7

Management, Control and Automation of Power Quality Improvement

Heidarali Shayanfar[1] and Ahad Mokhtarpour[2]
[1]*Center of Excellence for Power System Automation and Operation, Electrical Engineering Department, Iran University of Science and Technology, Narmak, Tehran*
[2]*Department of Electrical Engineering, Islamic Azad University, Science and Research Branch, Tehran, Iran*

1. Introduction

Electrical energy is a type of existing energy in the nature. Because of its capability of changing to different kinds of energy and possibility of transmission; electrical energy has become one of the major energy sources. Electrical energy from generation to consumption passes from three stages, generation, transmission and distribution. Distribution systems composed of a large scale area of power system with many nodes. Distribution networks transmit electrical energy from high voltage power towards low voltage customer's devices. Electrical companies have the duty of preparing good quality electrical energy in the consumer side. For properly work of a device it is essential to pay attention to the quality of the energy. In bad power quality condition, electric devices may fail completely. Thus, electrical companies should control and limit power quality problems. Also, consumers should not use devices that generate power quality problems. If not, electrical companies should find them. Fig. 1 shows a simple distribution system (Mulhausen et al., 2010). If a fault is occurred in jth node of network short circuit current will effect in ith node voltage such as Eq. (1).

$$\Delta v_i = -Z_{ij} I_f \tag{1}$$

where, I_f is the fault current. Voltage problems are generally voltage sag and swell, unbalance, zero sequence and harmonics. Current problems are generally zero sequence, unbalance, reactive power and harmonics. For the improvement of voltage problems, series active filters such as Distributed Voltage Regulator (DVR) that are from the family of Custom Power (CP) can be used in the distribution systems and for the improvement of current problems, parallel active filters such as Distribution STATic COMpensator (DSTATCOM) can be used. Nowadays, for the instantaneous improvement of both voltage and current problems, efficient combination of the above mentioned CP devices are being used (Mokhtarpour et al., 2009). This device is called Unified Power Quality Conditioner (UPQC). The scope of this chapter is the investigation and analysis of the control approaches for power quality improvement, power quality management, automation of distribution systems and analytical review of the power quality control papers. A typical distribution system power quality control will be attached as the case study.

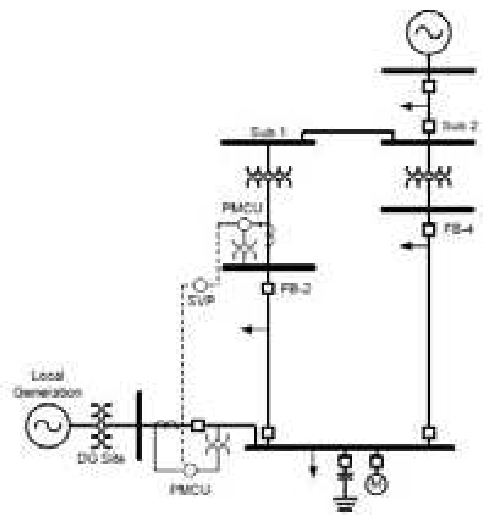


Fig. 1. A simple distribution system

2. Power Quality

How can we determine quality of electrical energy and what is a good power quality? Suppose that:

$$v = V_m \cos(\omega t) \tag{2}$$

$$i = I_m \cos(\omega t - \varphi) \tag{3}$$

Then, the instantaneous power can be fine as:

$$p = vi = V_m \cos(\omega t) \times I_m \cos(wt - \varphi) = \frac{V_m I_m}{2} \cos(\varphi)(1 + \cos(2\omega t)) + \frac{V_m I_m}{2} \sin(\varphi) \sin(2\omega t) \tag{4}$$

Eq. (4) shows that the electrical power is related to voltage, current and frequency. It is obvious from Eq. (4) that the instantaneous power is composed of two part, active and reactive power (Grainger & Stevenson, 1994). Active power has a dc and an ac part. Based on Eq. (5) it is obvious that the instantaneous active power oscillates around a dc amount by frequency of 2ω and can be found as:

$$\text{Active power } = \frac{V_m I_m}{2} \cos(\varphi)(1 + \cos(2\omega t)) \tag{5}$$

Also, reactive instantaneous power can be written as:

$$\text{Reactive power } = \frac{V_m I_m}{2} \sin(\varphi) \sin(2\omega t) \tag{6}$$

Fig. 2 shows these powers variation versus time. Based on Eq. (6), the second part of the instantaneous power which is named reactive power has zero dc amount and oscillates with frequency of 2ω. Obviously, the phase difference between ac amount of active and reactive powers is $\pi/2$. This means that the reactive power has zero amounts when active power has maximum amount. Based on Eq. (7) the average of the total power that has been named active power is constant and can be found as:

$$P = \frac{1}{2\pi}\int_{0}^{2\pi} p(\omega t)d(\omega t) = \frac{V_m I_m}{2}\cos\varphi = V_e I_e \cos\varphi \tag{7}$$

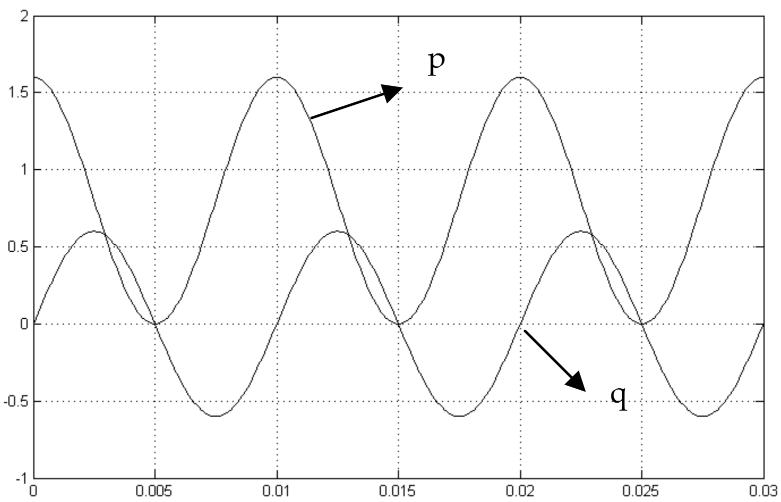


Fig. 2. Typical active and reactive powers

Obviously, for good quality of energy, voltage, current and frequency of distribution system should be proper. Thus, the investigation of energy quality can be divided into three parts, voltage quality, current quality and frequency. When the voltage quality is good? In other words, when the voltage is proper for a good performance of the device?

The magnitude of voltage is a quality problem in the first part. In good condition, the voltage of distribution system is changed by a sinusoidal function with the frequency of power system. The effective amount of voltage should be constant in all times and conditions. But, nonlinear loads and short circuit faults can produce voltage harmonics, unbalance voltages and negative and zero sequences of the voltage. This is the power quality problem which is produced by the utility side.

In the second case, the quality of the current is considerable. But, it is obvious that the load current is not controllable. In other words the characteristics of the load determine load current waveform. If there is a linear load, then the relationship between its voltage and current is linear. Thus, if voltage is a fixed magnitude sinusoidal function, then the current will be a sinusoidal function, with constant magnitude. This problem has been shown in Fig. 3. But, if characteristic of the load not be a linear function, then a sinusoidal voltage results in a nonsinusoidal current. This problem has been shown in Fig. 4. Based on the ohms law, $v=Ri$ and a nonsinusoidal current will cause nonsinusoidal voltage drop and finally nonsinusoidal voltage in all nodes. Therefore, the current quality can change the voltage quality. The load current is not controllable, but source current can be controlled that will be explained in the parallel active filter section.

In the third case, the quality of frequency is considered. The frequency of voltage and current in all conditions should be constant. Major cause of frequency change is linearity or nonlinearity of the load. If we calculate the Fourier transform of a nonlinear load current it can be fund that there are frequencies f, 2f, 3f and …in its spectrum. A nonlinear load current spectrum has been shown typically in Fig. 5. In other words the nonlinear loads can produce other frequency components in the current and voltage. Also, voltage frequency change can be produced by electrical source, because of non proper design of generator.

Power quality problems that are related to the voltage are voltage unbalance and negative sequences and zero sequences of the voltage. Power quality problem that are related to the current are harmonics and reactive power.

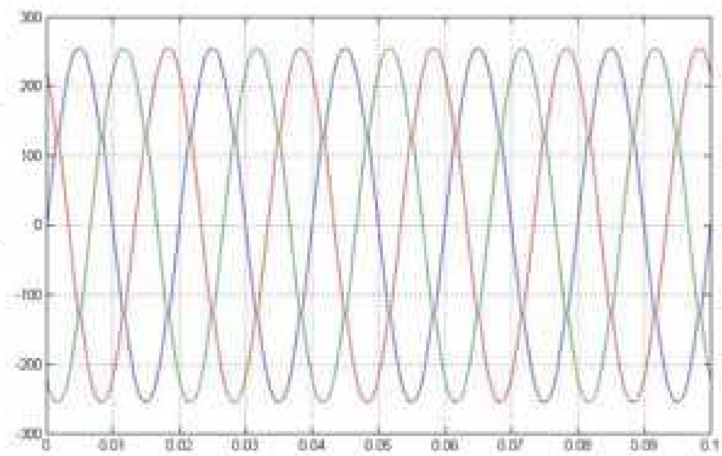


Fig. 3.(a) Voltage waveform;

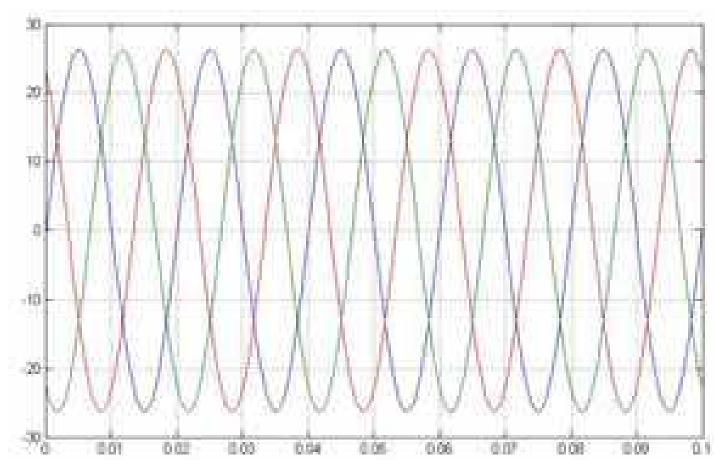


Fig. 3.(b) Linear load current waveform

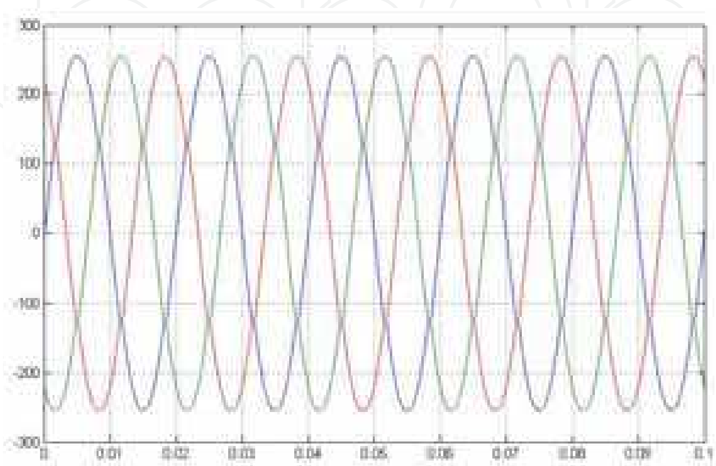


Fig. 4.(a) Voltage waveform;

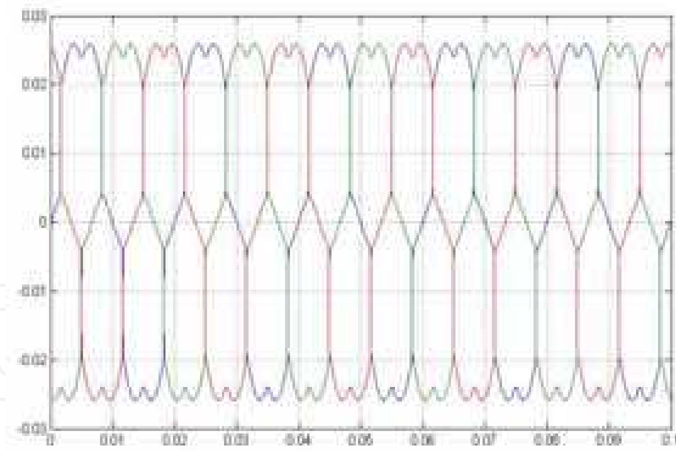


Fig. 4.(b) Nonlinear load current waveform

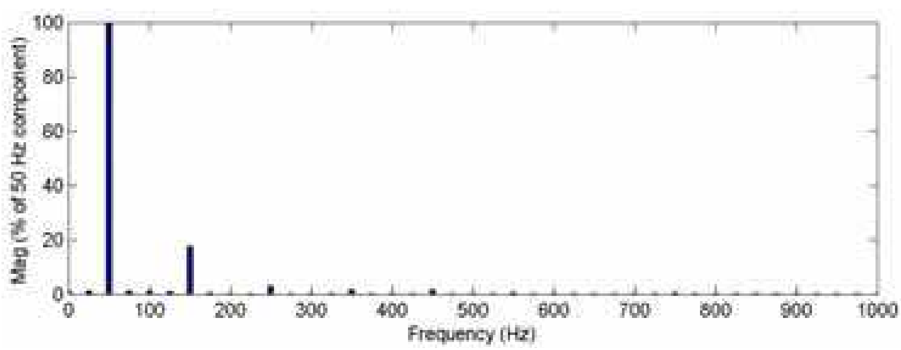


Fig. 5. Spectrum of a nonlinear load current

3. Power Quality control

Now, it is important to investigate how can we control these energy quality problems and improve them. Different approaches have been presented for the improvement of energy quality. Passive filters can compensate voltage and current harmonics. Passive filter has composed of an inductor in series or parallel by a capacitor that in the resonance frequency of $1/\sqrt{lc}$ acts as a short circuit. Thus, relative harmonic can be neglected. In the design of passive filters their resonance frequency are generally equal to third or fifth harmonic; because these harmonics are very important in the distribution systems. But, passive filters are designed for the predetermined conditions. Therefore, in the case of changing the operating point for a dynamic power system, passive filter can not compensate the quality of the energy. Also, passive filters can compensate only one or two harmonic of the voltage and current. Thus, they are not good devices for the improvement of the power quality. So, for the control of all power quality problems, it is better to use active filter. These filters can be divided into two parts of parallel and series active filters. Based on the mentioned problems, power quality problems can be related either to the load side or to the source side. Nonlinear load current should not appear in the source side current. This problem can be solved by the use of a parallel active filter. A parallel active filter has been composed of a current inverter fed by a DC link that is connected to the grid via a parallel transformer (Shayanfar et al., 2005a). Fig. 6 shows the structure of a parallel active filter. Parallel activefilters are used for compensating negative sequence, zero sequence and harmonics of the

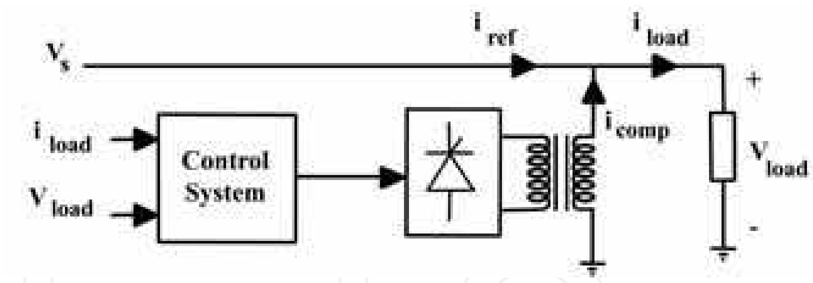


Fig. 6. Structure of a parallel active filter

load current. Major principle of its control is the measuring of load voltage and currents and then computing the reference and compensators current. The scope of using the parallel active filter is the injection of unwanted components of the load current via the inverter and transformer to the load instead of using main source. Reference current is a sinusoidal current that is extracted by the control circuit of the parallel active filter. Compensator current is the component of load current that has composed of negative sequence, zero sequence and harmonics of it. It is known that the power of electrical system has two part of active and reactive. Also, the average of electrical power is equal to the active power. This problem is explained in Eq. (7). From Eq. (6) reactive power will oscillate by frequency of 2ω. This means that the amount of it in a time of period is positive and in another time of period is negative. So, the direction of the reactive power in a time is from source to the load and in other time is from load to source. It says that the reactive power have the average of zero and only limits the capacity of the distribution line. It is known that the inductor current has 90 degree lag to the voltage. Eqs. (8) and (9) show the active and reactive powers of an inductor, as:

$$\text{Active power } = \frac{V_m I_m}{2}\cos(90)(1+\cos(2\omega t)) = 0 \tag{8}$$

$$\text{Reactive power } = \frac{V_m I_m}{2}\sin(90)\sin(2\omega t) = V_e I_e \sin(2\omega t) \tag{9}$$

But, capacitor current has 90 degree lead to the voltage. Eqs. (10) and (11) show the active and reactive powers of a capacitor, as:

$$\text{Active power } = \frac{V_m I_m}{2}\cos(-90)(1+\cos(2\omega t)) = 0 \tag{10}$$

$$\text{Reactive power } = \frac{V_m I_m}{2}\sin(-90)\sin(2\omega t) = -V_e I_e \sin(2\omega t) \tag{11}$$

From Eqs. (9) and (11) it seams that the signs of reactive power of inductor and capacitor are opposite. In other word the sum of reactive powers in inductor and a capacitor is zero in all times and can be said that the capacitors reactive power cancels that of an inductor. Load reactive power can be compensated by parallel active filter. In other words the reactive current is a component of load current that has 90 degree phase difference with the voltage and it can be concluded that the unwanted component of the load current. Thus, if the reactive current be included in the compensation current of parallel active filter, then the reactive power of load will be compensated. In other words, compensating current is the unwanted component of the load current. After calculation of compensating current, it should be fed to the network in parallel with load. This problem has been shown in Fig. 6. For injection of the compensation current by using of an inverter, there are some approaches for the generation of the fire pulses of the inverter and the best of them is PWM approach. For minimum error between calculated compensating current signal that has calculated from parallel control system and the injected current that is generated from an inverter, generally a PI controller is being uesd.

A typical two arm and 6 pulse thyristor based inverter has been shown in the Fig. 7. Power quality problems can be related to the source side. These are voltage problems such as

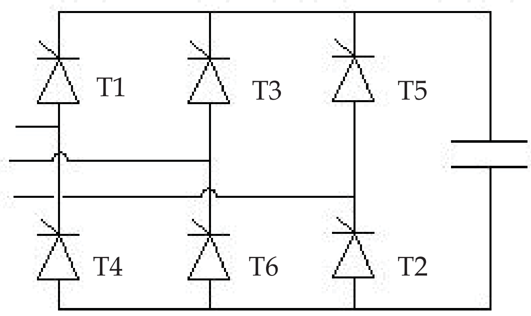


Fig. 7. Two arm and 6 pulse thyristor based inverter

unbalance, negative sequence, zero sequence and harmonics of the voltage (Shayanfar et al., 2006a). The cause of the voltage problems can be non symmetric short circuit faults, non symmetric distribution of loads between three phases and nonlinear load. Passive filters could improve a little voltage harmonics only in one point of the work and they can not improve all voltage problems completely. To improve this problem, series active filters are being used instead of passive filters. These filters have composed of a voltage inverter that is fed from a DC link (Mokhtarpour et al., 2009). This inverter is connected to the grid via a series transformer. Fig. 8 shows structure of a series active filter.

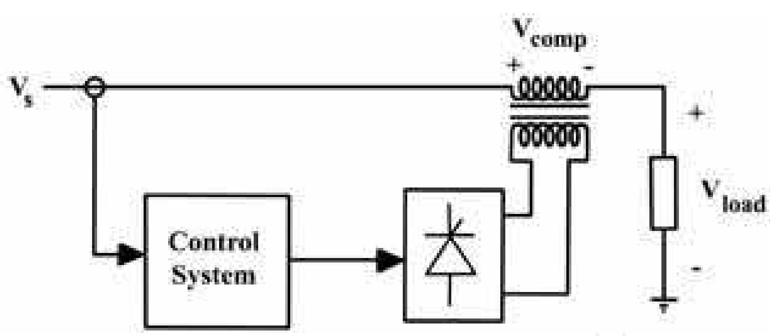


Fig. 8. Structure of a series active filter

Series active filter extracts the reference voltage from the source voltage. Reference voltage is a sinusoidal voltage. Compensator voltage is the difference between reference and source voltages. Compensator voltage is injected to the grid via an inverter and series transformer. Based on the mentioned problems it is obvious that the parallel active filters are being used for the current quality problems improvement such as negative sequence, zero sequence and harmonics and reactive power and series active filters can be used to improve the voltage quality problems such as unbalance, negative sequence, zero sequence and harmonics.

A typical harmonized, compensator and reference signals have been shown in the Figs. 9, 10 and 11. Obviously compensator signal include unwanted components of harmonized signal.

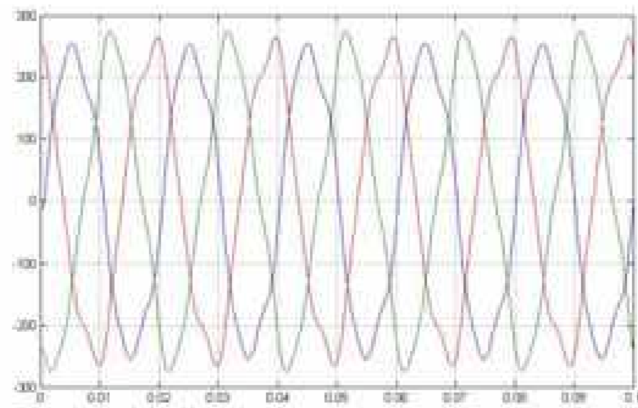


Fig. 9. A typical harmonized signal

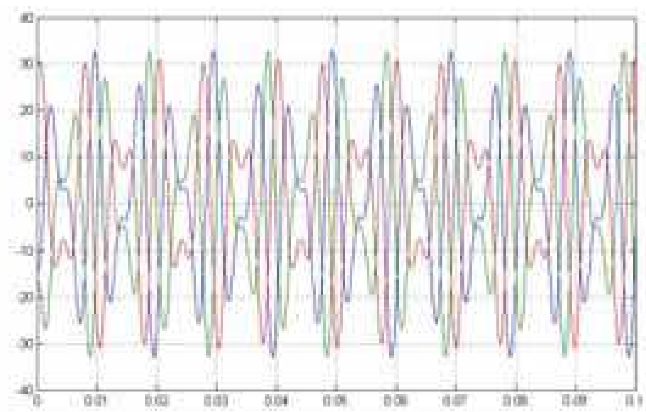


Fig. 10. Compensator signal

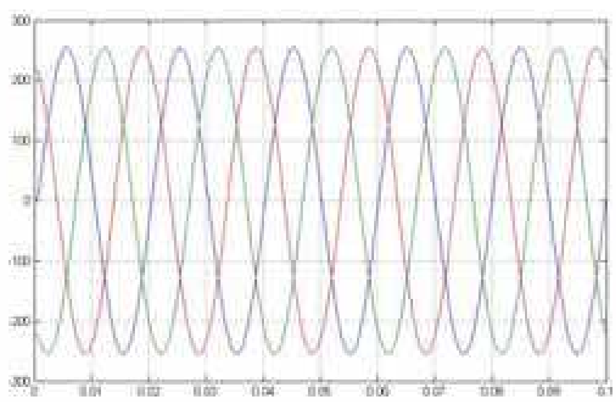


Fig. 11. Reference signal

4. Parallel active filter control

Parallel active filter compensates and improves current quality. As mentioned in the text, the current problems are related to the load and consumer side. They are including negative sequence, zero sequence, reactive power and harmonics. Design of the control circuit of the parallel active filter is based on the extraction of a sinusoidal current which has the same phase with compensated load voltage as the reference current and determination of the compensation current. The compensation current will be injected to the grid via an inverter and a parallel transformer. Generally, generation of the inverter pulses are based on the PWM approach. First, the load side voltage and current are measured, then the control circuit extracts a reference current from the measured voltage and current (Shayanfar et al., 2006b). The difference between different approaches is in the parallel active filter control circuits which is the way of reference current extraction. In this section a very simple control approach for learning the major principle is explained and in the case study of the chapter a full control approach of the parallel active filter will be described. Usually load current is non sinusoidal. After measurement of the voltages and currents and use of a low pass filter a reference current will be extracted. Compensator current (I^{*}_{comp}) is determined from the difference between load side current and the reference current. Block diagram of a parallel active filter has been shown in Fig. 12.

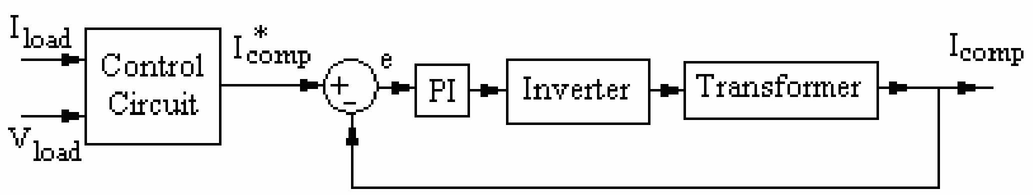


Fig. 12. Block diagram of a parallel active filter

5. Series active filter control

Series active filter compensates and improves voltage quality. As mentioned above the voltage problems are related to the source side and include unbalance, negative sequence, zero sequence and harmonics. The design of the control circuit of series active filter is based on the determination of a sinusoidal voltage as the reference voltage and the difference between that and the source side voltage as the compensation voltage (Shayanfar et al., 2006a, 2006c). Compensation voltage will be injected to the grid via an inverter and a series transformer.

Usually, generation of the inverter pulses are based on the PWM approach. First the source side voltage is measured, then the control circuit extracts a reference voltage from the measured voltage. Block diagram of a series active filter has been shown in Fig. 13. The difference between different approaches are in the series active filter control circuits which is a function of the reference voltage extraction. In this section a very simple control approach for learning the major principle is explained and in the case study of the chapter a full control approach of the series active filter will be described. Usually, source voltages are non sinusoidal. Using a low pass filter can extract a sinusoidal voltage as the reference voltage. Compensator voltage (V^{*}_{comp}) is determined from the difference between source side voltage and the reference voltage.

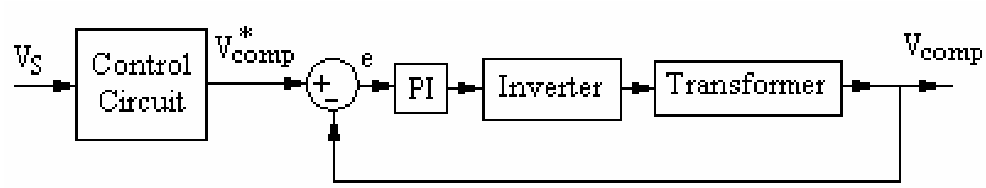


Fig. 13. Block diagram of a series active filter

6. Unified Power Quality Conditioner

Proper composition of parallel active filters as Distribution STATic COMpensator (DSTATCOM) and series active filters as Distributed Voltage Regulator (DVR) can compensate current problems such as reactive power, negative sequence, zero sequence and harmonics as well as voltage problems, such as unbalance, negative sequence, zero sequence and harmonics. This composition is named Unified Power Quality Compensator or UPQC. UPQC has composed of two inverters that are connected back to back. One of them is connected to the grid via a parallel transformer and can compensate the current problems. Another one is connected to the grid via a series transformer and can compensate the voltage problems. These two inverters are controlled for the compensation of all power quality problems instantaneously. Fig. 14 shows the schematic of a UPQC.

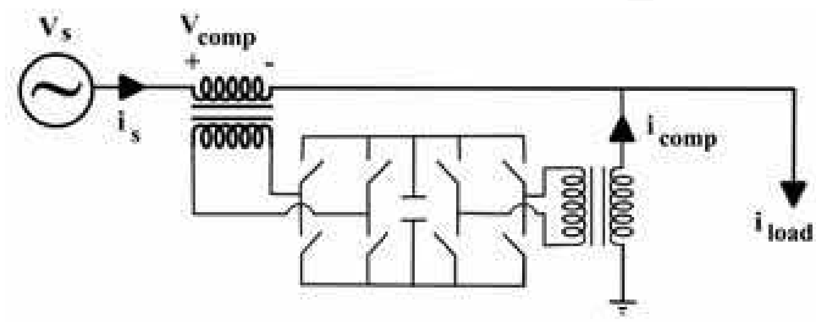


Fig. 14. Schematic of a UPQC

For control of this device there are different approaches in which their principles of them are the same. Parallel active filter control circuit extracts a sinusoidal current as the reference current (Kazemi et al., 2006). The difference between reference current and load current is the compensator current and will be injected via an inverter and a parallel transformer to the grid for the improvement of the power quality problems that are related to the load side. Series active filter control circuit extracts a sinusoidal voltage as the reference voltage. The difference between reference voltage and source voltage is the compensator voltage and is injected via an inverter and a series transformer to the grid for the improvement of the power quality problems that are related to the source side.

A case study for the power quality compensation by the UPQC and their mathematical functions will be described in the next section.

7. Automation and control of distribution systems

In the power system application, there are two layers; measurement and control. In Supervisory Control And Data Acquisition systems (SCADA) application, before the control action, measurement of essential parameters has been done in the measurement centers by relative devices. Then, these signals are sent to the control centers via communication channels. In the control centers proper process will be done and finally controller signals are generated. In automation and control of the distribution systems the need to measure parameters, communicate and control them exists. This process can be done in the SCADA systems, but different from each other. It will be excellent in the automation of power system to do the measurement and control of signal together. Integrated Object Network (ION) devices can be used in automation of distribution systems and do measurement and control actions in one the units (Shayanfar et al., 2005b). Fig. 15 shows a typical ION device.

Fig. 15. Measurement and control device (ION) (Shayanfar et al., 2005b)

IONs as an intelligent device with the capability of measuring and controlling the required parameters of compensation can improve power quality disturbances such as negative sequences of voltage and reactive powers. Intelligent devices of ION analyze the retrieved data from PTs and CTs and then determine compensating currents intelligently regarding the programmed control algorithm (Shayanfar et al., 2006a, 2006b). The process of measurement and control system is divided to the following sections.

7.1 Data acquisition

First stage is voltage and current measurements. The measurement transformers are being used to produce the applicable signals to the ION in high voltage and current cases. If we use the devices in low voltage and current systems it is not required to use PTs and CTs.

7.2 Data analysis

The acquired data will be analyzed and all of the required parameters for the power quality compensation will be calculated. If we use and determine the proper process function in these devices, reference voltages and currents for the control of UPQC can be determined. These signals will be transacted via the communication ports; such as: RS232, RS485 or modem for triggering blocks and inverters to the other ION's and computers. Using ION has the following benefits:

1. Intelligent operation and control.
2. The ability of easy communication.
3. Possibility of connection to several IONs.
4. Increasing of speed and resolution.
5. Capability of new control function determination.

Obtaining the mentioned advantages in the distribution systems, automation and control of the UPQC can be done via an ION device. The major principle of the distribution systems power quality management is data acquisition and analysis. This can be done by using power quality meters and controller such as ION. Fig. 16 shows a typical small intelligent distribution control system which uses meters data for the automation. Data are gathered from essential points of a distribution system. These data can be analyzed there or can be sent to the major control unit for other application. Distribution systems have many of nodes that are connected together. Based on the visibility and controllability of the system can be said that meters should be settle where and which of the parameters can be controlled in a typical network.

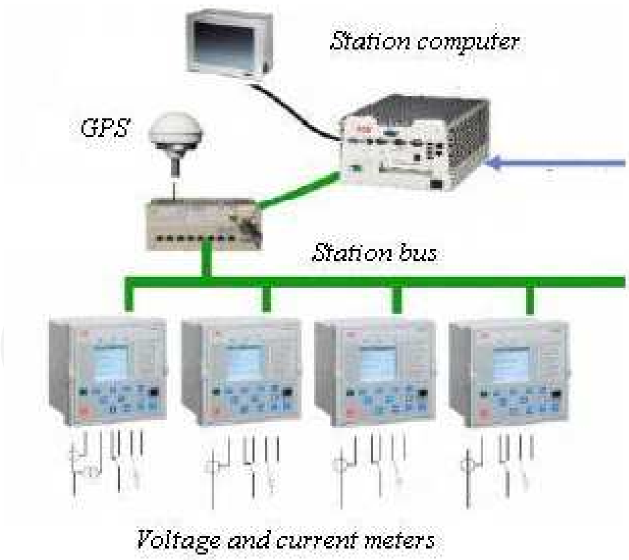


Fig. 16. A typical intelligent distribution control system (Valtari et al., 2009)

8. Case study

For display of the UPQC performance, different control strategies for the unified power quality conditioner are investigated. In the first case, the control strategy of Parallel Active Filter (PAF) and Series Active Filter (SAF) are based on Fourier transform theory. In the second case, the control strategy of PAF is based on the PQ theory and control strategy of SAF is based on the Fourier theory. In the third case, the control strategy of PAF is based on the Fourier transform theory and control strategy of SAF is based on the positive sequence detection (Shayanfar et al., 2007).

8.1 First control strategy

8.1.1 SAF control

First measure the load voltages and then, calculate their 1st order harmonics in magnitude and phase. This operation is based on the Fourier transform theory which can give us 1st order harmonics magnitude and phase. In Eq. (12), details and the theory have been illustrated. For detection of n'th order harmonic magnitude and phase, number of n should be replaced in Eq. (12). T is the major period of signal that is 0.02 s in this simulation. For detection of 1st order harmonics magnitude and phase, n=1 is replaced in the Eq. (12).

$$\begin{aligned} A(n) &= \frac{2}{T}\int_0^T f(t)\cos(\frac{2n\pi}{T}t)dt \\ B(n) &= \frac{2}{T}\int_0^T f(t)\sin(\frac{2n\pi}{T}t)dt \\ Amplitude(n) &= A(n)^2 + B(n)^2 \\ Phase(n) &= Arc\tan(\frac{A(n)}{B(n)}) \end{aligned} \tag{12}$$

The control strategy of SAF is based on considering the Fourier transform of utility voltages. Block diagram of parallel active filter control circuit has been shown in Fig. 17.

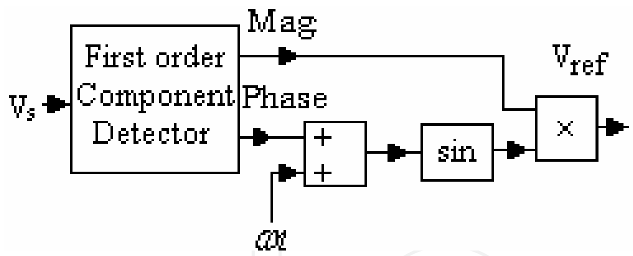


Fig.17. The control circuit of SAF

8.1.2 PAF control

Block diagram of parallel active filter control circuit is similar to Fig. 17. But tangent component of load current to the load voltage will be determined as reference current. Eq. (13) shows parallel active filter control method (Shayanfar et al., 2005a, 2006a).

$$\varphi = \theta_v - \theta_i \qquad I_{ref} = I_1 \times \cos\varphi \tag{13}$$

Where, θ_v and θ_i are 1st order harmonic of voltage and 1st order harmonic of current phases, respectively. I_1 is the magnitude of 1st order harmonic of current.

8.2 Second control strategy

8.2.1 SAF control

Series active filter control in this case is like first case because strategy of SAF control is based on the Fourier theory.

8.2.2 PAF control

For control of parallel active filter, one phase PQ theory is being used. We can show that active and reactive powers can be written as Eqs. (14) and (15):

$$p(t) = v_{la+}(t)i_a(t) + v_{lb+}(t)i_b(t) + v_{lc+}(t)i_c(t) \tag{14}$$

$$q(t) = v'_{la+}(t)i_a(t) + v'_{lb+}(t)i_b(t) + v'_{lc+}(t)i_c(t) \tag{15}$$

Where, $v'_{la+}(t)$ has 90 degree phase shift to $v_{la+}(t)$. Writing in matrix form of the above Eqs. can be done as:

$$\begin{bmatrix} p(t) \\ q(t) \end{bmatrix} = \begin{bmatrix} v_{la+}(t) - v_{lc+}(t) & v_{lb+}(t) - v_{lc+}(t) \\ v'_{la+}(t) - v'_{lc+}(t) & v'_{lb+}(t) - v'_{lc+}(t) \end{bmatrix} \begin{bmatrix} i_a(t) \\ i_b(t) \end{bmatrix} \tag{16}$$

$$\begin{bmatrix} i_a(t) \\ i_b(t) \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v'_{la+}(t) - v'_{lc+}(t) & -(v_{lb+}(t) - v_{lc+}(t)) \\ -(v'_{la+}(t) - v'_{lc+}(t)) & v_{lb+}(t) - v_{lc+}(t) \end{bmatrix} \begin{bmatrix} p_s(t) \\ q_s(t) \end{bmatrix} \tag{17}$$

It should be indicated that $q_s(t)$, compensated reactive power is zero. Then, Eq. (18) can be found as:

$$\begin{bmatrix} i_{refa}(t) \\ i_{refb}(t) \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v'_{la+}(t) - v'_{lc+}(t) & -(v_{lb+}(t) - v_{lc+}(t)) \\ -(v'_{la+}(t) - v'_{lc+}(t)) & v_{lb+}(t) - v_{lc+}(t) \end{bmatrix} \begin{bmatrix} p_s(t) \\ 0 \end{bmatrix} \tag{18}$$

8.3 Third control strategy

8.3.1 SAF control

The control strategy of SAF is based on considering the instantaneous positive sequence of utility voltages as the reference load side voltages. In this way, it is enough to subtract $V_{la+}(t)$, $V_{lb+}(t)$ and $V_{lc+}(t)$ from V_a, V_b and V_c, respectively, for computing the reference compensating voltages of SAF as follows:

$$\begin{bmatrix} V_{compa}(t) \\ V_{compb}(t) \\ V_{compc}(t) \end{bmatrix} = \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} - \begin{bmatrix} V_{la+}(t) \\ V_{lb+}(t) \\ V_{lc+}(t) \end{bmatrix} \quad (19)$$

8.3.2 PAF control

Block diagram of parallel active filter control circuit has been shown in Fig.18.

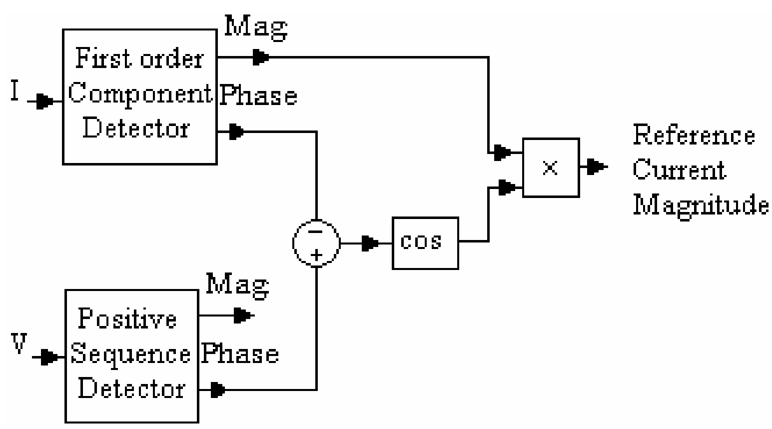


Fig. 18. The control circuit of PAF

9. Simulation results

Operation of three control circuits have been simulated using the power circuit of Fig. 19. This power system consists of a three phase 20 kV (RMS, L-L), 50 Hz utility, a three phase balanced R-L load, a nonlinear three phase load connected to the circuit in 0.05 s ($t_{on} = 0.05$ s) and one phase load connected to the circuit in 0.1s ($t_{on} = 0.1$ s) . For investigation of the proposed control strategy, operation under dynamic condition, magnitude of the first phase of the voltage is reduced to the 0.75 pu in 0.15 s. A number of selected simulation results for three control strategies are shown differently.

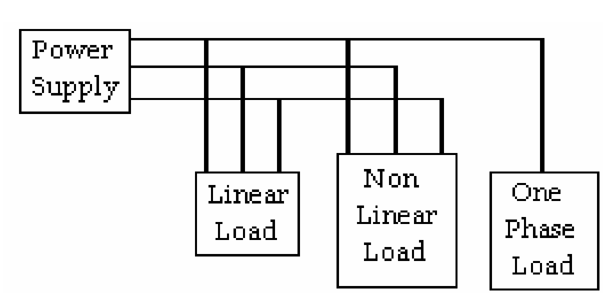


Fig. 19. Test circuit

Table 1 shows test circuit parameters. Fig. 20 shows the load voltages before compensation which are harmonized and unbalanced. Fig. 21 shows compensator voltages and Fig. 22 shows load side voltages in cases (1) and (2). Fig. 23 shows compensator voltages and Fig. 24 shows load side voltages in case (3). It is shown that the proposed control strategies can solve unbalance and reduction of voltage magnitude in the load side and balance them. Fig. 25 shows load side current before compensation. Figs. 26, 27 and 28 show compensator currents in cases (1), (2) and (3), respectively. Figs. 29, 30 and 31 show source side current in cases (1), (2) and (3), respectively. Fig. 32 shows load side current spectrum. Fig. 33 shows source side current spectrum in cases (1) and (3). Fig. 34 shows source side current spectrum in cases (2), respectively. It is seen from the results that control strategy in case (2) can not solve current harmonic problems as well as cases (1) and (3). Fig. 35 shows uncompensated power factor. Figs. 36, 37 and 38 show compensated power factor in case (1), (2) and (3), respectively. Finally Fig. 39 shows source side active and reactive powers after the compensation. Table 2 shows relative speed of three control strategies.

	Load 1	Load 2	Load 3	System Impedance
R	5 Ω	15 Ω if $\|V\| \leq 0.5$ pu 2 Ω if $\|V\| > 0.5$ pu	5 Ω	0.0002 Ω
X	8 mH	10 mH if $\|V\| \leq 0.5$ pu 5 mH if $\|V\| > 0.5$ pu	10 mH	4.5 mH
t_{on}	0 sec	0.05 sec	0.1 sec	-

Table 1. Test circuit parameters

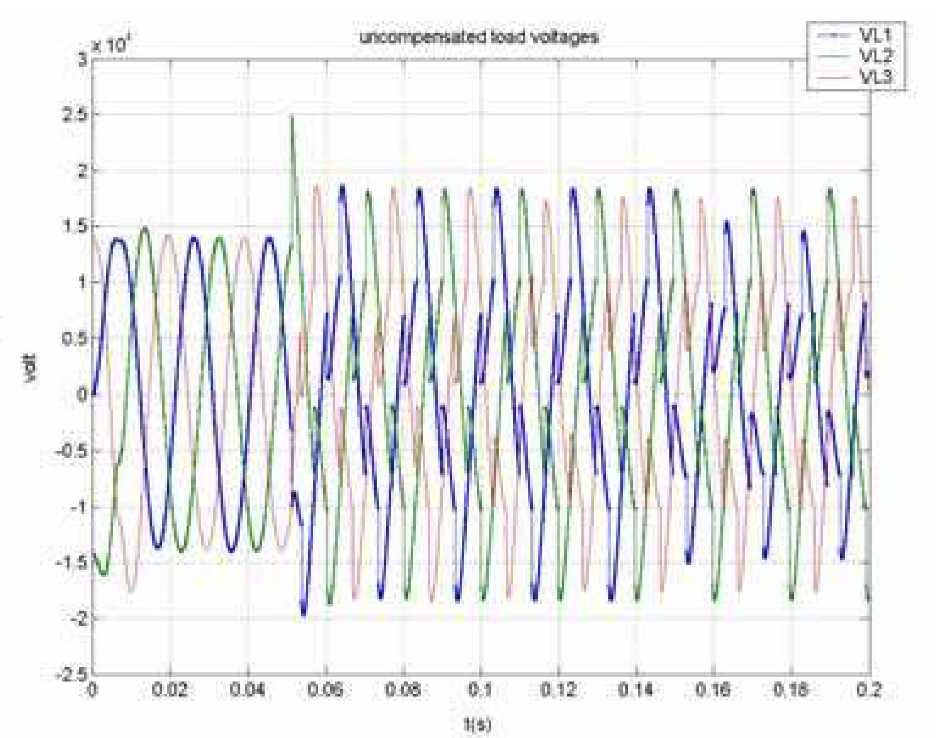


Fig. 20. Harmonized and unbalanced load side voltages (magnitude of phase 1 voltage is reduced to 0.75 pu in t=0.15 s)

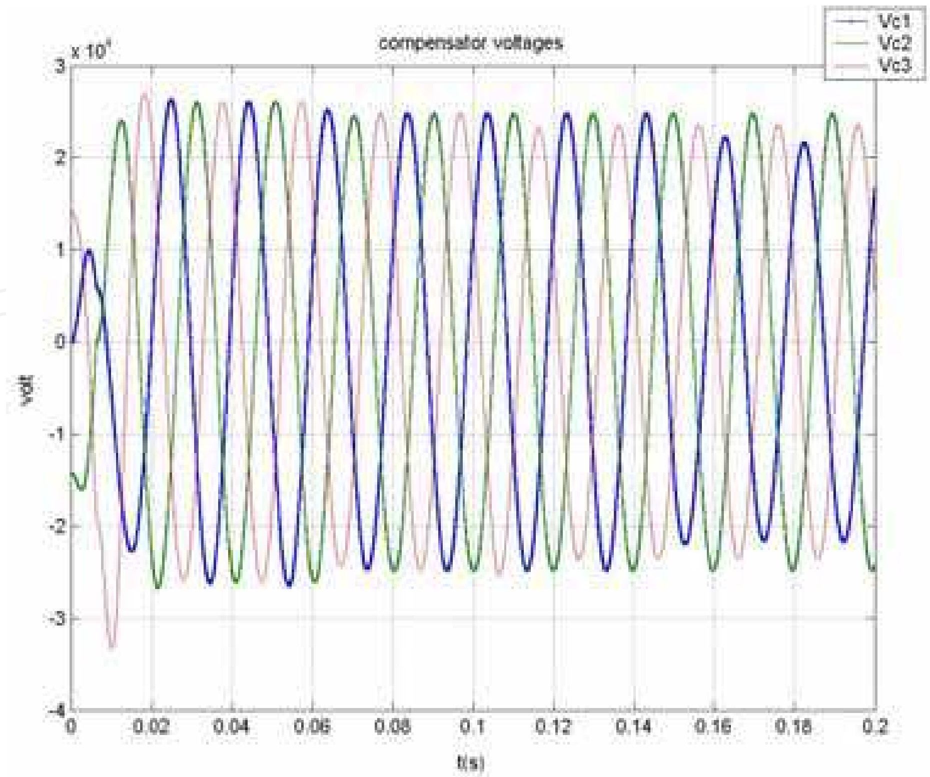


Fig. 21. Compensator voltages (these voltages have been injected to the power system to solve source harmonic and unbalance voltages) in case (1) and (2)

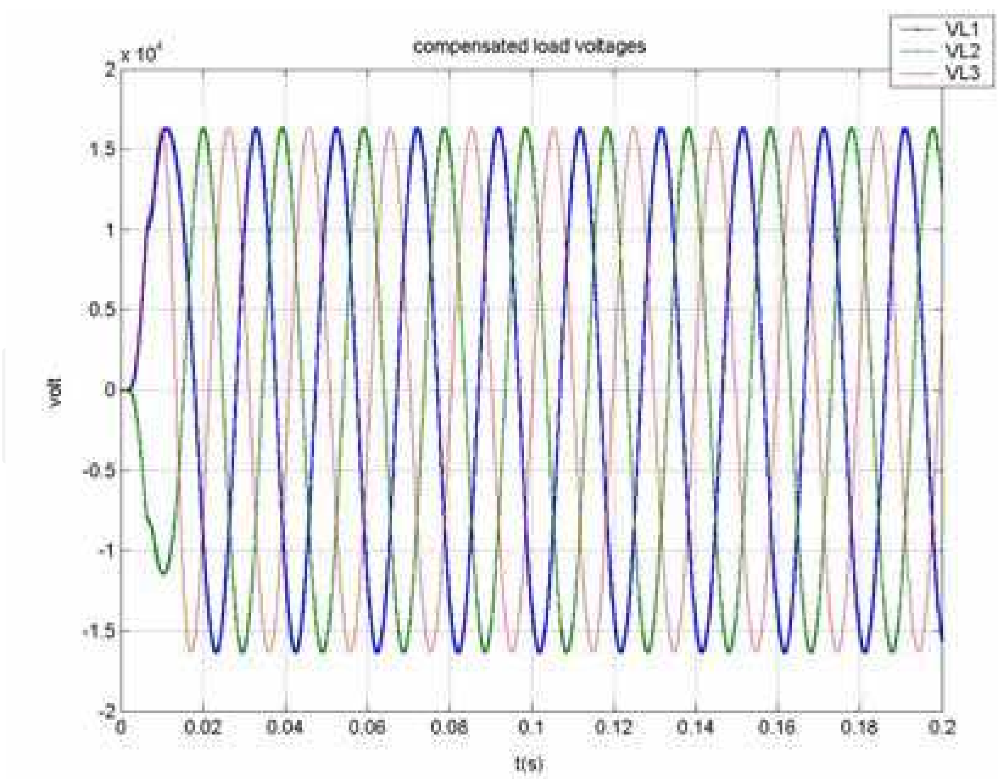


Fig. 22. Load side voltages (after compensation, load side voltages are sinusoidal and balance) in case (1) and (2)

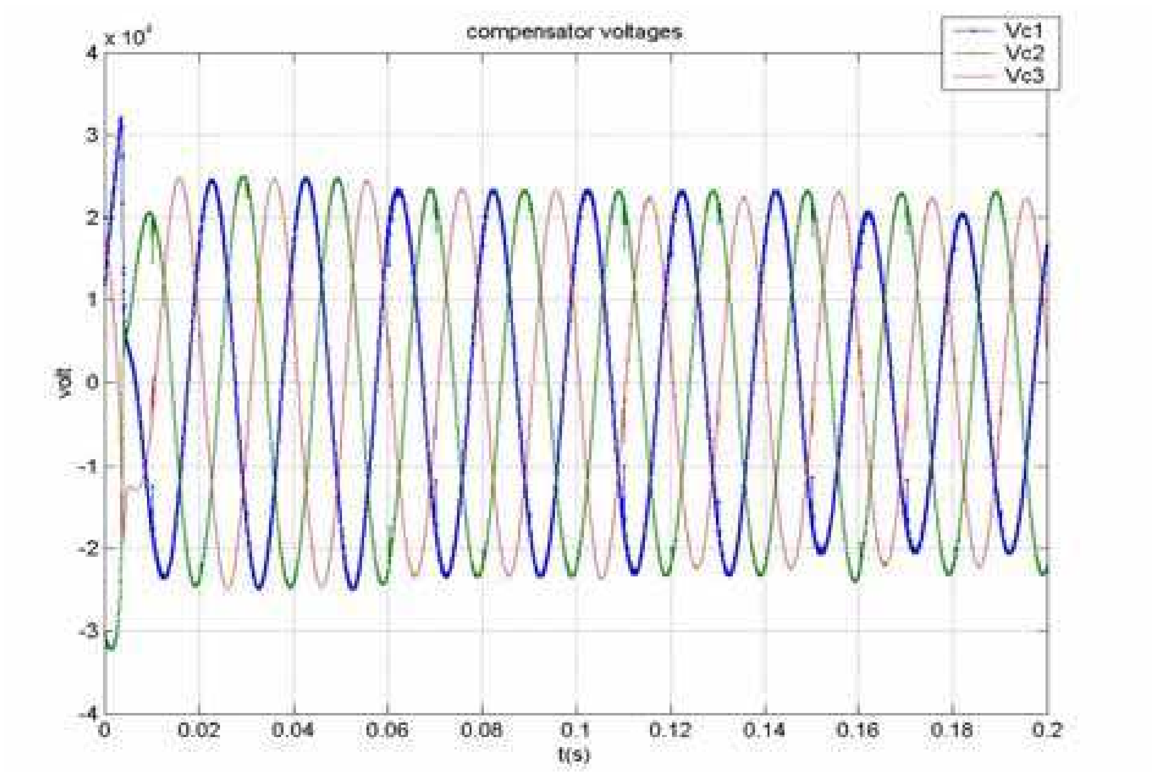


Fig. 23. Compensator voltages (these voltages have been injected to the power system to solve source harmonic and unbalance voltages) in case (3)

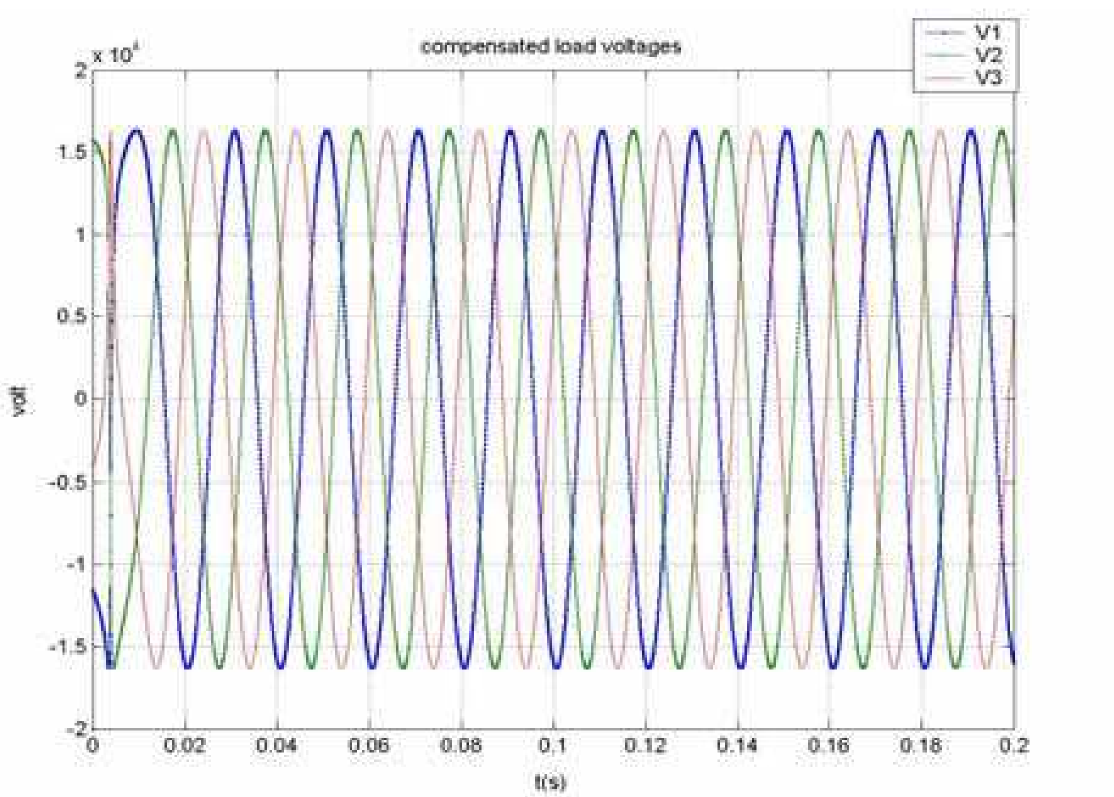


Fig. 24. Load side voltages (after compensation, load side voltages are sinusoidal and balance) in case (3)

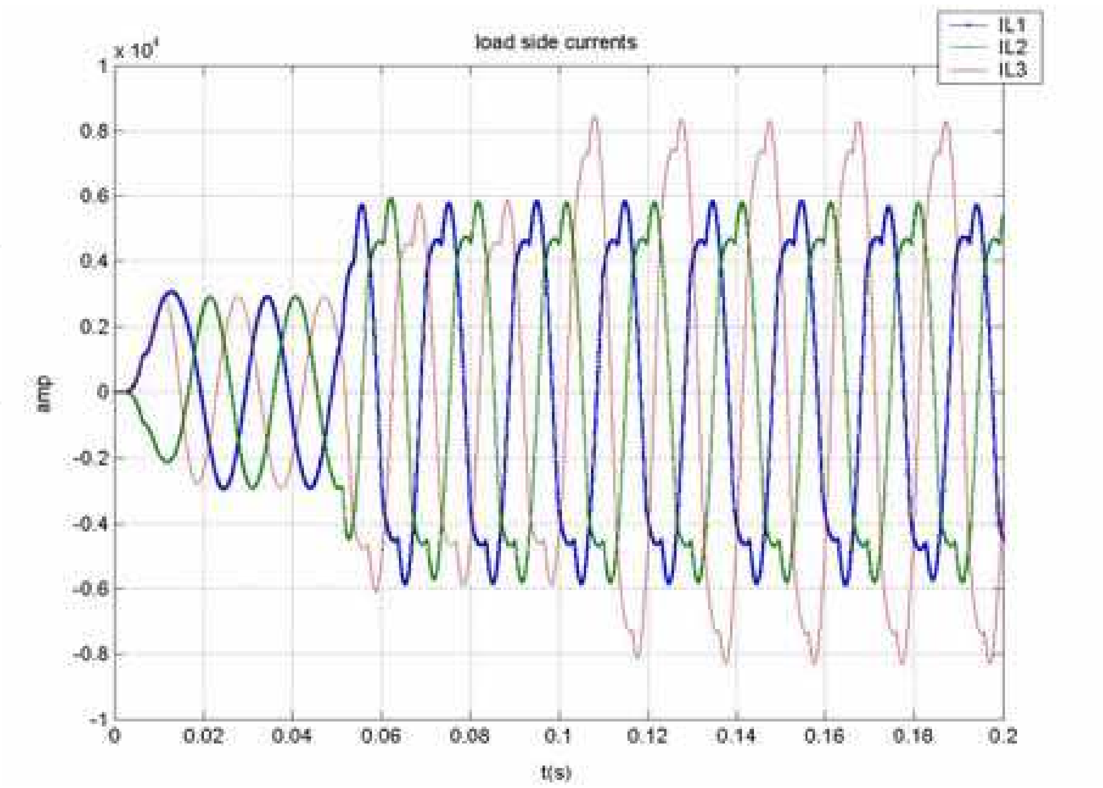


Fig. 25. Load side currents (because load is nonlinear, power system current is non sinusoidal too)

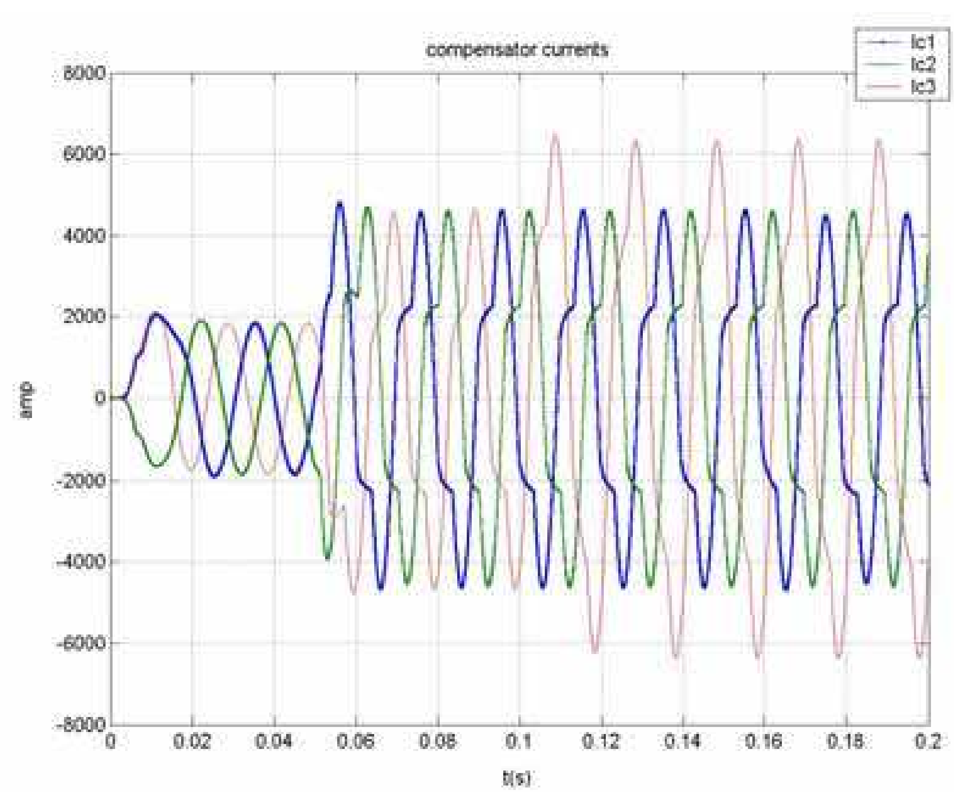


Fig. 26. Compensator currents (these currents have been injected to the power system to solve load harmonic currents) in case (1)

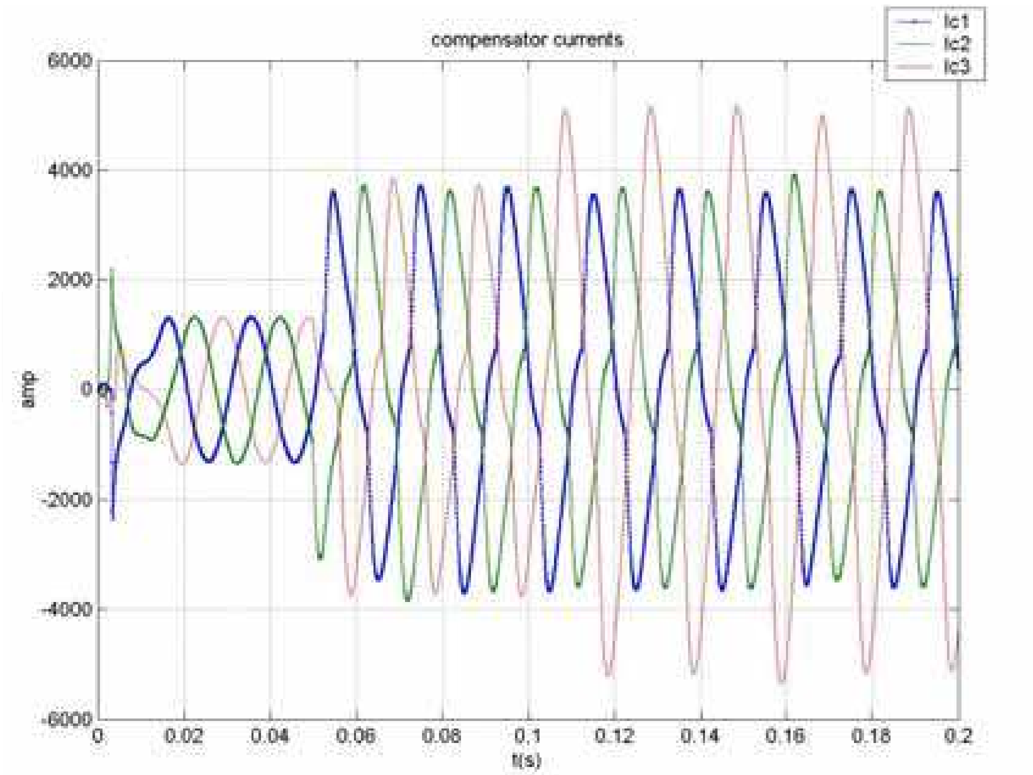


Fig. 27. Compensator currents (these currents have been injected to the power system to solve load harmonic currents) in case (2)

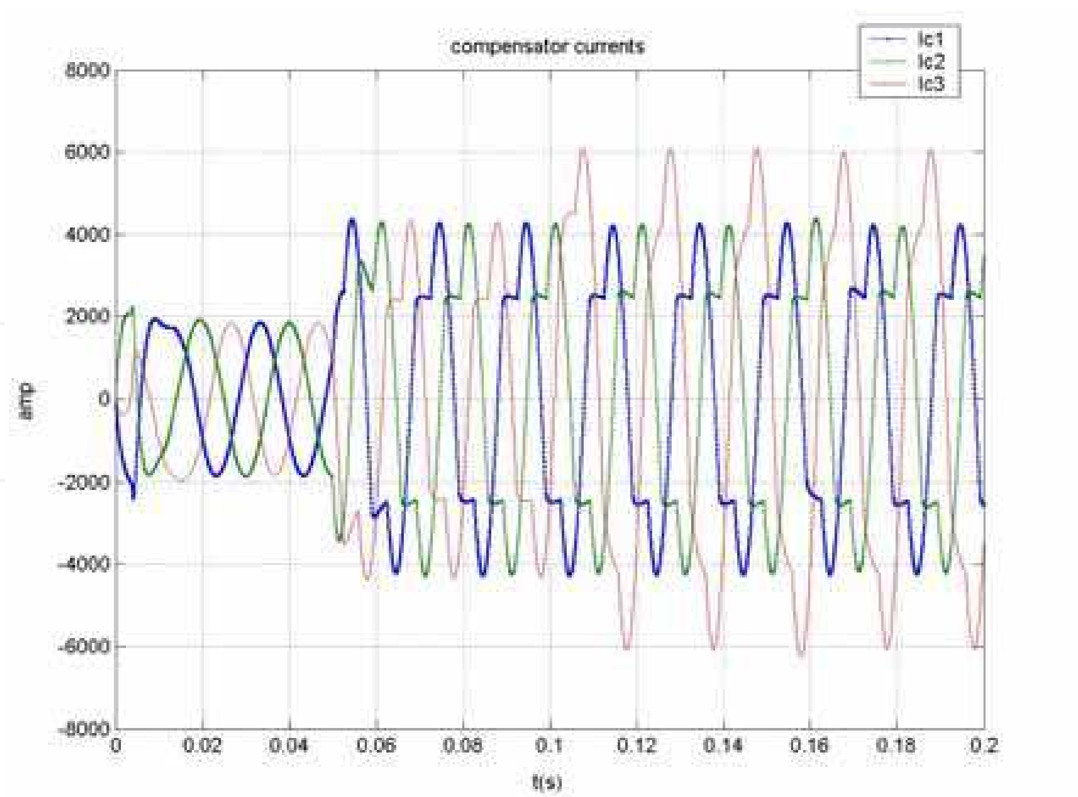


Fig. 28. Compensator currents (these currents have been injected to the power system to solve load harmonic currents) in case (3)

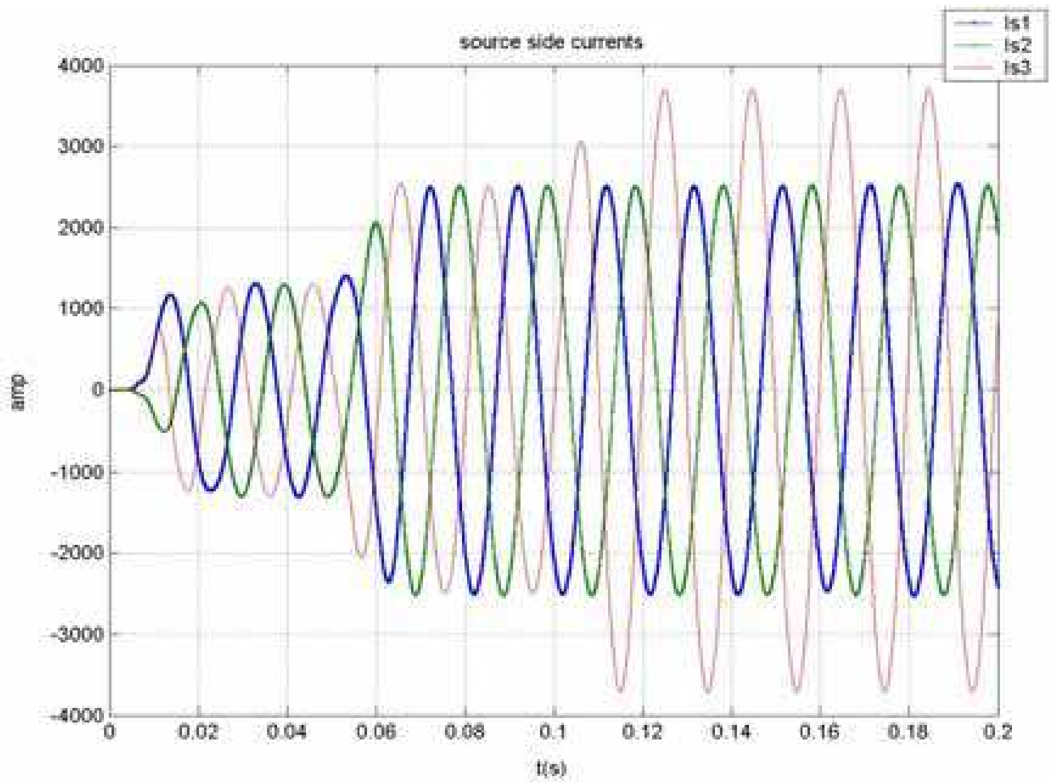


Fig. 29. Source side currents (after compensation, source side currents are sinusoidal) in case (1)

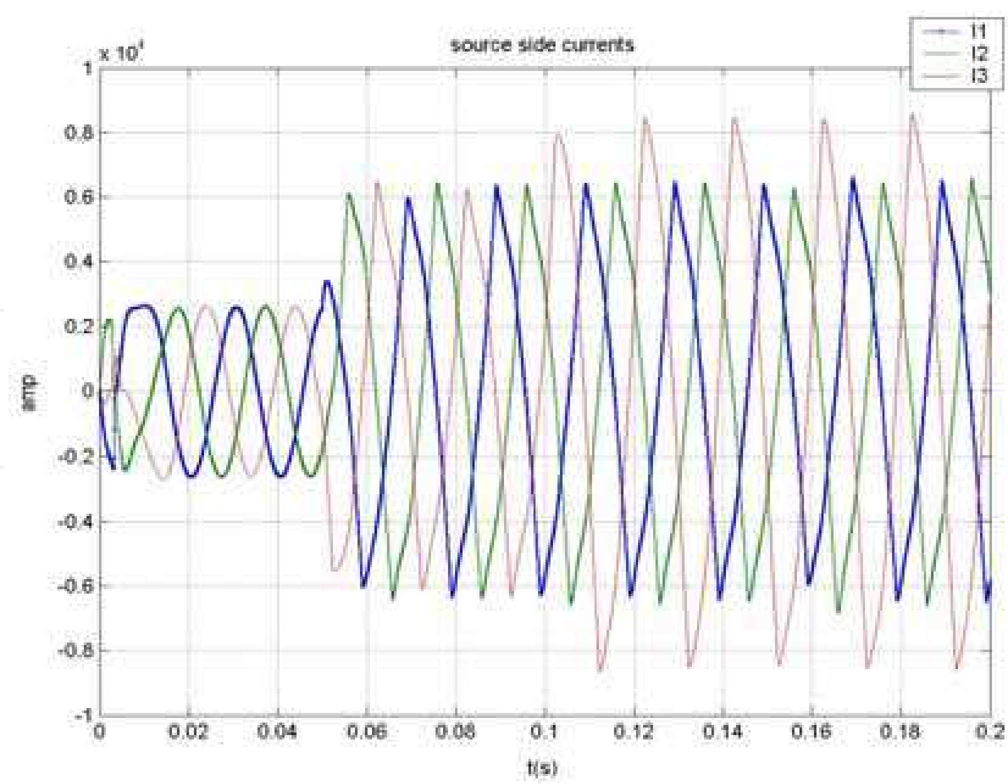


Fig. 30. Source side currents (after compensation, source side currents are sinusoidal) in case (2)

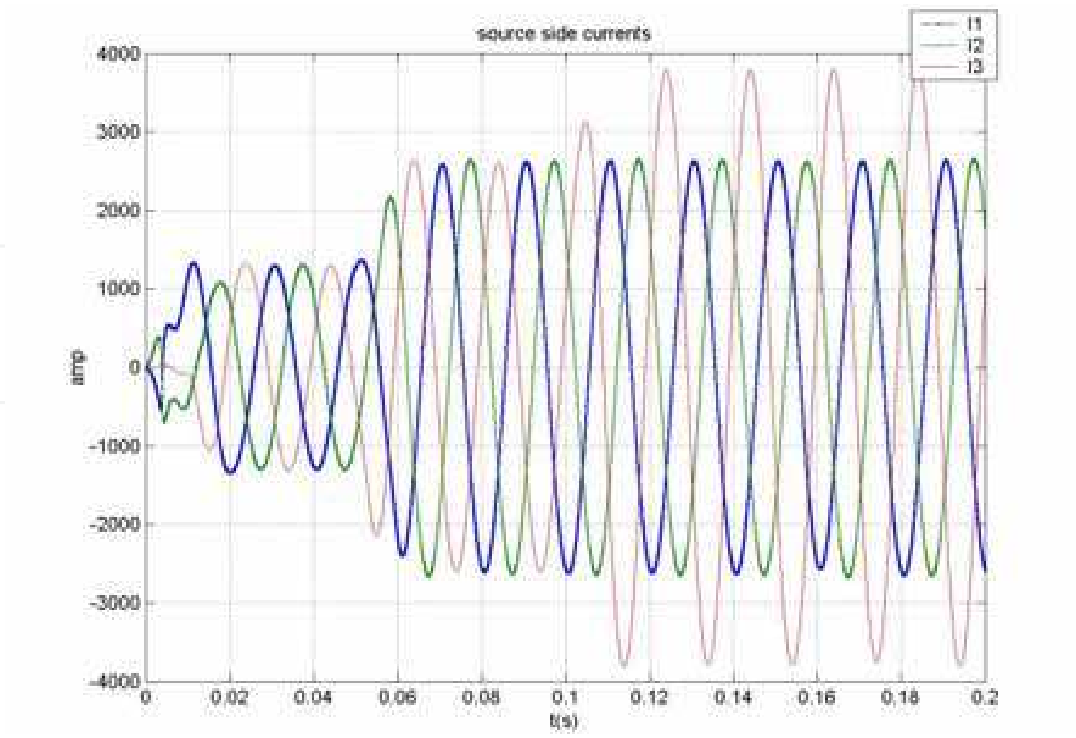


Fig. 31. Source side currents (after compensation, source side currents are sinusoidal) in case (3)

	SAF Speed Cycle	PAF Speed Cycle	Current THD	Voltage THD
Before compensation	-	-	17.6	51.2
Case (1)	0.5	0.5	0.5	0.34
Case (2)	0.3	0.3	0.27	0.29
Case (3)	0.3	0.8	11.44	0.73

Table 2. Relative speed of three control strategies

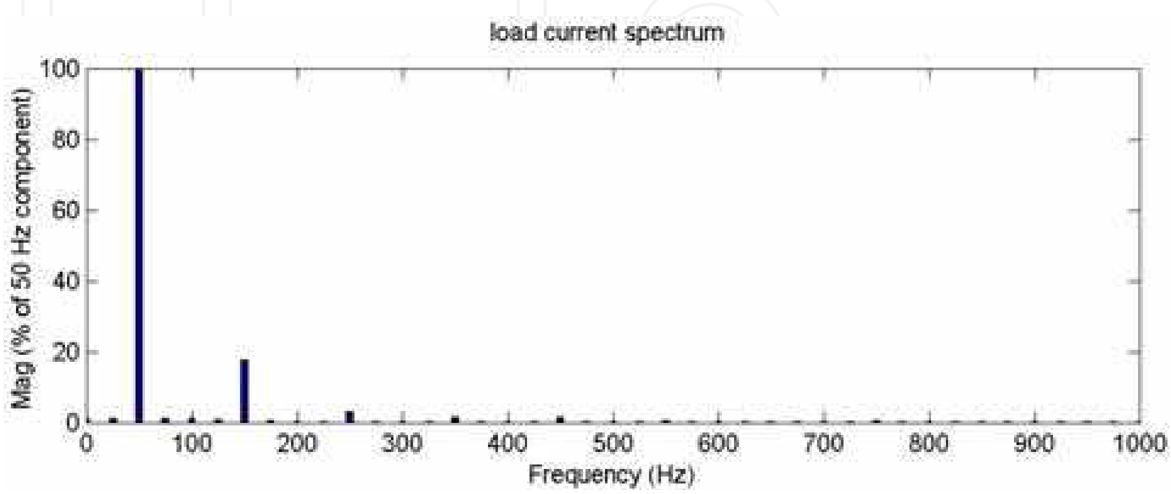


Fig. 32. Harmonic current spectrum before compensation

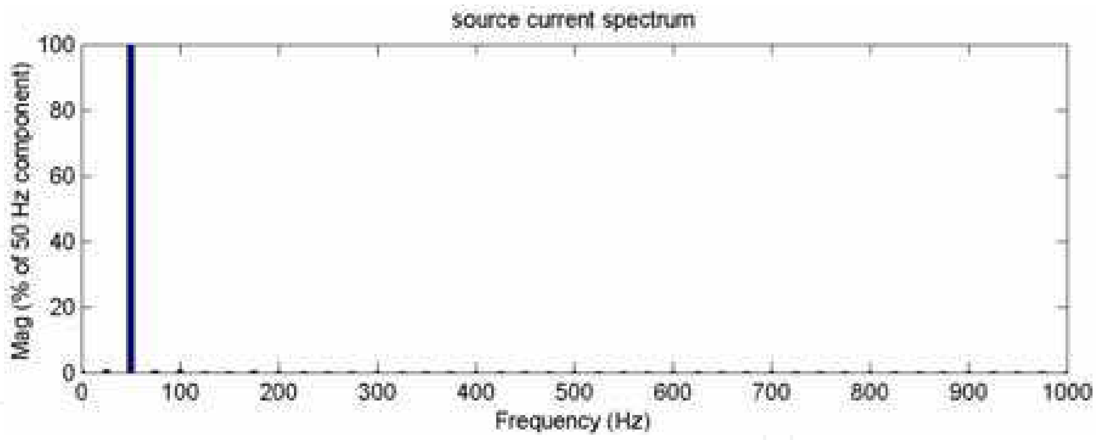


Fig. 33. Harmonic current spectrum after compensation in case (1) and case (3)

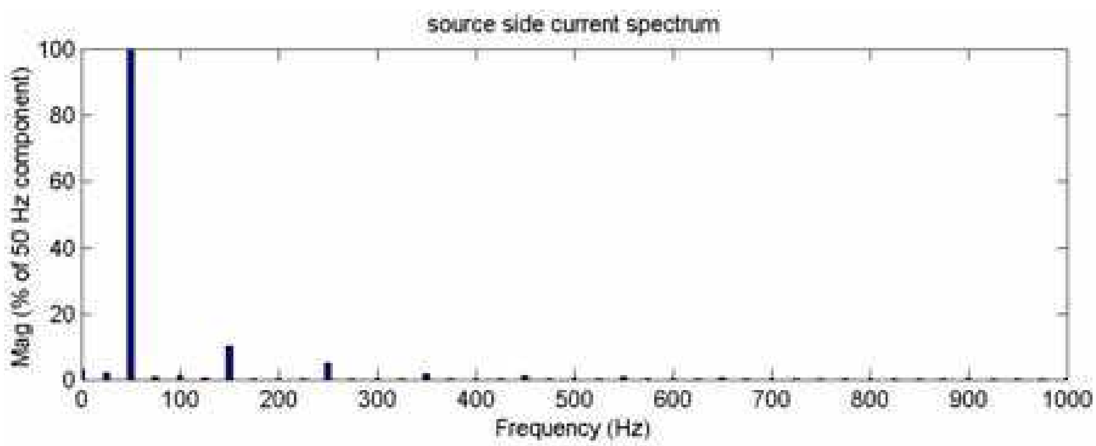


Fig. 34. Harmonic current spectrum after compensation in case (2)

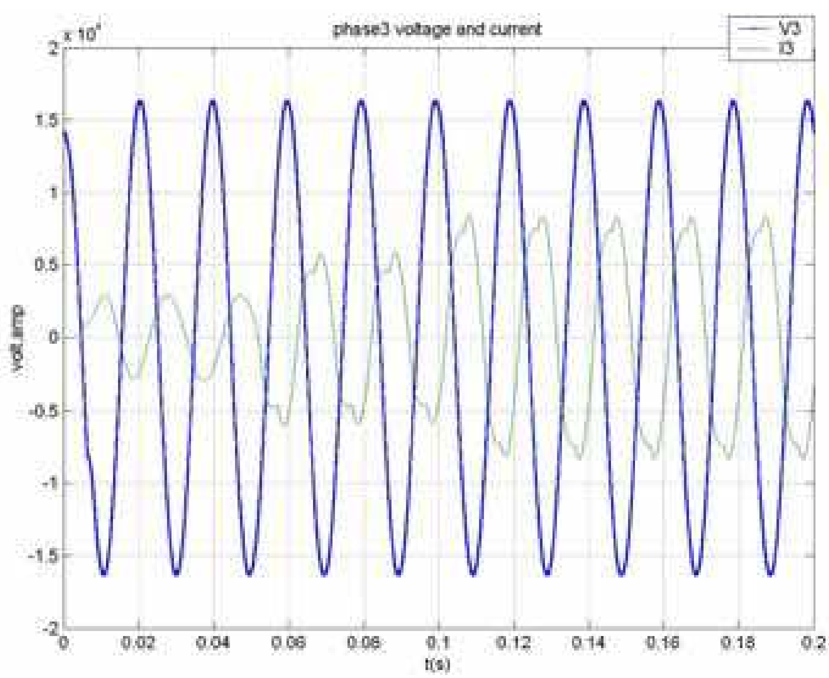


Fig. 35. Load voltage and current before compensation

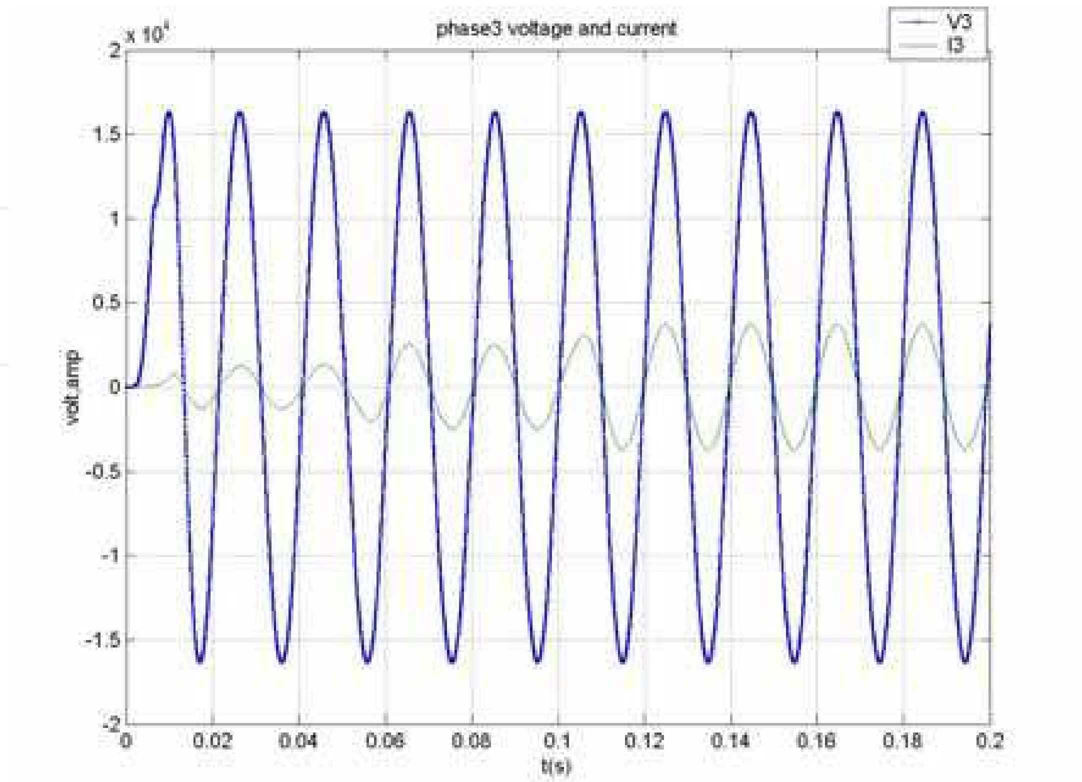


Fig. 36. Load voltage and current after compensation in case (1)

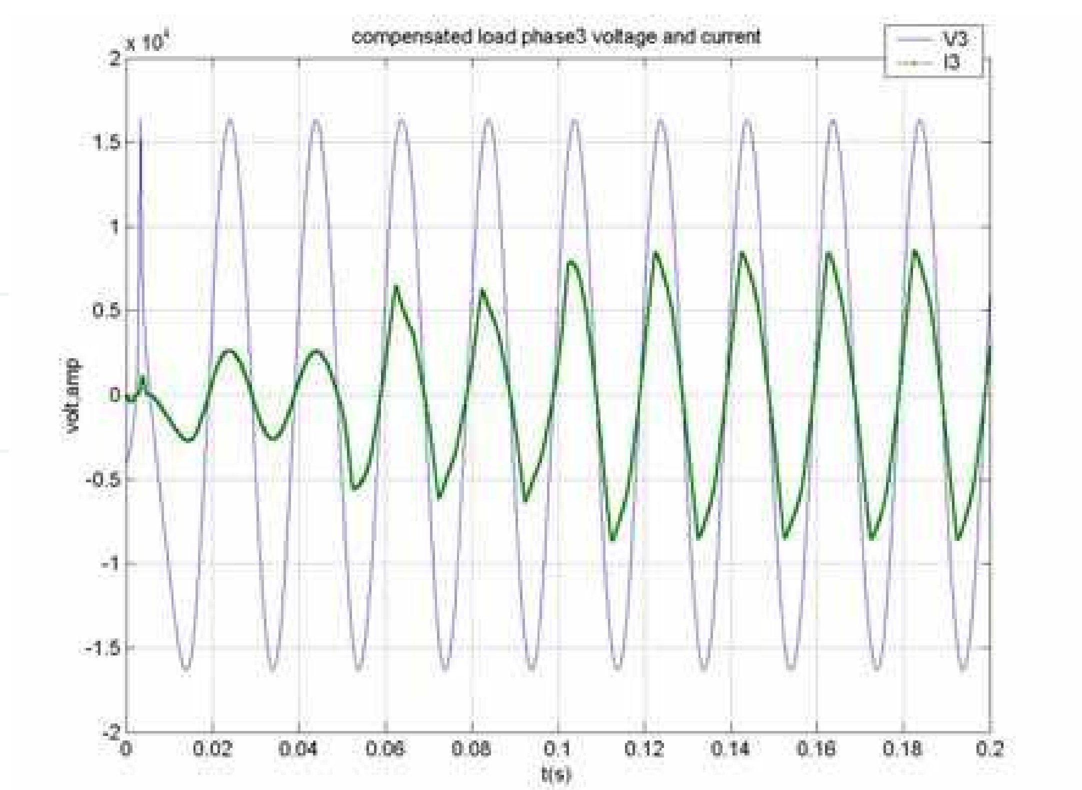


Fig. 37. Load voltage and current after compensation in case (2)

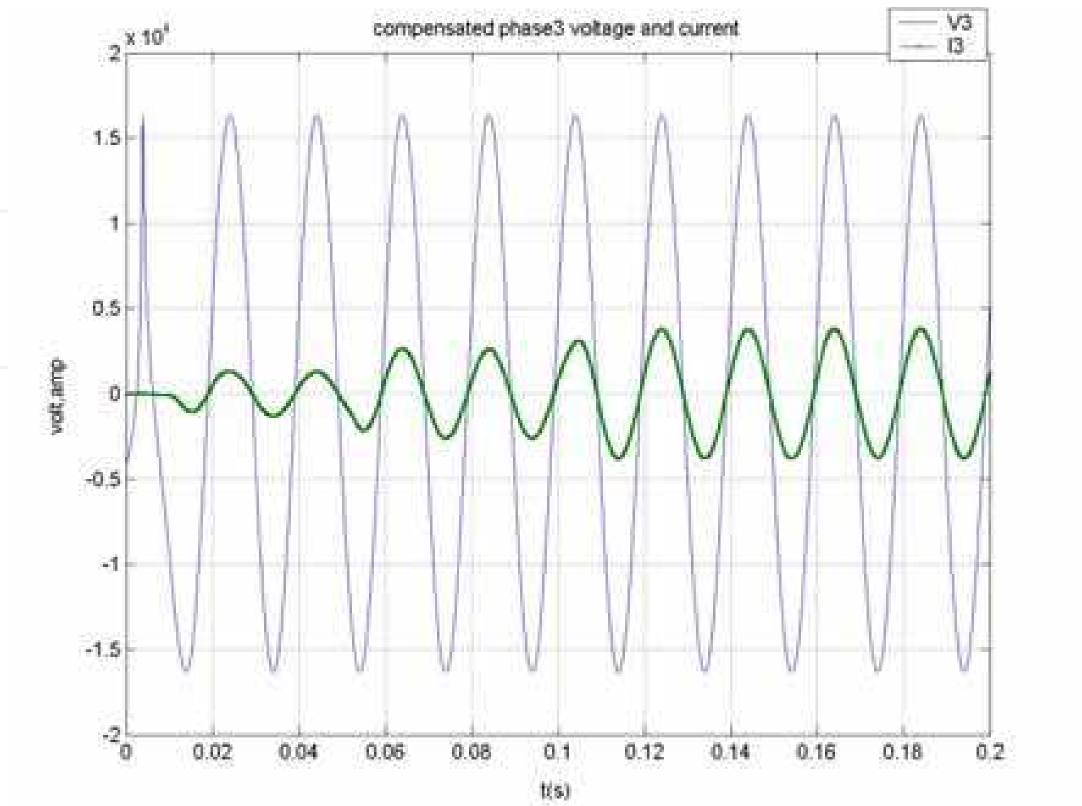


Fig. 38. Load voltage and current after compensation in case (3)

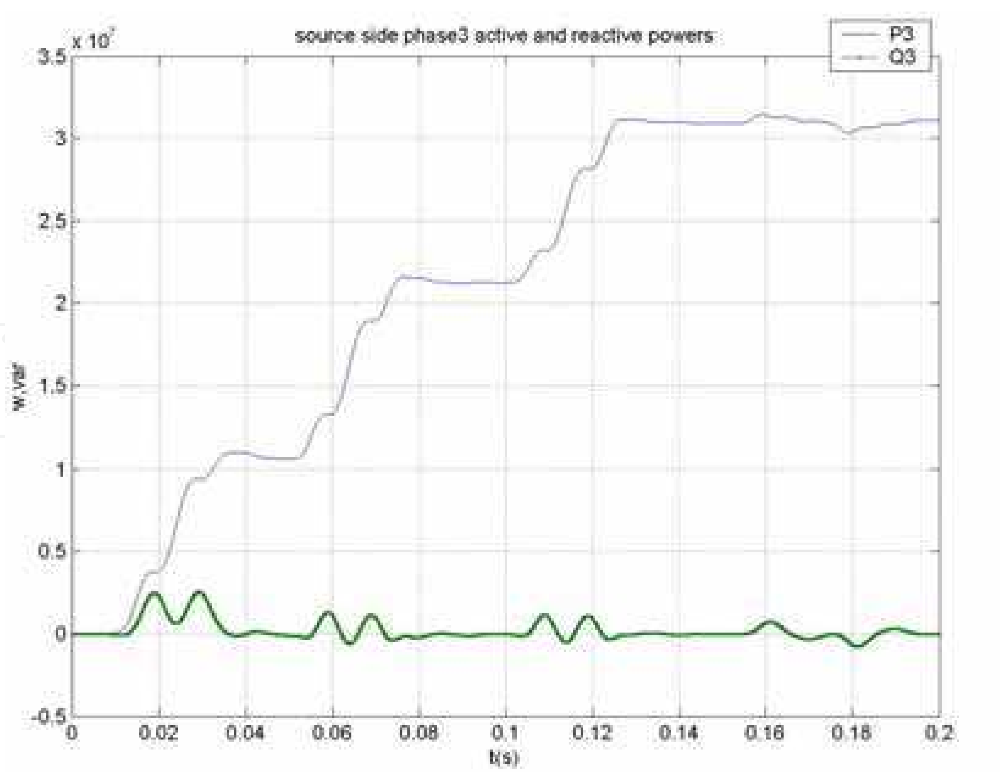


Fig. 39. Source side active and reactive powers

10. Conclusion

Power quality problems are generally divided into two parts of voltage and current problems. Voltage problems are related to the source side and current problems are related to the consumer side. Also, voltage problems can be produced from the current problems; because distribution systems have many nodes and one consumer power quality problem can affect all power quality of nodes. Voltage problems are generally voltage sag and swell, unbalance, zero sequence and harmonics. Current problems are generally zero sequence, unbalance, reactive power and harmonics. Series active filters can be used for the improvement of voltage problems and parallel active filters can be used for the improvement of current problems. Instantaneous improvement of both voltage and current problems, can be done by efficient combination of the above mentioned CP devices which is called Unified Power Quality Conditioner (UPQC).

11. References

Mulhausen, J.; Schaefer, J.; Mynam, M.; Guzman, A. & Donolo, M. (2010). Anti-Islanding Today, Successful Islanding in the Future, *Proceedings of the 63rd IEEE Annual Conferences for Protective Relay Engineers*, pp. 1-8, ISBN 978-1-4244-6073-1, Texas, U.S.A., March 29 2010-April 1 2010, IEEE, College Station

Mokhtarpour, A.; Shayanfar, H.A. & Tabatabaei, N.M. (2009). Power Quality Compensation in two Independent Distribution Feeders, *International Journal for Knowledge, Science and Technology*, Vol. 1, No. 1, (October 2009) page numbers (98-105), ISSN 1889-7762

Grainger, John J. & Stevenson, William D. (1994). *Power System Analysis*, McGraw-Hill Book Company, ISBN 0-07-061293-5, New York

Shayanfar, H.A.; Tabatabaei, N.M. & Mokhtarpour, A. (2005a). Modified Strategy for Unified Power Quality Conditioner (UPQC) Based on Intelligent Devices, *Proceedings of the Ninth World Multiconference on Systemic, Cybernetics and Informatics*, pp. 13-17, Florida, U.S.A, July 10-13 2005, Orlando

Shayanfar, H.A.; Tabatabaei, N.M. & Mokhtarpour, A. (2006a). Control of Series Active Filter Based on Modelling of ION Devices, *Proceedings of the Third International Conference on Technical and Physical Problems in Power Engineering*, pp. 915-918, Turkey, May 29-31 2006, Gazi University, Ankara

Shayanfar, H.A.; Tabatabaei, N.M. & Mokhtarpour, A. (2006b). A Novel Intelligent Control Strategy for Reactive Power and Current Harmonics Compensation, *Proceedings of the Third International Conference on Technical and Physical Problems in Power Engineering*, pp. 272-275, Turkey, May 29-31 2006, Gazi University, Ankara

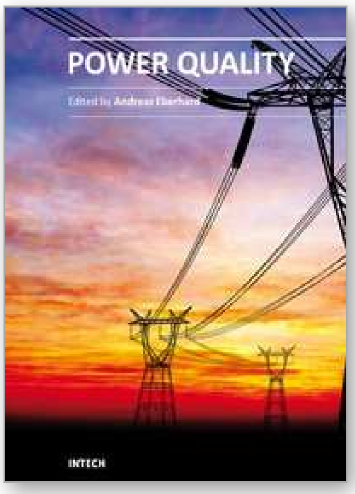
Shayanfar, H.A.; Tabatabaei, N.M. & Mokhtarpour, A. (2006C). Unified Power Quality Conditioner (UPQC) Control Based on Fourier Transform, *Proceedings of the IEEE International Conference on Power System Technology (POWERCON 2006)*, pp. 1-5, ISBN 1-4244-0110-0, China, October 22-26 2006, IEEE, Chongqing

Kazemi, A.; Mokhtarpour, A. & Tarafdar Haque, M. (2006). A New Control Strategy for Unified Power Quality Conditioner (UPQC) in Distribution Systems, *Proceedings of the IEEE International Conference on Power System Technology (POWERCON 2006)*, pp. 1-5, ISBN 1-4244-0110-0, China, October 22-26 2006, IEEE, Chongqing

Shayanfar, H.A.; Tabatabaei, N.M. & Mokhtarpour, A. (2005b). Use of Intelligent Measurement and Control Devices in Electrical Energy Disturbance Compensation, *Proceedings of the Eighth Baku International Congress of Energy, Ecology, Economy*, pp. 764-770, Azerbaijan, June 1-3 2005, International Ecoenergy Academy, Baku

Valtari, J.; Verho, P.; Hakala-Ranta, A. & Saarinen, J. (2009). Increasing Cost Efficiency of Substation Automation Systems by Centralized Protection Functions, *Proceedings of the 20th International Conference and Exhibition on Electricity Distribution*, pp. 1-4, ISBN 978-1-84919126-5, Czech Republic, June 8-11 2009, IEEE, Prague

Shayanfar, H.A.; Tabatabaei, N.M. & Mokhtarpour, A. (2007). Best Control Strategy for Unified Power Quality Conditioner (UPQC) Based on Simulation, *Proceedings of The IASTED International Conference on Power and Energy Systems (PES 2007)*,pp. 257-262, Florida, U.S.A., January 3-5 2007, Clearwater



Power Quality
Edited by Mr Andreas Eberhard

ISBN 978-953-307-180-0
Hard cover, 362 pages
Publisher InTech
Published online 11, April, 2011
Published in print edition April, 2011

Almost all experts are in agreement - although we will see an improvement in metering and control of the power flow, Power Quality will suffer. This book will give an overview of how power quality might impact our lives today and tomorrow, introduce new ways to monitor power quality and inform us about interesting possibilities to mitigate power quality problems.