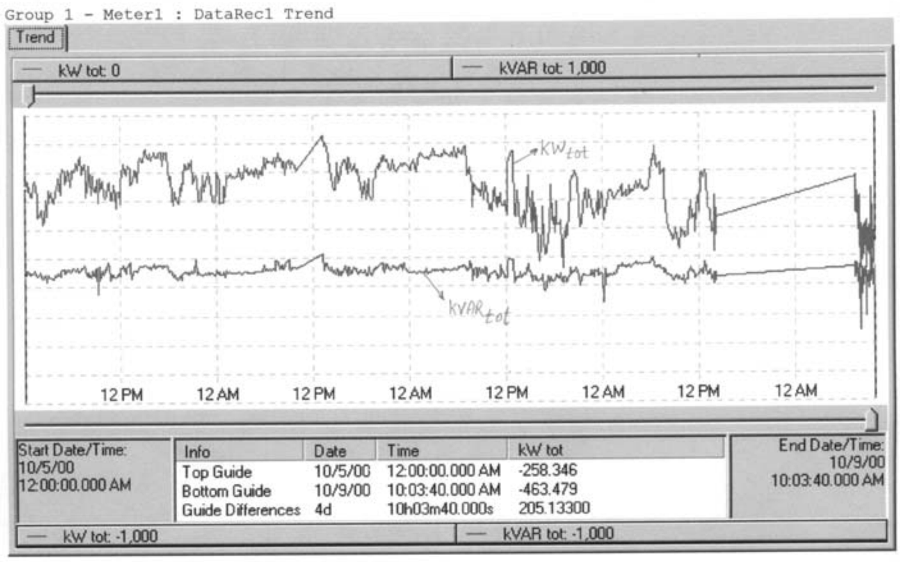

Fig (4-a): Total active and reactive power vs. time.

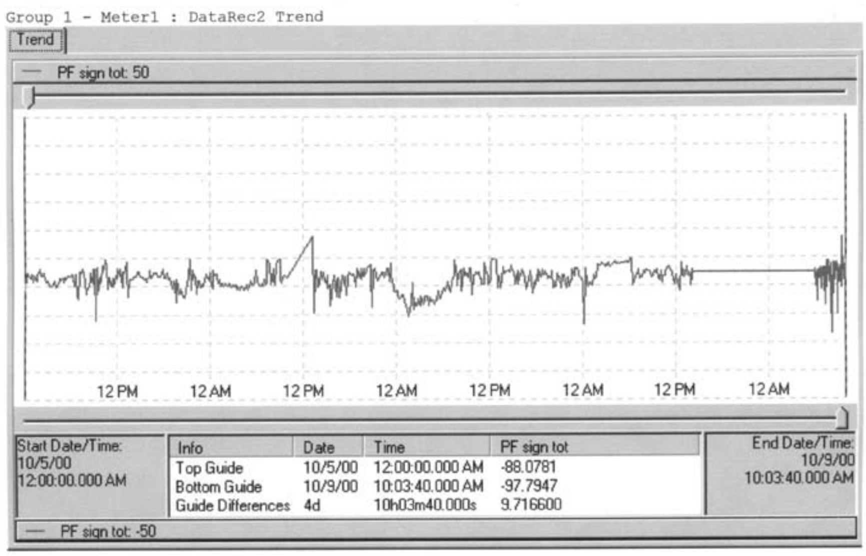

Fig (4-b): Power factor vs. time.

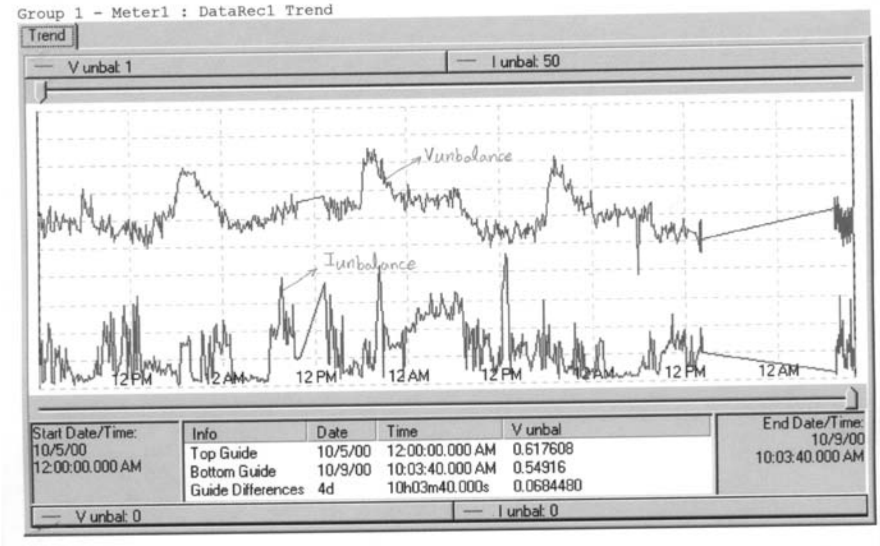

Fig (4-c): Voltage imbalance and current imbalance vs. time.

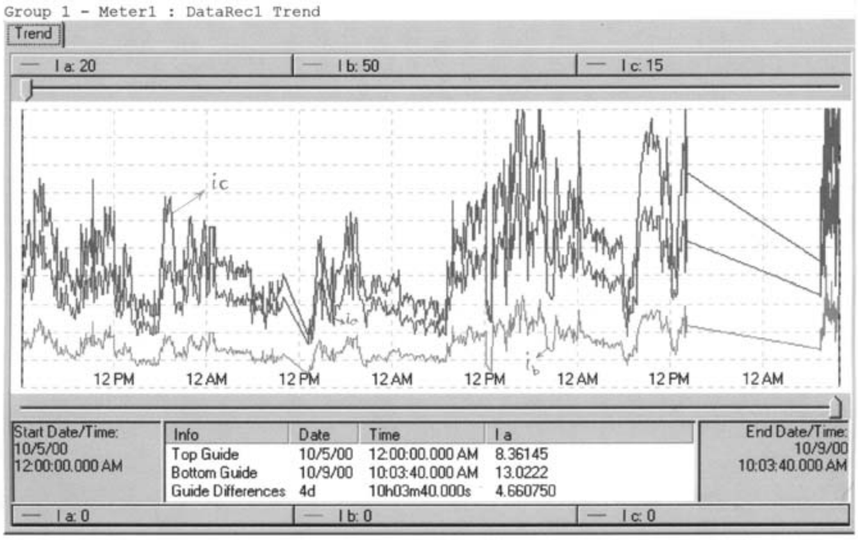

Fig (4-d): Load side currents vs. time.

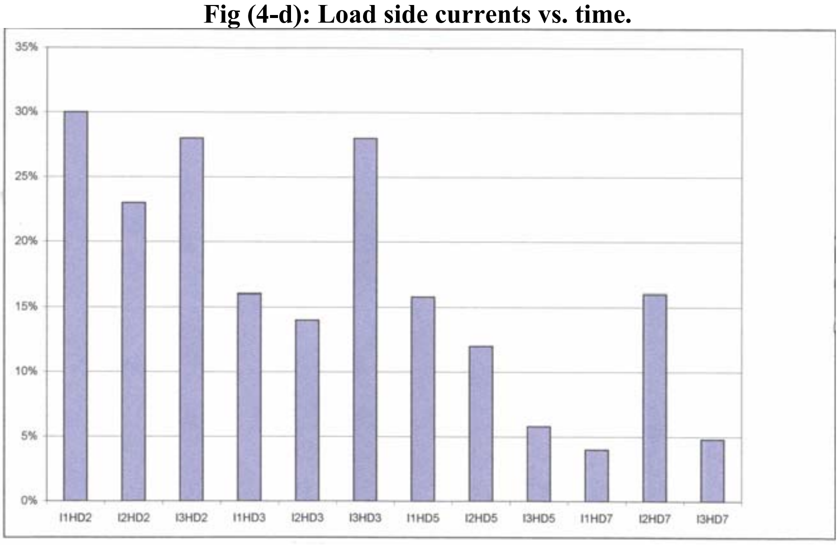

Fig (4-e): Harmonic spectrum of load side currents.

4. Control System of UPQC

The control system of UPQC has two parts:

1) Shunt converter (PAF) control system
2) Series converter (SAF) control system

These are described in the below subsections.

4.1. Shunt Converter Control system

The PAF is used for compensation of reactive power, unbalance and harmonics of load currents. Also, it is controlling the DC link capacitor voltage. In the presented control system, the voltages and currents of load are measured and transferred to the d-q forms by transformation (4). Then active and reactive power is calculated from equations (5), (6).

$$\begin{pmatrix} V_d \\ V_q \\ V_0 \end{pmatrix} = T \begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} \quad , \begin{pmatrix} I_d \\ I_q \\ I_0 \end{pmatrix} = T \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \tag{3}$$

$$T = \sqrt{\frac{2}{3}} \begin{bmatrix} Cos\theta & Cos(\theta - \frac{2\pi}{3}) & Cos(\theta + \frac{2\pi}{3}) \\ -Sin\theta & -Sin(\theta - \frac{2\pi}{3}) & -Sin(\theta + \frac{2\pi}{3}) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \quad , \theta = \omega_0 t \tag{4}$$

$$P = \widetilde{P} + \overline{P} = \frac{3}{2}(V_d\, I_d + V_q\, I_q) \tag{5}$$

$$Q = \widetilde{Q} + \overline{Q} = \frac{3}{2}(V_d\, I_q - V_q\, I_d) \tag{6}$$

In the above equations $\widetilde{Q}, \overline{Q}, \widetilde{P}$ are undesirable components and are due harmonics, unbalances and reactive power of load. The term of $\overline{P}$ is desirable component and is due the active power of load. Thus, the PAF must be compensating undesirable components. For obtaining undesirable component of active power $(\widetilde{P})$ the active power signal, calculated from equation 5, is flowed from a high pass filter with cut off frequency 10 HZ.

The d-q forms of reference currents of PAF are calculated from equations (7), (8).

$$I_d^* = \frac{\widetilde{P}\, V_d - Q V_q}{V_d^2 + V_q^2} \tag{7}$$

$$I_q^* = \frac{\widetilde{P} V_q - Q V_d}{V_d^2 + V_q^2} \tag{8}$$

The unbalanced component of load current can be calculated as bellow:

$$I_{unbalance} = \frac{1}{3}(i_{la} + i_{lb} + i_{lc}) \tag{9}$$

For controlling of DC link capacitor voltage (as shown in Fig (5)) error signal of $V_{dcref} - V_{dc}$ is applied to a PI controller and then is added to Iq^* (that is named Iq_1^*). Finally, reference currents of PAF are obtained from equation 10.

$$\begin{pmatrix} i_{aref} \\ i_{bref} \\ i_{cref} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} Cos\,\theta & -Sin\,\theta \\ Cos\,(\theta - \frac{2\pi}{3}) & -Sin\,(\theta - \frac{2\pi}{3}) \\ Cos\,(\theta + \frac{2\pi}{3}) & -Sin\,(\theta + \frac{2\pi}{3}) \end{pmatrix} \begin{pmatrix} I_d^* \\ I_{q1}^* \end{pmatrix} + \begin{pmatrix} I_{unbalance} \\ I_{unbalance} \\ I_{unbalance} \end{pmatrix}, \theta = \omega_0 t \tag{10}$$

From above equations the PAF control system can be formed as Fig. 5.

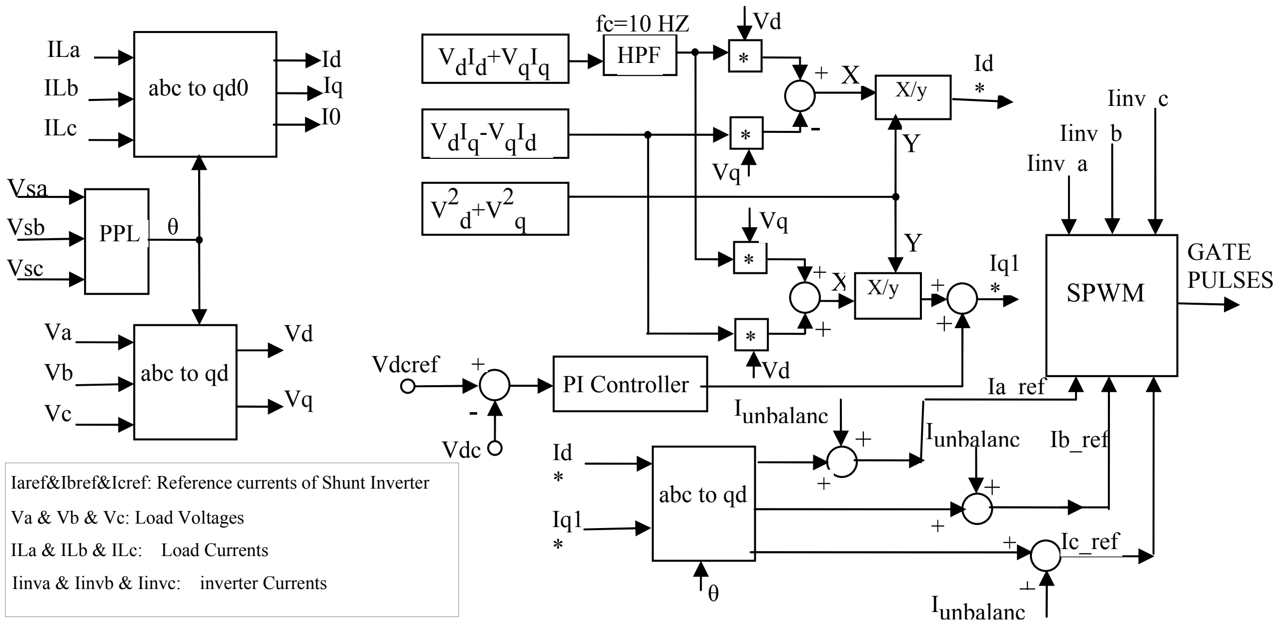

Fig (5): Control bloke diagram of PAF.

4.2. Series Converter Control System

SAF is used for compensating of harmonics and unbalances of utility side voltages. Therefore, voltage on load will be balanced and sinusoidal. The references voltage of SAF is calculated as below:

$$\begin{pmatrix} V_d \\ V_q \\ V_0 \end{pmatrix} = T \begin{pmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{pmatrix} \tag{11}$$

$$V_d = \tilde{V}_d + \overline{V}_d \tag{12}$$

$$V_q = \tilde{V}_q + \overline{V}_q \tag{13}$$

$$\begin{pmatrix} v_{aref} \\ v_{bref} \\ v_{cref} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} Cos\theta & -Sin\theta \\ Cos(\theta - \frac{2\pi}{3}) & -Sin(\theta - \frac{2\pi}{3}) \\ Cos(\theta + \frac{2\pi}{3}) & -Sin(\theta + \frac{2\pi}{3}) \end{pmatrix} \begin{pmatrix} \tilde{V}_d \\ \tilde{V}_q \end{pmatrix} + \begin{pmatrix} V_0 \\ V_0 \\ V_0 \end{pmatrix} \tag{15}$$

From these equations the series active filter control system can be formed as bellow:

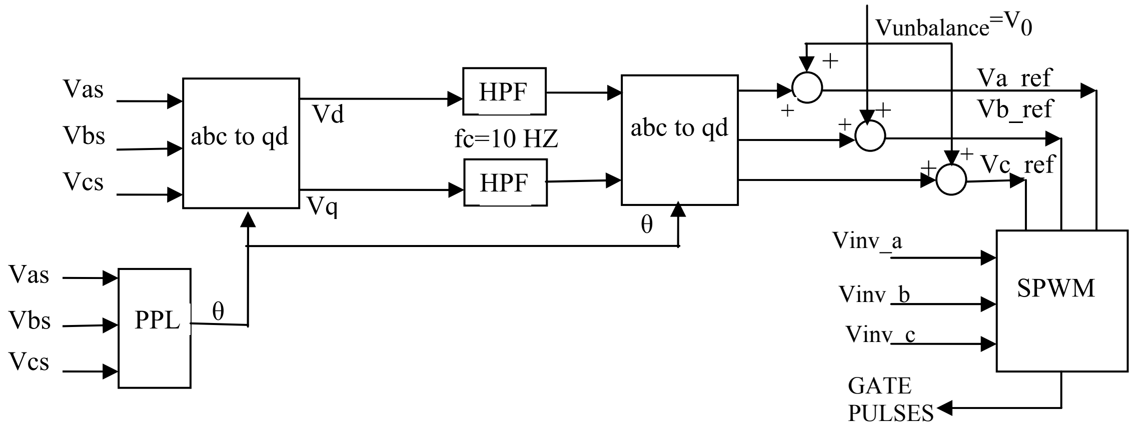

Fig (6): Control block diagram of SAF.

The oscillations parts of V_d and V_q are due unbalances and harmonics of utility side voltages. Therefore, SAF injects these voltages in series with utility until load voltages be balanced and sinusoidal.
The gating signals of shunt and series inverters are generated by SPWM technique (as shown in Fig (7)).

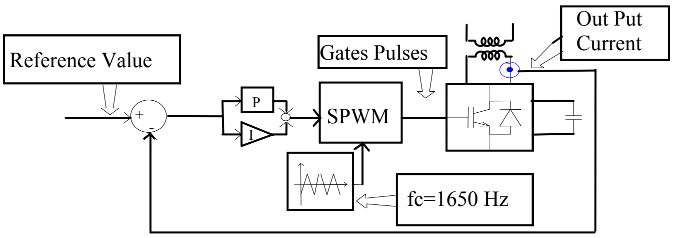

Fig (7): SPWM generating circuit.

5. Simulation Results

In this section the UPQC will be used for the compensation of power quality problems through the application of PSCAD/EMTDC Program [4].
UPQC can isolate the utility from consumer power quality problems and vice versa, thus it can improve the power quality at the point of installation [5, 6]. Fig (8) shows the test circuit. This circuit includes a R-L unbalanced load and a nonlinear load (a 3-phase rectifier).
Fig (9) and Fig (10) show the simulation Results of UPQC. Fig (9) shows the operation results of PAF. This figure shows that the PAF compensates the harmonics of load current and reactive power of load. Fig (9.c) reports that source line current is in the same phase with source voltage. Therefore, the source reactive power is kept to zero. Fig (10) shows the operation results of SAF. This figure refers that, if the source voltage is including unbalanced and harmonics the SAF compensates them and therefore, load voltage will be symmetrical and sinusoidal. The Fig (11) shows the variations of DC link capacitor voltage.

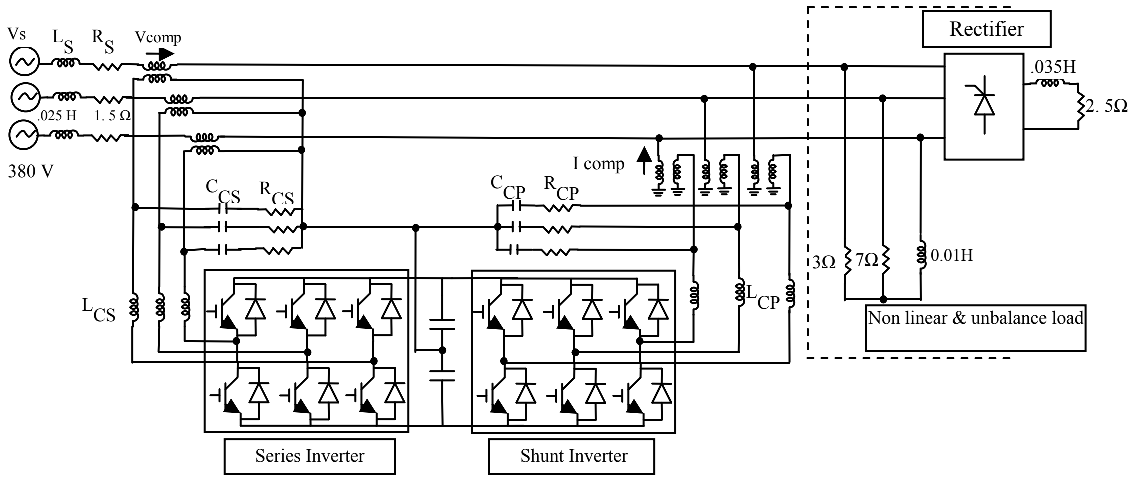

Fig (8): Test circuit.

6. Conclusion

This paper presents a simple control scheme for a UPQC. The active Filters and UPQC are proposed for solution of power quality problems in distribution systems. The operation of UPQC in compensation for power quality problems is studied through simulation using PSCAD/EMTDC. The presented simulation results show the suitable operation of control system. Power quality problems such as current harmonics, unbalance currents, voltage imbalance and reactive power are measured and demonstrated in an industrial city near Tabriz, Iran, too.

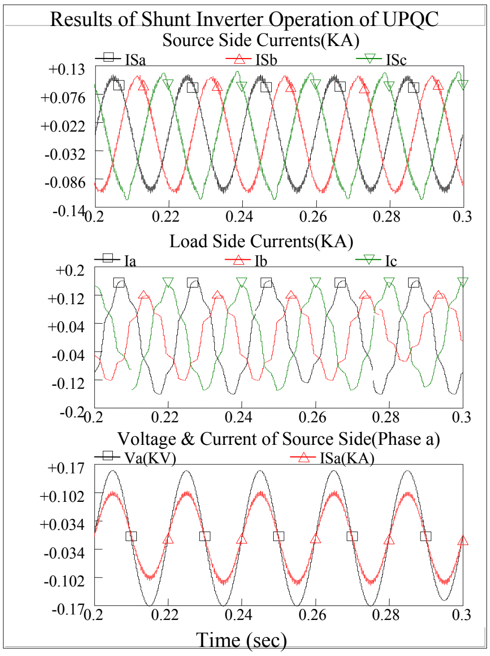

Fig (9): Simulation results of shunt part of UPQC.

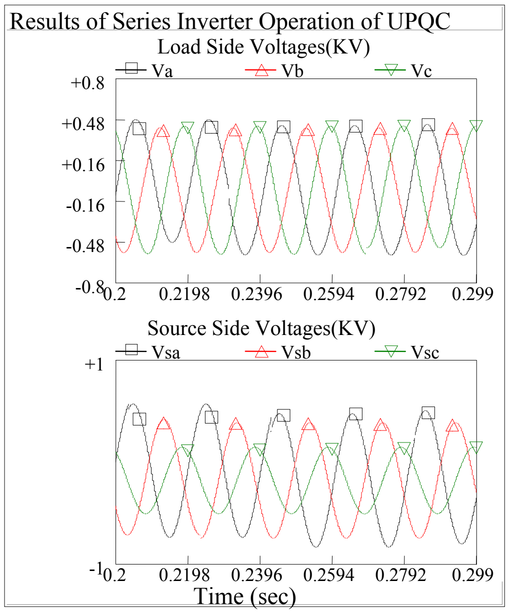

Fig (10): Simulation results of series part of UPQC.

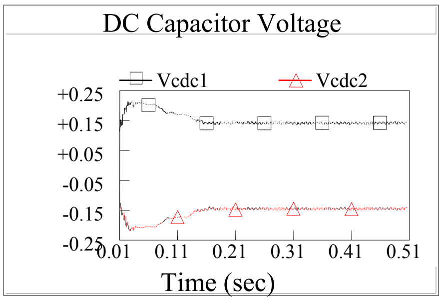

Fig (11): The DC link capacitor voltage.

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ELEKTROENERJİ SİSTEMLƏRİNDƏ ENERJİNİN KEYFİYYƏTİNİ İDARƏ ETMƏK ÜÇÜN YENİ QURĞU

ƏCƏMİ A., HÜSEYNİ S.H.

Məqalədə enerjinin keyfiyyətinə nəzarət etmək üçün tətbiq olunan yeni idarəedici qurğunun sxemi və enerjinin keyfiyyətinə dair yeni anlayış verilir. Enerjinin keyfiyyəti üzrə problemləri kompensə etmək üçün PSCAD/EMTDC proqramından istifadə edərək

modelləşdirilmənin nəticələri təqdim olunmuşdur. Eyni zamanda Power Measurement CO (Kanada) şirkəti tərəfindən hazırlanmış ION-7330 markalı qurğudan istifadə edərək, sənaye qurğusu vasitəsilə Təbriz (İran) şəhəri yaxınlığındaki Səlimi şəhərində enerjinin keyfiyyətini xarakterizə edən effektiv parametrlər üzrə ölçmələrin nəticələri verilmişdir.

НОВОЕ УСТРОЙСТВО УПРАВЛЕНИЯ КАЧЕСТВОМ ЭНЕРГИИ В ЭЛЕКТРОЭНЕРГЕТИЧЕСКИХ СИСТЕМАХ

АДЖАМИ А., ХОССЕЙНИ С.Х.

В данной статье представлена схема управления для Унифицированного Контроля Качества Энергии и вводится новое определение “качества энергии". Приводятся результаты моделирования с использованием программы PSCAD/EMTDC для компенсации проблем качества энергии. Также показаны результаты измерения эффективных параметров качества энергии в типичной индустриальной установке в городе Салими вблизи Тебриза (ИРАН) с помощью устройства ION-7330, изготовленного компанией Power Measurement CO (Канада)..