An Adaptive Noise Canceling Approach Theory Based Single-Phase Unified Power Quality Conditioner

AHAD KAZEMI, MOSTAFA SARLAK, MOJTABA BARKHORDARY

Department Electrical Engineering of
Iran University of Science and Technology
Iran

Keyword - Unified Power Quality Conditioner (UPQC), Adaptive Noise Canceling (ANC)

Abstract:

The most critical issues associated with Unified Power Quality Conditioner (UPQC) control is that of finding an algorithm which can obtain an accurate harmonic reference signal for control purpose, particularly in the practical case where the harmonics and the system frequency of a power system are time varying. In this paper, application of Adaptive Noise Canceling (ANC) theory in unified power quality conditioner is proposed. It uses a primary input containing the corrupted signal and a reference input correlated with the fundamental component of the system voltage. The reference input is adaptively filtered and subtracted from the primary input to get the wanted control reference signal. Its validity is assessed by the simulation and experimental results.

I. Introduction

Distribution of sinusoidal voltage and current waveforms caused by harmonics is one of the major power quality concerns in the electric power industry. Considerable efforts have been made in recent years to improve the management of harmonic distortion in power systems [1]. Static power converters and other nonlinear loads are the culprits of these distortions. The switching actions of the static power converters result in distorted input currents, which contain a fundamental component and other higher harmonic components. Hence, these static power converters behave as a current source, injecting harmonic current in to the supply network. This constitutes the problems of power system harmonics. One of the problems of power system harmonics is the supply voltage distortion at the point of common coupling (PCC). When a static power converter injects a distorted current into the supply network, a harmonic voltage is developed across the source impedance. The voltage at the PCC, being the difference between the source voltage and the voltage across the source impedance, is distorted [2].

Active filters have been known as the best tool for harmonic mitigation as well as reactive power compensation load balancing, voltage regulation, and voltage flicker compensation. Active filters have been designed, improved, and commercialized in the last 25 years. They are applicable to compensate current-based distortions such as current harmonics, reactive power, and neutral current. They are also used for voltage-based distortions such as voltage harmonics, voltage flickers, voltage sags and swells and voltage unbalances. Many configurations such as shunt, series, hybrid (a combination of shunt and series active filters), and unified power quality conditioner combination have been introduced and improved [1].

According to the basic idea of UPQC, it consists 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. 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 load and in the same time, isolates the load from voltage quality problems of utility. The configuration of the system is shown in Fig1. [2].

The unified power quality conditioner is firstly introduced in [3]. Traditionally, it was used to mitigate current and voltage disturbances. Subsequently, it was developed to compensate some problems in the distribution systems such as current disturbances (harmonics and unbalance) [4], voltage flicker [5], zero – sequence compensation [4, 6]. Some modification is made to enable UPQC to perform more than one function such as current harmonic mitigation and balanced voltage sags compensation [7].

Many contributions were introduced to modify the configurations [8, 9] and the control algorithms to enhance its performance [10, 11].

The control algorithms are classified into three classes;

1-Time domain techniques: the control techniques are based on instantaneous derivation of the compensating commands in the form of either voltage or current signals from the distorted and harmonic-polluted voltage or current signals, for example, p-q theory [15], d-q orthogonal coordinates [12], synchronous detection method [11], sliding mode, and deadbeat control [3]. 2-Frequency domain techniques: most of the frequency domain techniques depend on FFT for disturbance extraction. 3-Time-frequency domain: Wavelets transform [13].

This paper introduces an adaptive noise canceling theory based control strategy for UPQC. The simulation results demonstrate its effectiveness despite its very simple structure. In section II, system configuration of full-bridge UPQC is described. Principles of control system are discussed in section III. Compensating current and voltage calculation is described in section IV. Control system is presented in section V. In section VI simulation results are presented.

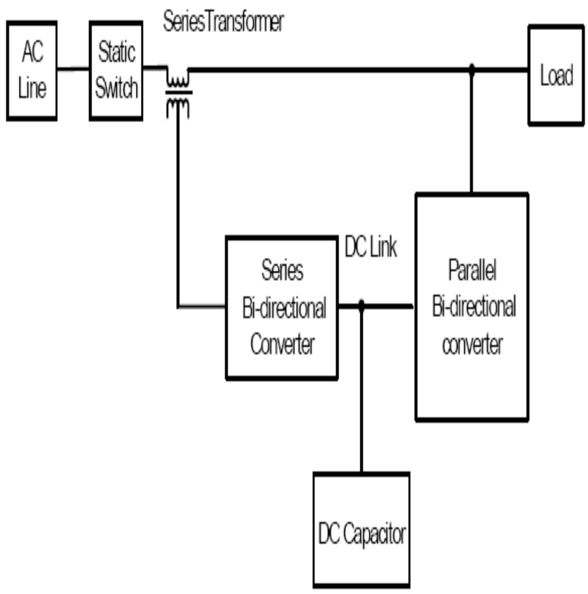

Figure 1.Block diagram of a typical unified power quality conditioner

II. Configuration of full-bridge UPQC

A conventional UPQC topology consists of two full-bridge bidirectional converters connected to a common DC link bus, as shown in Figure 2.

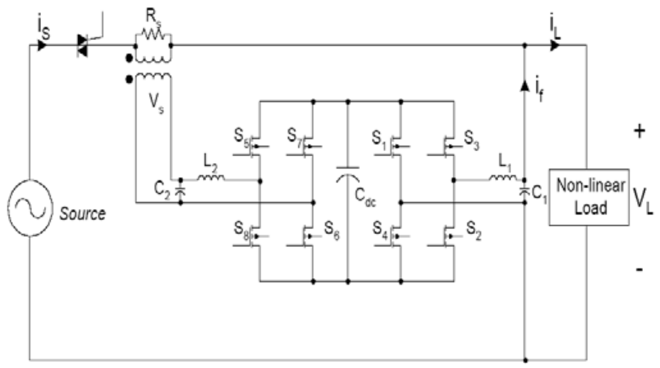

Figure 2. A full bridge single-phase UPQC

The series bi-directional converter consists of four switches. It is connected via a transformer in series with the AC line. The parallel bi-directional converter also consists of four switches. Two passive filters formed by L1, C1, L2, and C2 remove switching frequency harmonics from the output current of the parallel converter and the output voltage of the series converter, respectively. L1 also acts as a link between the filter and the system. Parallel converter delivers its current to the system through this inductor. Its inductance directly Influences the bandwidth of the parallel converter. Load is a sensitive non-linear electronic device. The series converter compensates the voltage difference of the input and reference voltage and regulates the voltage of the load terminal. This converter has the ability to cancel voltage disturbances such as harmonics, voltage sags and swells, and spikes. It gives or absorbs active power in the case of voltage sags and swells, respectively. For compensating the voltage harmonic of the source side, it only delivers reactive power. Parallel inverter mitigates load's current harmonics, compensates the reactive current, and draws a small component of the fundamental

III. Principle of control

An analogue adaptive detecting circuit based on adaptive interference canceling theory is used to extract the reactive power and harmonics components of the load current and the load voltage as the control signals of the UPQC and then a current and a voltage equal in magnitude but opposite in phase of the detected current and voltage are injected into the system by the UPQC. By using a fixed switching frequency, the high-frequency ripple current generated by proposed UPQC can be easily removed from the power system. The block diagram of the UPQC control system can be found in Fig.3. It consists of a control system unit, the dc voltage control unit, two adaptive detecting circuit units and the gating signals generators. The ac current and voltage generated by the inverter is forced to follow the reference current and voltage signals obtained from the adaptive detecting circuit. The adaptive detecting circuit is used to retrieve the reactive and harmonic components from load current and load voltage as reference signals for the unified power quality conditioner. A constant switching frequency is achieved by comparing the current error signal with a triangular reference waveform and makes the design of high-frequency filter and inductor L easier. The constant voltage across the dc capacitor is maintained to prevent the power inverter from entering the uncontrollable rectifying range and deteriorating the quality of compensation. By keeping the dc voltage constant, the inverter voltage gain is increased and the amplitude of high-frequency inverter ripple current component is reduced. In this paper, the voltage-source inverter is adopted due to its simple structure, small size and high efficiency.

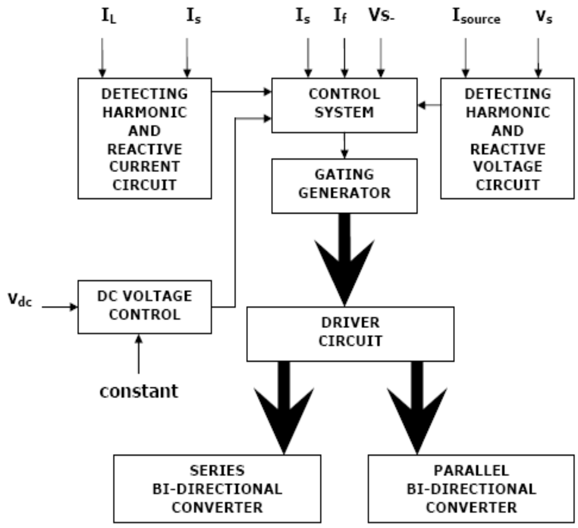

Figure 3. Block diagram of the UPQC control

In Fig.4, s1-s2 is four ideal switches. By controlling on-time and off-time of these switches, arbitrary current waveform i_L can be achieved. If the current and voltage injected by UPQC is same as that of reactive power and harmonic components of a nonlinear load, the current and voltage provided by ac power source will only have fundamental real component as shown in Fig.2,

$$I_S = I_L + I_f \quad (1)$$

$$V_{SOURCE} = V_L + V_S \quad (2)$$

where the source line current is I_S, I_f is the compensating current, I_L is the load current, the source line voltage is V_{SOURCE}, V_S is the compensating voltage, and V_L is the load voltage.

The mathematical model of the voltage-source inverter is as follows

$$\dot{i} = \frac{1}{L}(v_s - Sv_c) \quad (3)$$

$$v_c = \frac{1}{c} i_c = \frac{1}{L} Si_L \quad (4)$$

where
S=1: s1, s4 turn-on, s2, s3 turn-off
S=-1: s2, s3 turn-on, s1, s4 turn-off
and s1 , s2 , s3 , s4 are the switch states related to Fig.4.

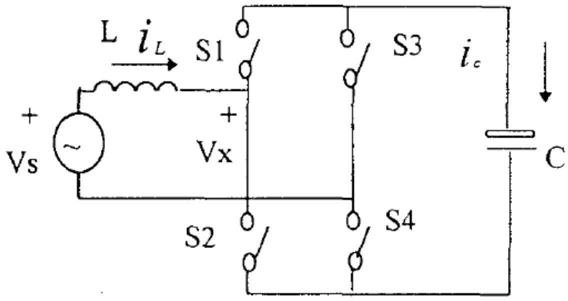

Figure.4.Block diagram of power inverter

From eqs.(3) and (4), the voltage across the dc capacitor should be greater than the peak value of ac source voltage in order to guarantee the current flow in positive and negative direction, i.e. the current can go up and down in one period time. The ability to track the reference current and voltage are affected by the difference (v_s-v_c) and L.

Reducing and increasing (v_s-v_c) will improve this ability and the quality of compensation for reactive and harmonic current and voltage [14].

IV. Compensating and voltage calculation

The critical problem of a unified power quality conditioner is to find an algorithm which can obtain an accurate harmonic reference signal for control purpose. In this paper, a detecting method based on adaptive noise canceling theory [16], which is used widely in the signal processing in recent years, is adopted to measure the reactive power and harmonic components of the nonlinear load current and load voltage is implemented. The block diagram of the adopted scheme is shown in Fig.5 where I_L is the load current, and V_L is the load voltage, I_f is the output signal of the adaptive detecting circuit, V_S is the output signal of the adaptive detecting circuit; and D' is the fundamental reference voltage which is in phase with ac source voltage D'=$E \sin \omega t$. As seen in Fig.5,

$$I_f = I_L - (K.D' .\int_0^t I_f .D'.dt) \quad (5)$$

$$V_S = V_L - (K.D'.\int_0^t V_S .D'.dt) \quad (6)$$

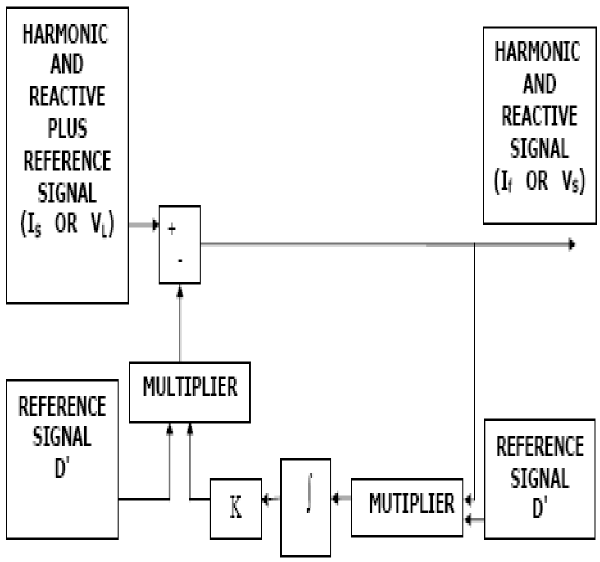

Figure.5.Block diagram of the ANC circuit

From the theory of ANC and eq.(4), as the input sinusoid reference signal, i.e. the fundamental component of the system voltage, has the same frequency and in phase with the desired fundamental components of load current and load voltage, the dc component of the output of integrator will tune accordingly until they are equal in magnitude. The corresponding fundamental real components of the current and voltage are then extracted from the sampled load current and load voltage. Under the action of ANC loop, in steady state the output current and voltage I_f and V_S of detecting circuit have no larger include the fundamental real components, the dc component of the integrator output will keep a constant value, which is in proportional to the magnitude of the fundamental real component of load.

$$I_f = I_L - kE_m \sin\omega t(K_0 + \frac{1}{\omega RC}.\int_0^t I_f.E_m.\sin\omega t d\omega t) = I_L - kK_0 E_m \sin\omega t - kK_1 E_m \sin\omega t \quad (7)$$

where, $$K_1 = \frac{1}{\omega RC}.\int I_f.E_m.\sin\omega t d\omega t$$

and, $$V_S = V_L - kE_m \sin\omega t(K_0 + \frac{1}{\omega RC}.\int_0^t V_S.E_m.\sin\omega t d\omega t) = V_S - kK_0 E_m.\sin\omega t - kK_1 E_m.\sin\omega t$$

(8) where,

$$K_1 = \frac{1}{\omega RC}.\int I_f.E_m.\sin\omega t d\omega t$$

For eq.(7) and eq.(8), E_m is the peak value of the fundamental reference voltage; K_1 is the proportional coefficient; and K_o is the dc component of the integrator output.

Due to the large time constant of the integrator and the orthogonally, all the components in K_1 except the fundamental real component which is in phase with the reference input, i.e. the real component in system voltage and real component in I_f in steady state are approximated to zero, K_1 will be also approximated to zero. Then the last term in eq. (7) and eq. (8) can be omitted. Assume that the load current and load voltage can be expressed as

$$I_L = I_p + I_q + I_h \quad (9)$$

$$V_L = V_p + V_q + V_h \quad (10)$$

where I_p is fundamental active component load current; I_q is fundamental reactive component of load current; I_h is harmonic components in load current; V_p is fundamental active component of load voltage; V_q is fundamental reactive component of load voltage; and V_h is harmonic components in load voltage. Then

$$\begin{aligned} I_f &= I_L - kK_0.E_m \sin\omega t = I_p + I_q + I_h - kK_0 E_m.\sin\omega t \\ I_f &= I_q + I_h; \end{aligned} \quad (11)$$

$$I_p = kK_0.E_m.\sin\omega t \quad (12)$$

From eq. (11) and eq. (12), the output signal of the adaptive detecting current and voltage are just the reactive power and harmonic components of the nonlinear load voltage and current. The adaptation speed and accuracy of the adaptive detecting circuit which determine tracing ability of UPQC is related to the time constant RC and the proportional coefficient K. If the time constant RC is kept constant, as the coefficient K increase, the response time gets shorter, and the detecting accuracy varies non-linearly with K value [14]. A trade-off must be considered in the selection of K and RC. In our case, the optimum K value is in the range 250 to 300 as the time RC is approximately 50ms corresponding to the shorter response time.

V. System control

One current control technique is proposed for the shunt inverter. The strategy for current control of the series inverter remains the same in the scheme. These control schemes of the proposed UPQC are shown in Fig. 5 and 6, respectively. Both the inverters of the UPQC are operated in current control mode employing PWM control technique. With a view to have a self regulated dc bus, the cycle to cycle energy balanced is maintained by employing a suitable closed loop control of the dc bus of the UPQC. Next we will discuss them one by one.

A. Control scheme for the series AF

The series inverter, which is operated in current control mode, isolates the load from the supply by introducing a voltage source in between. This voltage source compensates harmonics in the load voltage. This control scheme of the proposed UPQC is shown in Fig.6.

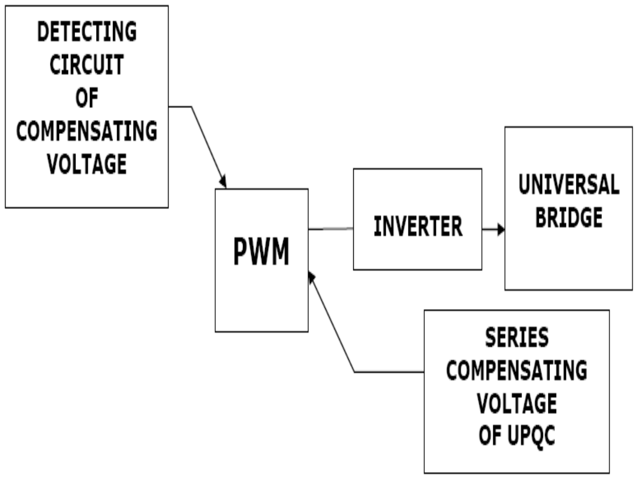

Figure.6. Block diagram of the control scheme for series inverter

Detecting circuit results in single phase reference voltage (v_s) are injected in series with the load. By taking recourse to a suitable transformation, the single phase reference (i*) of series inverter is obtained from the single phase reference voltage (v_s). This reference current (i*) is fed to a PWM current controller. The gating signals obtained from PWM current controller ensure that the series inverter meets the demand of voltage harmonics in the load and thus the supply voltage remains sinusoidal.

B. Control scheme for the parallel AF

The double loop control strategy is adopted in the control system of the single-phase APF proposed in this paper. The control system includes an inner loop of the current-following control and outer loop of the dc voltage control. The main block diagram is shown in Fig. 7.

The constant frequency PWM technology is incorporated in current-following control. The differential signal ΔV_r between the synthetic reference current signal (i_p+i_o) and the actual compensating current signal i_L is modulated by triangular-carrier signal and produces the pulse sequence which width varies with the synthetic current signal, then this pulse sequence is delivered to the pulse distribution and drive units as the gate driving signal by which the power device are controlled, to force the compensating current i_f to following the synthetic reference current signal.

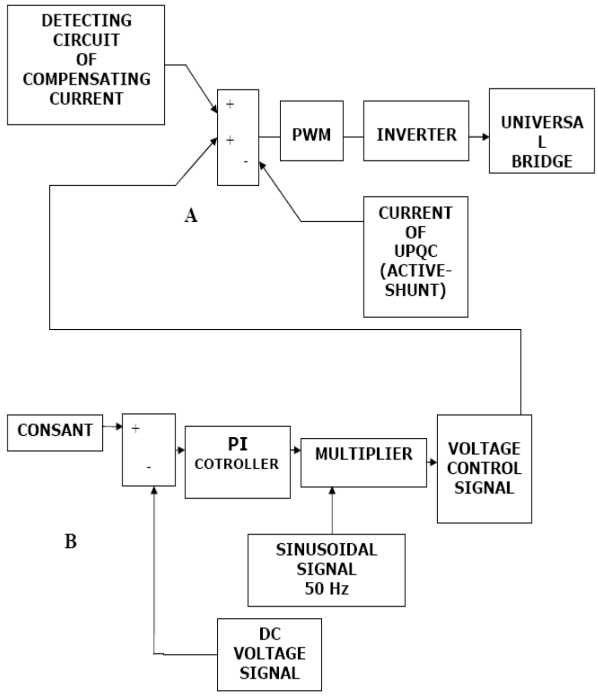

Figure. 7 Block diagram of control scheme for the parallel inverter

The dc voltage across the capacitor should be maintained higher than the peak value E_m of ac source voltage to prevented entering uncontrolled rectified state from the power inverter. Fundamental component should be absorbed into the inverter to counteract the switching and other losses. The dc voltage control is performed in the outer loops in control system. The dc voltage regulator is used to generate a voltage control signal as shown in Fig. 7. This signal forces the shunt active filter to draw additional active current from the network to compensate for losses in the power circuit of the UPQC. Additionally, it corrects dc voltage variations caused by abnormal operation and transient compensation errors. This point is clarified later, where simulation results are discussed. Fig. 7B shows the dc voltage regulator circuit. It consists only of a PI controller. Control parameters are shown in Table 1.

Table 1.Control parameters used for system under study

P gain for DC voltage controller	k_{vp}	0.15A/V
I gain for DC voltage controller	K_{vi}	10e5 A/Vsec
P gain for current controller	K_{ip}	5V/A
DC voltage reference	V_{dc}	120V

VI. Simulation results

Using the Matlab/Simulink software, several simulations are implemented to evaluate the proposed "Adaptive Noise Canceling" based UPQC. Data used for simulation system are shown in Table 2.

The following simulations correspond to a high frequency voltage with 10%-third harmonic content, as shown in Fig.8, with amplitude of 100V and frequency of 50 Hz.

The voltage source supplies the parallel association of a non-linear load (composed of a series connection of a diode, a 5-ohm-resistance and a 0.05mH-inductance). Fig.9 shows the load current, without compensation, for this test.

From Figs.8 and 9 it can be seen that the both voltage and current present a high harmonic content. The shunt active filter of the UPQC is controlled to mitigate current harmonics. In this way, it is expected that the source current becomes sinusoidal and also, is phase with the fundamental source voltage.

Table 2. Data used for system under study

NETWORK	Rated Voltage		100,50Hz
	Supply Resistance		10mΩ
	Supply Inductance		50μH
	Load Resistance		5Ω
	Load Inductance		0.05mH
UPQC	Series Inverter	Control	PWM
		Switching Frequency (f_c)	5kHz
		Capacitance(C_{se})	10μF
		Inductance(L_{se})	5mH
		Series transformer(N_1:N_2)	1:12
	Shunt Inverter	Control	PWM
		Switching Frequency(f_c)	5kHz
		Capacitance(C_{sh})	27μF
		Inductance(L_{se})	12MH
		parallel transformer(N_1:N_2)	1: 2
	DC Link		2200μF

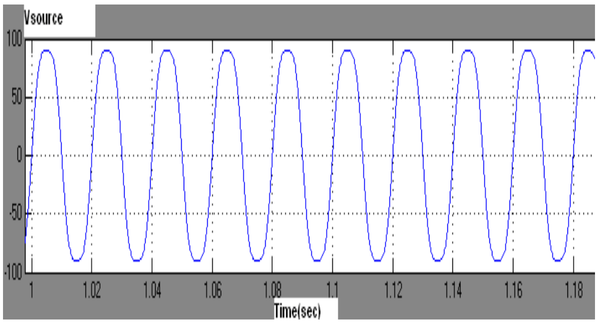

Figure.8. Source voltage without compensation

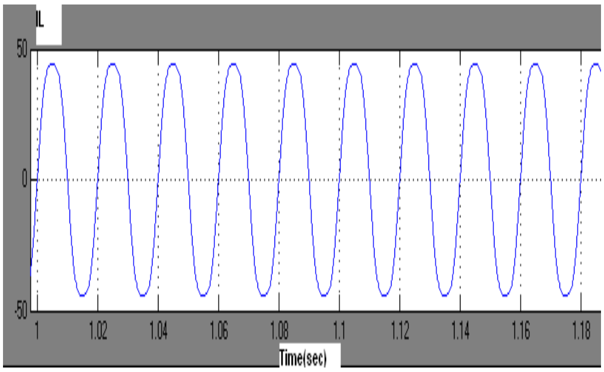

Figure.9. Source current without compensation

The shunt-active filter and the series-active filter start their operation at t=0.4s. The total simulation time is 1.2s. The thyristor rectifier is connected at t=0.2s.

The compensating current and the resulting source current are shown in Figs. 10 and 11, respectively. It can be seen that the source current is similar to a sine wave. The shunt active filter has supplied the current harmonics.

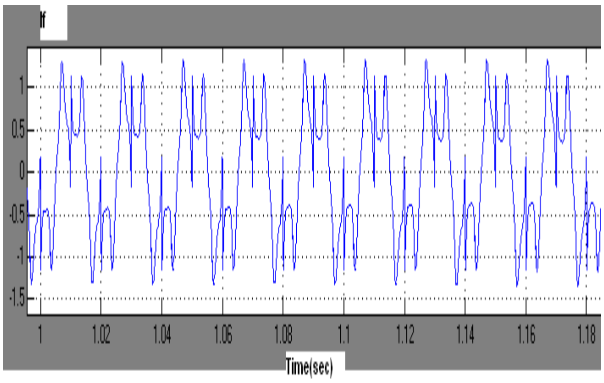

Figure.10. Compensating current for source current

I_f is the output current of the shunt-active filter. This output current is calculated by eq. (10). Before the shunt-active filter starts, the load current is distorted because the diode rectifier, which is a harmonic voltage source, is connected in parallel to the RL linear load; the total harmonic distortion (THD) of the diode rectifier current is 15%. The source current will be purely sinusoidal if the shunt-active filter starts. The THD of I_s about 3.5%. It can be seen that not only the harmonic currents but also the reactive current was compensated. The shape of the diode rectifier current waveform is the same as before and after starting of the shunt-active filter. This means that the proposed compensator overcomes those problems previously associated with shunt-active filters, namely, that they fail to cancel harmonics completely and enlarge the dc ripples and ac peak current of the diode rectifier.

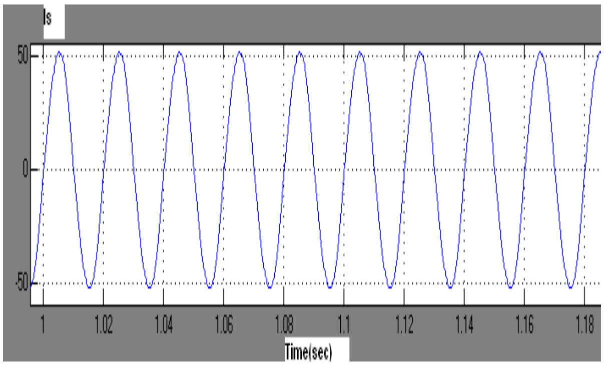

Figure.11. Source current after compensation

Fig.12 presents the compensating voltage and Fig.13 presents the resulting source voltage, after compensation. It can also be seen that the resulting voltage is almost a perfect sine wave. The THD value of the source voltage before the compensation was 10%, and it was improved to 1.7% after the compensation. The series active filter of the UPQC has compensated the voltage distortion.

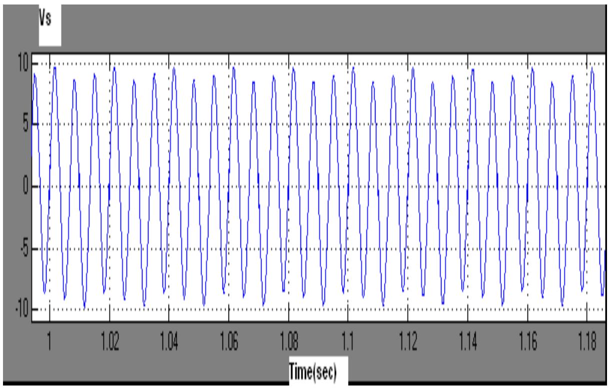

Figure.12. Compensating voltage for source voltage

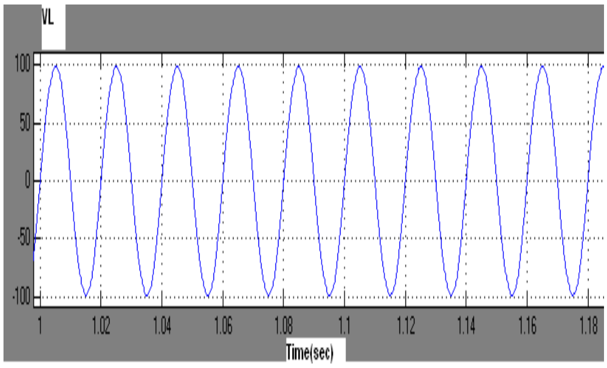

Figure.13. Source voltage after compensation

Fig.14 shows the dc link voltage v_{dc} and the losses in the UPQC, represented by the voltage control signal. The reference value at the terminals of the dc-link is 120 volts. It may be noticed, that the ripple at the dc-link voltage is very small, in the order of 4% of the reference value during a short transient period, after the start of the UPQC, and less than 0.8%, in steady state operation. The switching losses of the inverters may not represent the reality, since ideal models of switches in the digital simulator are used.

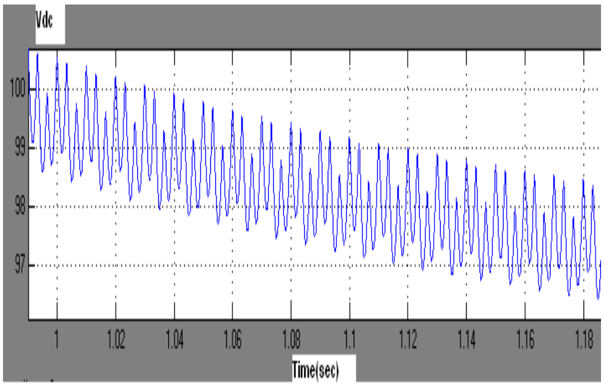

Figure. 14 DC Link voltage in UPQC

VII. Conclusion

In this paper, an Adaptive Noise Canceling approach theory based single-phase unified power quality conditioner has been proposed and the design procedure of control system of UPQC is discussed. The simulating results demonstrate the validity of the proposed UPQC for compensating reactive and harmonic components to improve the system performance. The characteristic of maintaining the null exactly at the reference frequency, in our case power system frequency, during the total adaptive process makes it generally superior to other kinds of frequency fixed schemes of UPQC. The requirement of improving the effectiveness of harmonic elimination, which calls for a large time constant of integrator, is contradiction with that of a fast adaptation speed. However, the high compensating accuracy, the wide adaptability to the frequency variation and the simple structure make it a promising way in developing UPQC. The method of adaptive noise canceling has more 25ms detecting time-delay. So it can not guarantee real-time and fit to detect slow-change load.

References

[1] A.Nasiri and A.Emadi, "Different Topologies for Single-Phase Unified Power Quality Conditioners", Industry Applications Conference, Volume: 2, pp 976-981, Oct. 2003.

[2]. M.Tarafdar Haque and T.ISE and S. H. Hosseini, "A Novel Control Strategy for Unified Power Quality Conditioner (UPQC)", IEEE 2002, pp94-98.

[3]. Farrukh Kamron, "Combined Deatbeat Control of Series-Parallel Converter Combination Used as a Universal Power Filter", IEEE PESC 1995, pp196-201.

[4]. Mauricio Aredes, and K. Lemrense Heumann, "A Universal Active Power Line Conditioner", IEEE Trans. On Power Delivery, Vol.13, No.2, Appril, 1998, pp545-551

[5]. H. Fujita, and H. Akagi, " The Unified Power Quality Conditioner: The integration of Series Active Filter and Shunt Active Filter", IEEE PESC 1996, pp494-501.

[6]. Yop Chung, and Seung Moon, "The Control and Analysis of Zero Sequence Components in DVR System", IEEE Winter Meeting, 2000.

[7]. Leon M. Tolbert, and pang Zheng Peng, " A Multilevel Converter Based Universal Power Conditioner" , IEEE Trans, On Industry Application, Vol.36, No.2, March/Appril 2000.

[8]. Fang Zheng Peng, Hirofumi Akagi, and Akira Nabae, "A New Approach to Harmonic Compensation in Power System-A Combined System of Shunt Passive and Series Active Filters", IEEE Trans. On Industry Application, Vol. 26, No. 6, Novambere 1990, pp 983-989.

[9]. H. Akagi, and H. Fujita,"A New Line Conditioner for Harmonic Compensation in Power Systems", IEEE Trans. On Power Delivery, Vol. 10, No. 3, July 1995.

[10]. H. Akagi, and Y. Kanazawa, "Generalized Theory of Instantaneous Reactive Power in Three-Phase Circuit" IPEC, Tokyo, 1983, pp 1375-1383.

[11]. S. Bhattacharya, and D. M. Divan, "Synchronous Frame Harmonic Isolator Using Active Series Filter", EPE 1991, pp 3-030 to 3-035.

[12]. M. Takeda, and K. Ikeda, "Harmonic Current and Reactive Power Compensation With an Active Filter", IEEE PESC 1988, pp 1174-1179.

[13]. A. Elnady, A. Goauda, M. M. A. Salama, "Unified Power Quality With A Novel Control Algorithm Based on Wavelet Tansform", IEEE Conference 2002, pp 1041-1045.

[14]. Chen Weiji, Chen Wenhong, Ma Xiaojun, Chen Jianye, Wang Zhonghong, Han Yingduo, "AN ADAPTIVE NOISE CANCELING THEORY BASED SINGLE-PHASE SHUNT ACTIVE POWER FILTER" , IEEE 1997,pp191-196.

[15]. Hirofumi Akagi et al "Instantaneous Reactive Power Compensations Switching Device without Energy Storage Components" IEEE Trans on Ind Appl, Vol.1.A-20, No.3, May 1994.

[16]. S. Luo et al, "An adaptive Detecting Method for Harmonic and Reactive Currents" IEEC, Trans. 42-46, Aug. 1993.

ELEKTRİK ENERJİSİNİN KEYFİYYƏTİNƏ NƏZARƏT EDƏN CİHAZA TƏTBİQ OLUNAN KÜY MÜHAFİZƏSİ

Kazəmi A., Sərlak M., Barhudari M.

Harmonik siqnal əldə etmək üçün alqoritmdən istifadə edərək elektrik enerjisinin keyfiyyətinə nəzarət etmək üsulu şərh olunur. Tələb olunan siqnal çıxışda, daxil olan siqnalı süzgəcdən keçirməklə əldə etmək olur. Üsulun dəqiqliyi təcrübi və modelləşdirmə nəticələri ilə təsdiq olunur.

АДАПТИВНЫЙ ПОДАВИТЕЛЬ ШУМА ПРИМЕНИТЕЛЬНО К УНИФИЦИРОВАННОМУ КОНТРОЛЛЕРУ КАЧЕСТВА ЭЛЕКТРИЧЕСКОЙ ЭНЕРГИИ

Каземи А., Сарлак М., Бархордари М.

Описан способ контроля качества электрической энергии с использованием алгоритма для получения требуемого гармонического сигнала. Полезный сигнал выделяется на выходе системы после фильтрации входного сигнала. Корректность способа подтверждена результатами моделирования и экспериментов.