Implementation of a Novel Control Strategy for Shunt Active Filter

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Abstract: - Use of nonlinear loads, such as thyristor controlled inductors for FACTs devices, converters for HVDC transmission and large adjustable speed motor drives, is expected to grow rapidly. All of these loads inject harmonic currents and reactive power into the power system.

This paper presents a new control scheme for a 3 phase parallel active filter. The presented control system is able to compensating current harmonics, reactive power and current unbalance of non linear loads. The conventional controllers based on pq theory need more calculations, since they need the use of Clark transformation (abc to $\alpha\beta$ transformation). The proposed control system is very simple and therefore practical implementation of active filters is available. The presented simulation and experimental results show the validity of control strategy. In this paper the PSCAD/EMTDC program and LAB VIEW software are used for simulation and hardware implementation, respectively.

Key-Words: - Shunt Active Filter, Harmonic Compensation, Power Factor Correction, Lab View Soft ware.

1 Introduction

In power systems, thyristor controlled inductors for static VAR compensators, converters for high voltage DC transmission line, large adjustable speed motor drivers and a variety of nonlinear loads are used widely in industrial plants. These devices are major sources of current harmonics and low power factor in power system.

Conventionally, passive filters were the choice for the elimination of harmonics and to improve power factor. These passive filters have the disadvantages such as large size, resonance and fixed compensation. Active filters avoid the disadvantages of passive filters by utilizing a switch mode power electronic converter to supply harmonic currents equal to those in the load currents [1-3]. Almost, all controllers developed by other authors, for active filters use the pq theory [4, 5]. The major disadvantages of active filter controllers based on pq theory are:

1. These need to low pass filters to separate the average and oscillating parts of instantaneous powers. This factor introduces time delays and therefore, the dynamic performance of active filter is not guaranteed.
2. These demand more calculation, since they need the use of Clark transformation, and are not suitable for hard ware implementation.

This paper presents a simple control scheme for shunt active filter. In active filter the main object is to maintain sinusoidal and unity power factor supply currents. The simulation and experimental results, carried out by PSCAD/EMTDC [6] and LAB VIEW [7] soft wares respectively, show effective and validity of presented control system. The steady state and transient performance of the proposed control scheme is found quite satisfactory to eliminate the harmonics, unbalances and reactive power components from source currents.

2 Basic Configuration of Active Filter

The basic configuration of shunt active filter is shown in Fig.1. The AF is composed of a standard 3-phase voltage source inverter bridge with a DC link capacitor to provide a effective current control.

The shunt active filter generates the compensating currents ica, icb, icc to compensate the load currents ia, ib, ic in order to guarantee sinusoidal, balanced, compensated currents isa, isb, isc drawn from the AC system. For the 3- phase ungrounded system only two current sensors could be used, since ic=-ia-ib.

The non linear load is combination of RL load supplied by 3-phase controlled rectifier and a 3-phase unbalanced RL load.

3 Proposed Control System

The presented control system of shunt active filter is concise and requires less computational efforts than many others found in the literature. It is formed by a DC voltage regulator and reference current calculation box. Also, closed loop PWM is used for generating switching signals of AF to force the desired currents into the AF phases. The compensating currents of AF are calculated by sensing the load currents, DC bus voltage, peak voltage of AC source (Vsm) and zero crossing point of source voltage. The last two parameters is used for calculation of instantaneous voltages of AC source as below:

$$\begin{aligned} v_{sa}(t) &= V_{sm}\,Sin(\omega t) \\ v_{sb}(t) &= V_{sm}\,Sin(\omega t - 2\pi/3) \\ v_{sc}(t) &= V_{sm}\,Sin(\omega t - 4\pi/3) \end{aligned} \tag{1}$$

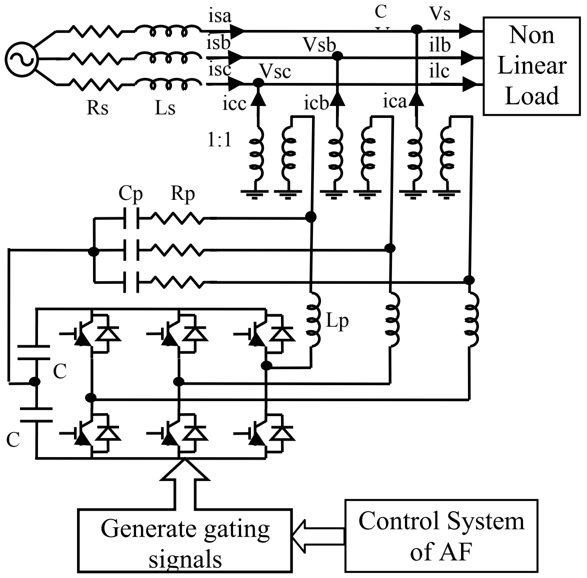

Fig.1. Basic configuration of shunt active filter.

The basic function of the proposed shunt AF is to eliminate harmonics and compensation of current unbalance and reactive power of load. After compensating the AC source feeds fundamental active power component of load current and loses of inverter for regulating the DC capacitor voltage. Therefore the peak of source reference current (Ism*) has two components. The first component is corresponding to the average load active power (Isp*). Instantaneous power of load can be obtained as bellow:

$$\begin{aligned} P_L(k) = {} & v_{sa}(k)*i_{La}(k)+v_{sb}(k)*i_{Lb}(k)+ \\ & v_{sc}(k)*i_{Lc}(k) \end{aligned} \tag{2}$$

The average power of load is obtained from equation 3.

$$P_{Lav}=\frac{1}{n}\sum_{k=1}^{n}P_L(k) \tag{3}$$

$$n = T * f_s \quad ; \; T = 1/f$$

f is the fundamental system frequency (4)
fs is the sampling frequency

In order to compensating the current harmonics and reactive power of load the average active power of AC source must be equal with PLav. With considering the unity power factor for AC source side currents the average active power of AC source can be calculated as bellow:

$$P_s = 3/2\,V_{sm}\,I_{smp} = P_{Lav} \tag{5}$$

From this equation, the first component of AC side current can be obtained.

$$I_{smp}^{\;*} = 2/3\,P_{Lav}/V_{sm} \tag{6}$$

The second component of AC current (Ismd*) is obtained from DC source capacitor voltage regulator as Fig.2.

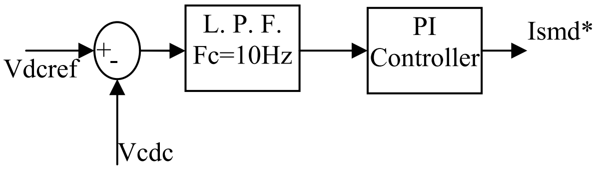

Fig.2. DC capacitor voltage regulator.

The desired peak current of AC source can be calculated as bellow:

$$I_{sm}^{\;*} = I_{smp}^{\;*} + I_{smd}^{\;*} \tag{7}$$

The Ac source currents must be sinusoidal and in phase with source voltages. Therefore the desired currents of Ac source can be calculated with multiplying peak source current to a unity sinusoidal signal, that these unity signals can be obtained from equation 8. The desired source side currents can be obtained from equation 9.

$$\begin{aligned} i_{ua} &= v_{sa}/V_{sm} \\ i_{ub} &= v_{sb}/V_{sm} \\ i_{uc} &= v_{sc}/V_{sm} \end{aligned} \tag{8}$$

$$\begin{aligned} i_{sa}^{\;*} &= I_{sm}^{\;*}\, i_{ua} \\ i_{sb}^{\;*} &= I_{sm}^{\;*}\, i_{ub} \end{aligned} \tag{9}$$

$$i_{sc}^* = I_{sm}^* \, i_{uc}$$

Finally, the reference currents of AF can be obtained as equation 10.

$$\begin{aligned} i_{ca}^* &= i_{sa}^* - i_{La} \\ i_{cb}^* &= i_{sb}^* - i_{Lb} \qquad (10) \\ i_{cc}^* &= i_{sc}^* - i_{Lc} \end{aligned}$$

4 Switching Strategy of Converter

There are two basic control strategies that can be used to control the switching of semiconductor switches in the converters.

1- Pulse Width Modulation (PWM) method.
2- Phase Control Strategy.

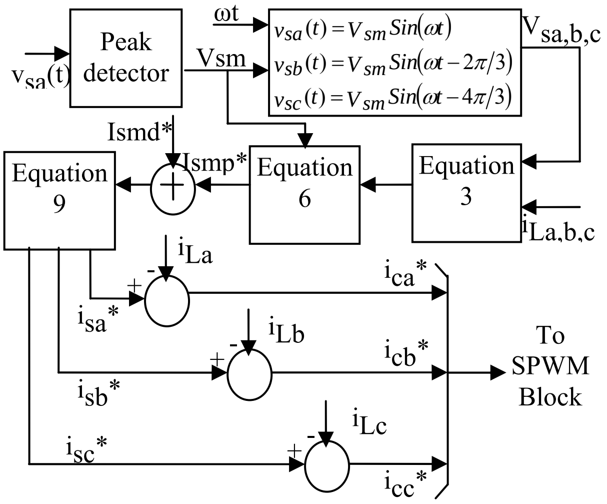

Fig.3. Presented control system of shunt active filter.

GTO switches operate adequately at the low switching frequencies required in phase control, but present losses at the high switching frequencies needed for PWM control. However, recent advances in high voltage semiconductor technology have led to the development of the Integrated Gate Commutated Thyristor (IGCT) and Insulated Gate Bipolar Transistor (IGBT), which is basically an optimum combination of thyristor and GTO technology at low cost, low complexity and high efficiency.

It can handle higher switching frequencies with relatively low losses, allowing for the practical implementation of PWM control methodologies.

In the phase control approach in order to generating the output voltage waveforms with low harmonics, must be used multi connected phase shifted converters with a common DC link and coupled through appropriate magnetic circuits.

The PWM technique is based on fast switching of semiconductor switches to produce an output voltage waveform with low harmonic, which depends on the number of notches per cycle. The advantage of this technique is that it allows independent and easy control of active and reactive power components, provided that the DC voltage is kept constant and sufficiently high.

In this paper we use a closed loop carrier based PWM technique for tracking the computed currents by AF. Presented PWM technique scheme is shown in Fig.4. In this technique the difference of reference and measured currents is applied to a PI controller and its out put signal is given to conventional carrier based PWM. In this paper the carrier signal is considered as triangle wave form with 1650 Hz frequency.

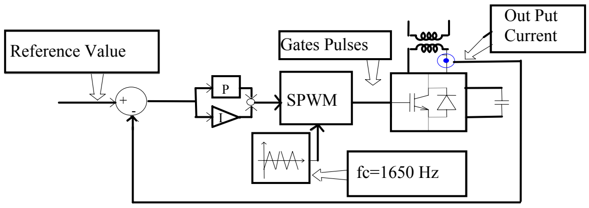

Fig.4. Presented PWM technique scheme.

5 Hard Ware Implementation

The presented AF is contents a 3-phase voltage source IGBT based inverter and DC bus with a capacitor.

Since the IGBT is very sensitive device to variations of current and voltage, therefore it must be protected in face these parameters. For this propose we use a protection and Opto isolated driver device [8]. This device not only protects IGBT from over current and voltage but also isolates the base signals of IGBT from control system. Fig. 5 shows the protection and isolation circuit. In this paper for sensing the voltages and currents the Hall Effect sensors is used. The advantages of these sensors are:

1- Linearity.
2- They can be used in the AC and DC signals.

For transmitting measured signals to the computer and gate pulses to inverter a Data Acquisition card (Axiom 5095P [9]) is used.

Fig. 6 shows the block diagram of designed hardware system.

The presented control system is implemented by LAB VIEW soft ware.

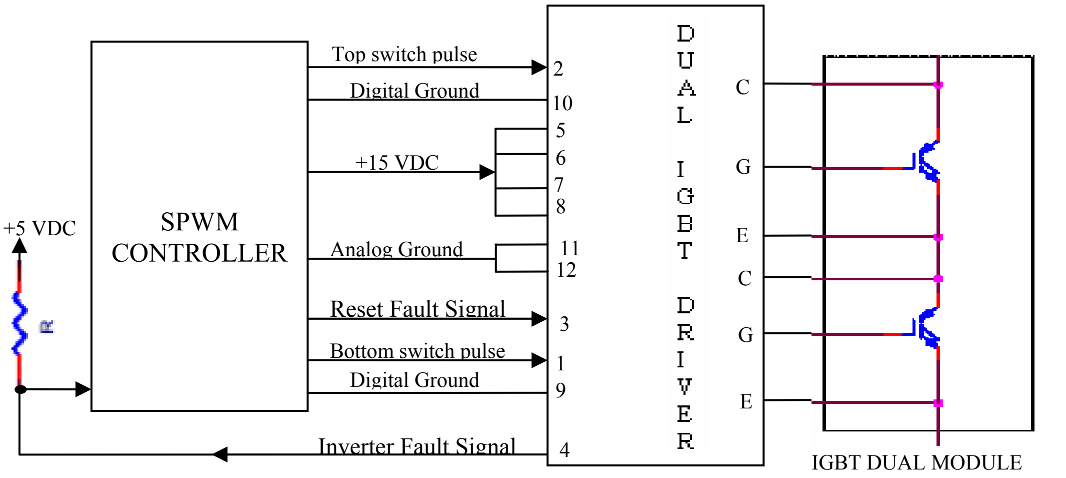

Fig. 5. IGBT protection and isolation circuit.

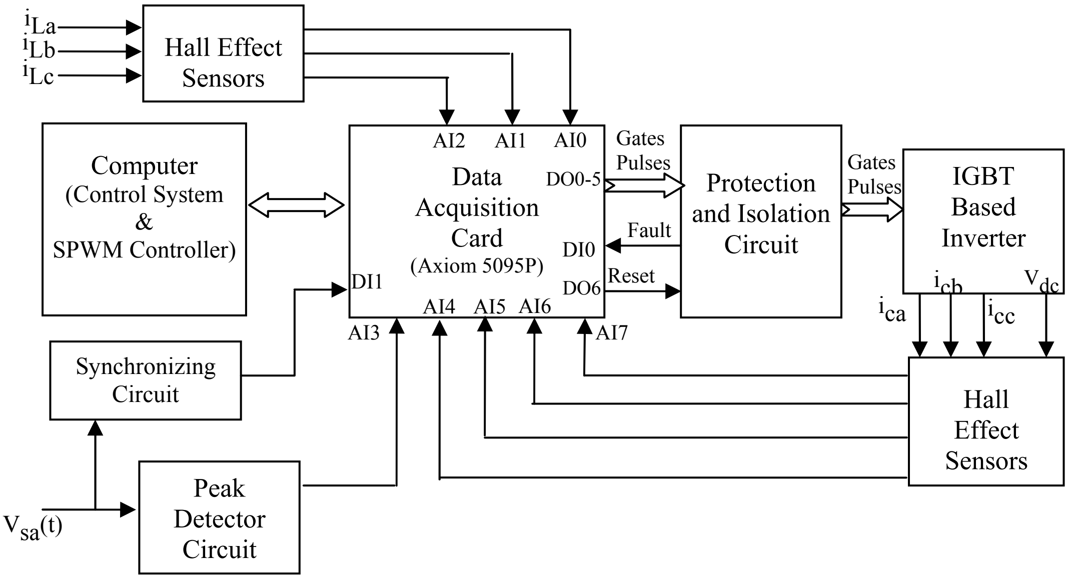

Fig. 6 Block diagram of designed hardware system.

6 Simulation and Experimental Results

A power system corresponding to Fig.7 was simulated. Table 1 shows the test system and active filter parameters. The nonlinear load configuration is described in figure 7.

Table 1. Parameters of test system and active filter.

System voltage(v)	Rs+jLsω	C(μF)	Rp(Ω)	Lp(mH)	Cp(μF)
110	1+j.63	200	0.5	10	16

Fig.8 shows the simulation results carried out by PSCAD/EMTDC simulation program. This figure shows Ac source voltage, load current, source side current in the steady and transient states. These results show that source currents always remain sinusoidal and lower than the load currents. In this simulation nonlinear load is considered a 3-phase full controlled rectifier with fire angle 30 degree. Fig. 9 presents the reference current of active filter for phase a.

Fig.10 shows the DC link capacitor voltage. It can be seen that the presented control system can properly regulate the DC link capacitor voltage.

Fig.11 shows the experimental results of designed AF by LAB VIEW soft ware. A suddenly exchanging in the fire angle of rectifier (from 30 ^{o} to 90 ^{o}) is applied and the experimental results show fast response of AF with presented control system. Figures 11a, 11b, 11c and 11d show load currents, source currents carried out from control system, real source currents and injected current by active filter, respectively.

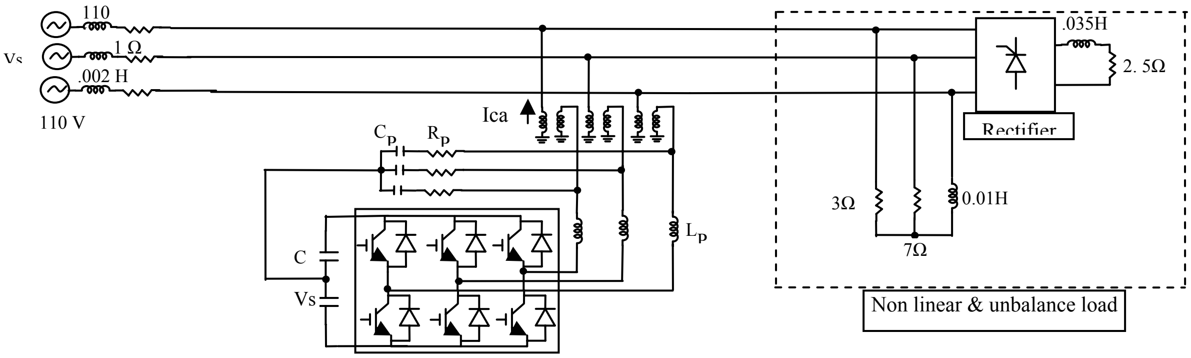

Fig.7. Test power system configuration.

Figures 12a and 12b reveal the harmonic spectra of load currents before and after changing the fire angle of rectifier. Figures 13a and 13b describe the harmonic spectra of source currents before and after changing the fire angle of rectifier. It can be observed from the harmonic spectra of currents that, presented algorithm is effective to meet IEEE519 standard recommendations on harmonic level. Fig. 14 shows the DC capacitor voltage. It can be seen that the presented control system is capable to regulating DC link voltage. The presented experimental results show the validity and effectiveness of presented control system and simulation results.

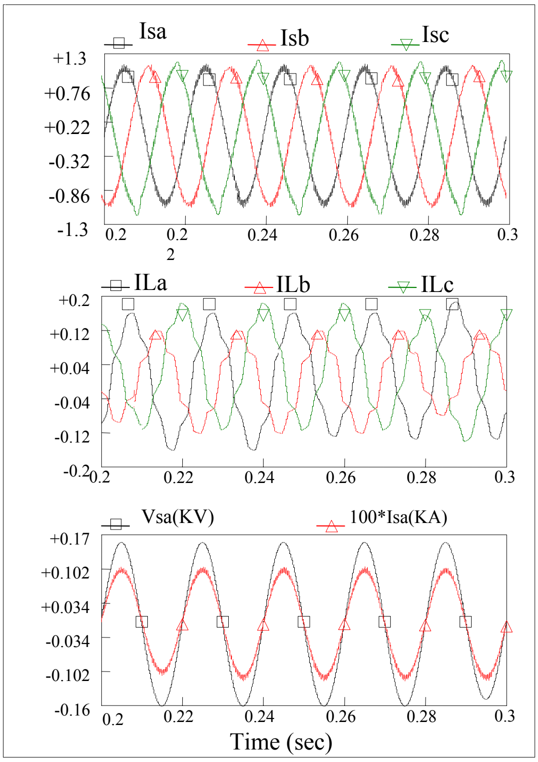

Fig.8. Ac source side currents, load current, voltage and current of source.

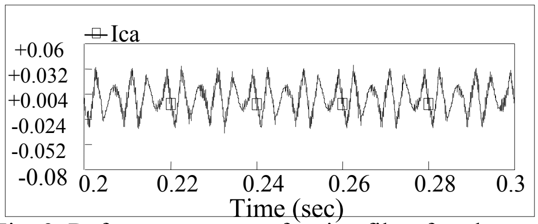

Fig. 9. Reference current of active filter for phase a.

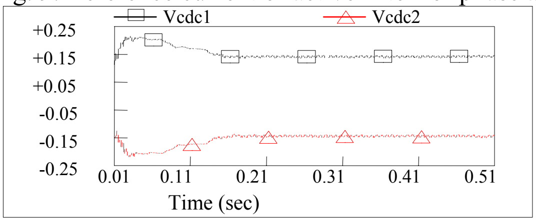

Fig.10. DC link capacitor voltage.

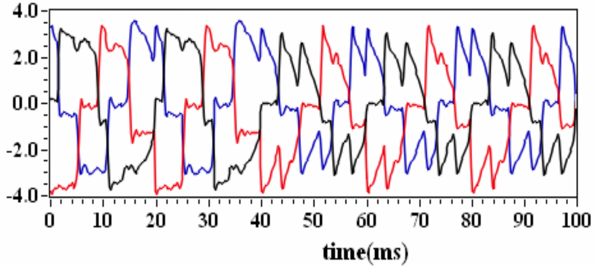

Fig.11a. Load currents.

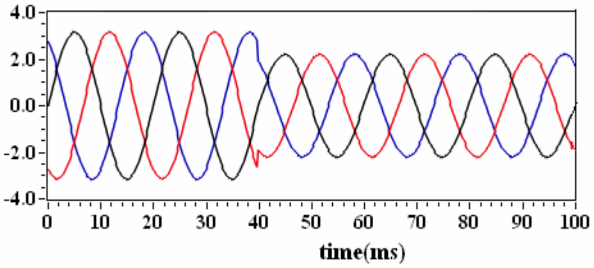

Fig.11b. Source currents carried out from control system.

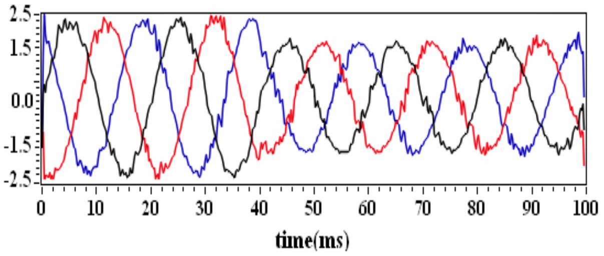

Fig.11c. Real source currents.

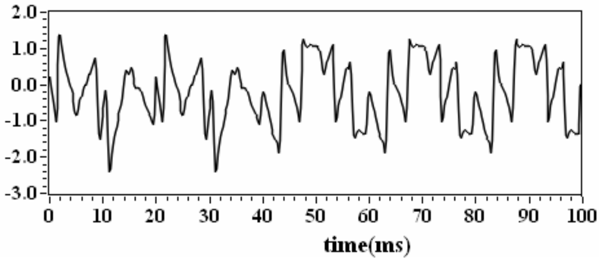

Fig.11d. Injected currents by active filter.

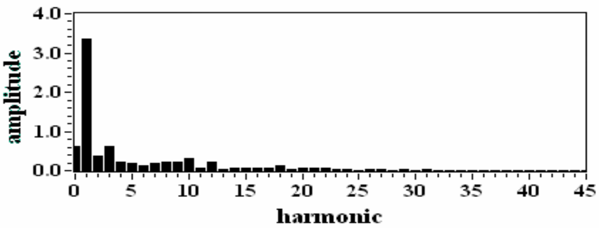

Fig.12a. Harmonic spectra of load currents before fire angle changing.

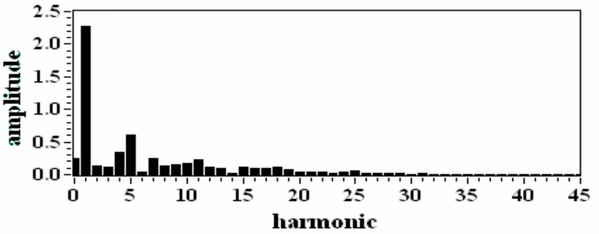

Fig.12b. Harmonic spectra of load currents after fire angle changing.

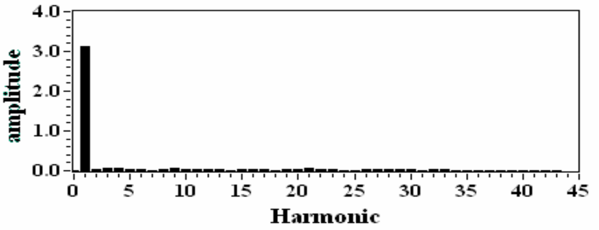

Fig.13a. Harmonic spectra of source currents before fire angle changing.

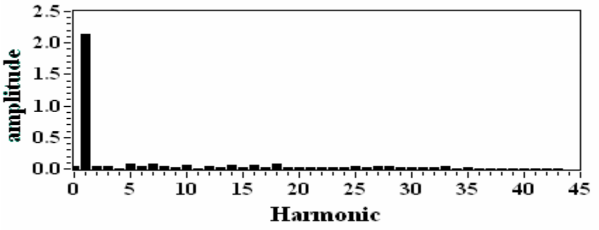

Fig.13b. Harmonic spectra of source currents after fire angle changing.

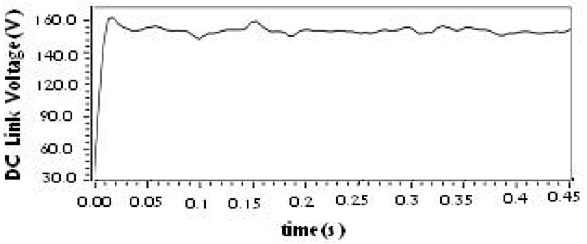

Fig. 14. DC capacitor voltage.

7 Conclusion

In this paper a simple control system of AF is presented. The presented control system the number of equations is reduced, since it does not use any transformation, such as park transformation. Therefore the presented control system is very suitable for the hard ware implementation.

In this paper both simulation results carried out by PSCAD/ EMTDC and experimental results are presented.

These results show the validity and effectiveness of presented control system of AF for compensation of harmonic currents, reactive power and unbalance currents.

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