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7. 7. APPENDIX: INFLUENCE OF DSP DELAY ON COMPENSATION

It is supposed that the sampling and the output current producing both are done instantaneously (this is acceptable in practice), and only DSP needs 400μs for data processing and preparing the reference signal. (This delay is normal, too).

The Fundamental frequency is considered to be $50Hz$. Considering load current harmonic as I_{Lh} and filter delivered current as I_{Fh}, then:

$$I_{Lh}=A_n \sin(n\omega t) \quad (4)$$

and

$$I_{Fh}=-A_n \sin(n\omega t + \varphi_n) \quad (5)$$

Where n, ω are the harmonic order and the angular frequency, respectively. Assuming φ_n as the delay corresponding to $400\mu s$ time delay, then:

$$\varphi_n = n.\omega.\tau \quad (6)$$

Where τ is the time delay. Hence, the remained harmonics after compensation will be as follows:

$$I_{rh} = I_{Lh} + I_{Fh} \quad (7)$$

For example, for 25th order harmonic we have:

$$I_{r25} = I_{L25} + I_{F25} =$$
$$= A_n \sin(25\,\omega t) - A_n \sin((25\,\omega t) + \pi) \quad (8)$$

$$I_{r25} = 2A_n \sin(25\,\omega t) \quad (9)$$

This means, not only compensation has not been accomplished, but also the value of this component has been doubled.

The remained values have been calculated for several different delays and the results are shown in Fig. 8.

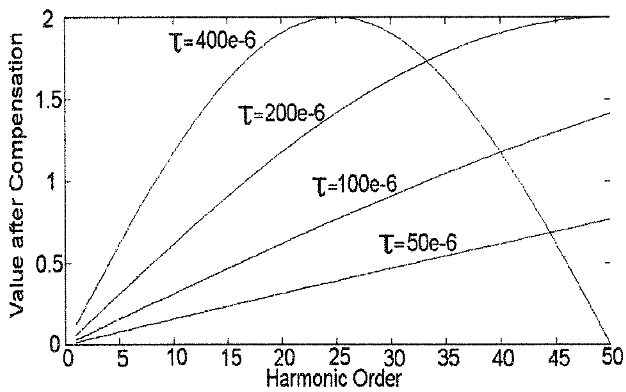
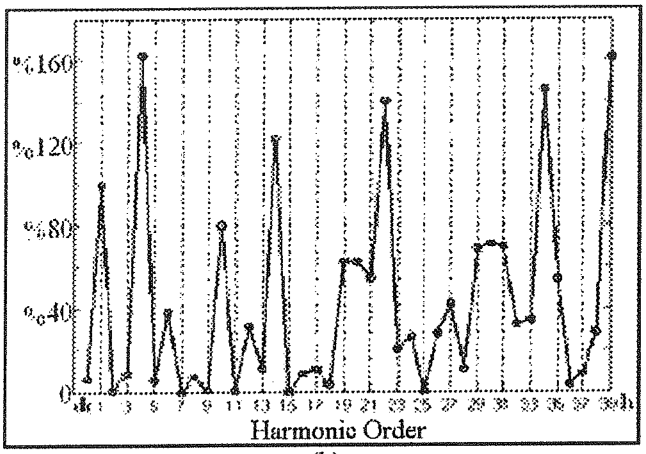


Figure 8: Remaining harmonics after compensation

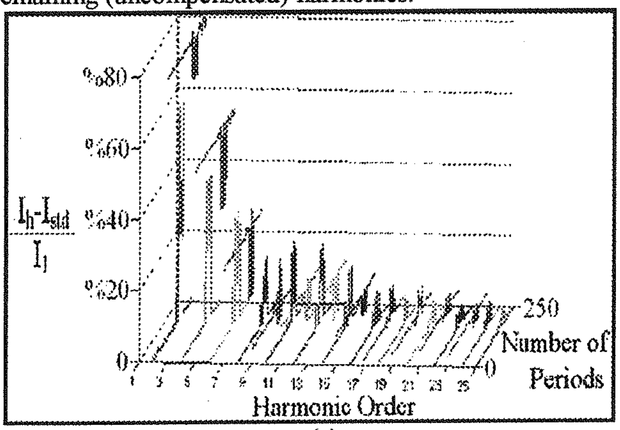


(b)

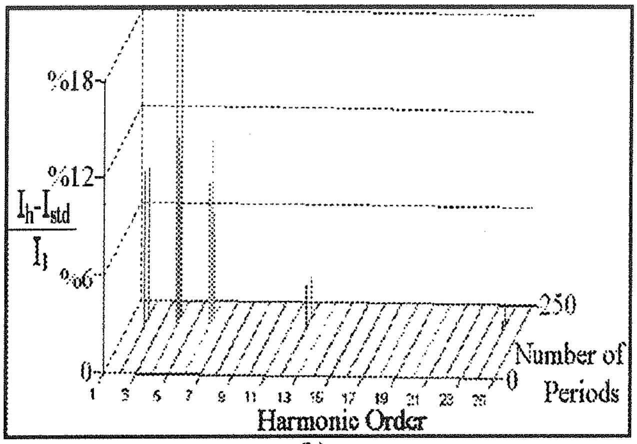
Figure 6: Ratio of the amplitudes after to before compensation with one period delay method.
(a) Residential complex,
(b) Compact fluorescent lamps.

C. C. cInjection of the compensating current after two periods

Considering the requirement of the frequency domain methods, the correcting current is injected after two periods. One period for sampling and preparing adequate data for FFT, and the next to avoid the phase shift arising from the processing time delay. The case study is P.C. and the results are shown in Fig.7. In this figure, as in Fig. 5, the zero surface of the Z-axis is scaled to show the standard permitted levels for different harmonic components of the load current. As mentioned in section 3, the harmonic content variations of this load are low. Thus, a few harmonics, with small amplitudes, will be remained in supply current after compensation with two periods delay. In general, the larger harmonic variations, the more remaining (uncompensated) harmonics.



(a)



(b)

Figure 7: Harmonics exceeding standard levels during 250 periods of the P.C. current.
(a) Before compensation,
(b) After compensation with two periods delay

5. CONCLUSION

In shunt active filter the time required for data processing and producing reference current signal, delays the compensating current injection. The delay arising from the limitations of the processors, on one hand, and the sampling requirements (specially, in frequency domain methods), on the other hand, might lead to unsatisfactory harmonic-compensation performance.

Current injection with one or two periods delay - which seems unavoidable in ordinary frequency and time domain methods - makes the compensation undesirable. This can be seen in many nonlinear single loads and some cumulative loads, consisting of linear and nonlinear loads.

In this paper, several actual load currents are measured and analyzed in order to observe the effects of simulated delays on the performance of shunt active filter. The results of simulation demonstrate that in the cases of harmonics content varying loads, active filter can not successfully compensate for the distortions. Also, this shortcoming is observed in the case of the loads with large content of high-order harmonics.

Therefore, prior to selecting the reference wave derivation method and output current control strategy, and prior to making a decision for using a pure active filter in order to compensate for a nonlinear load, one must study and take into account the harmonic characteristic of the load, specially the variation model of it. In fact, if harmonics vary rapidly or high order high level harmonics exist in the load current, aforementioned delaying methods will not be effective.

6. 6. REFERENCES

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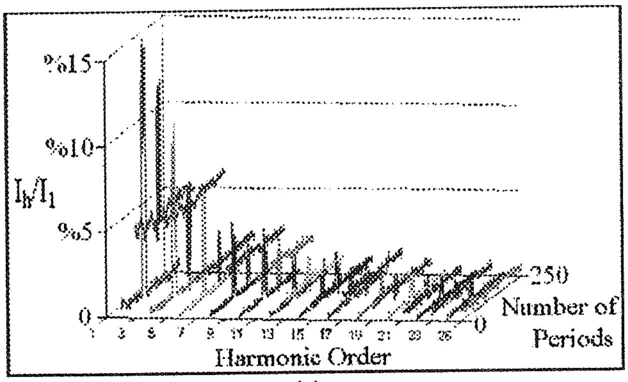
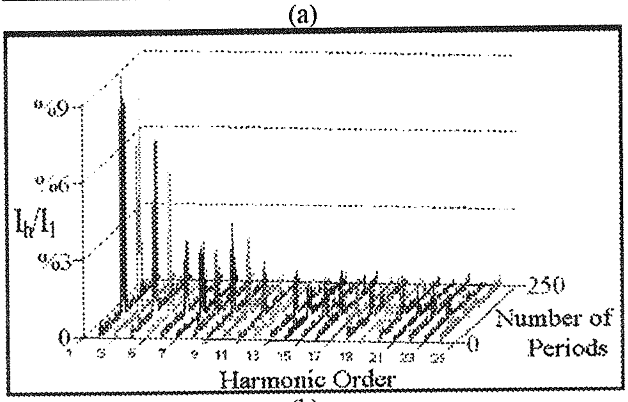


(a)

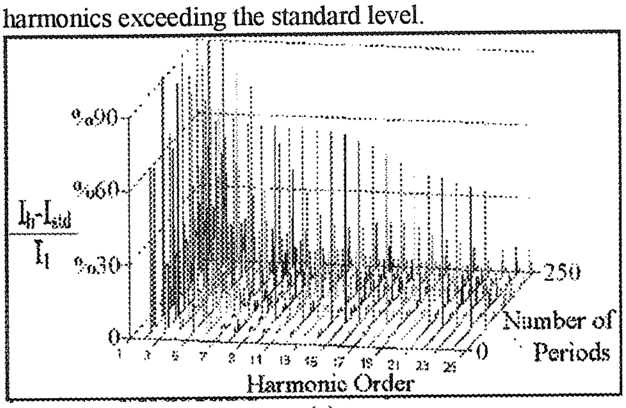


(b)

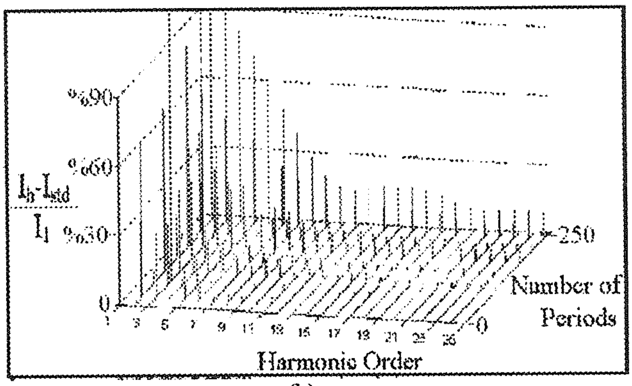
Figure 4: Load current harmonics of residential complex during 250 periods.
(a) Before compensation,
(b) After compensation.

For the loads with large harmonic contents, however, one period delay causes the amplitudes not to be reduced to the necessary levels. This problem is illustrated in Fig. 5. In order to evaluate the efficiency of the compensation, harmonics (before and after compensation) are compared whit the IEEE standard harmonic levels. This comparison is made on harmonic components from 2nd to 25th order.

It should be noted that in Fig. 5 the zero point of the Z – axis indicates the permitted standard levels for each harmonic. Thus the bars crossing the surface Z=0 indicate harmonics exceeding the standard level.



(a)



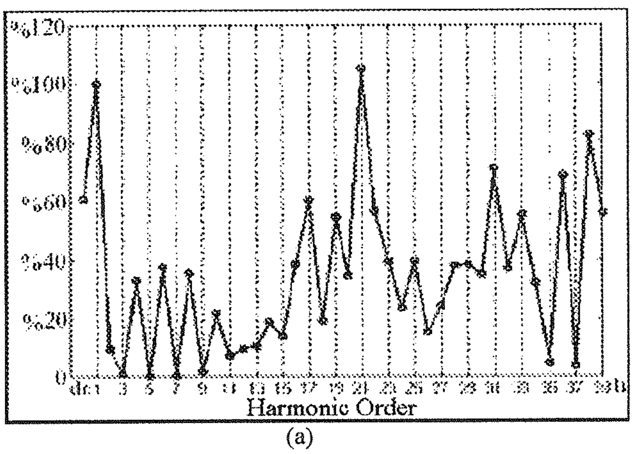
(b)

Figure 5: Harmonics exceeding standard levels during 250 periods of the welding machine current.
(a) Before compensation,
(b) After compensation with one period delay.

As it can be seen in Fig. 5 (b) many of harmonics are greater than the standard level. It must be mentioned that the compensating current is calculated as to compensate the whole harmonics but, referring to figures 4 and 5, one can claim that full compensation is almost impossible for any type of the loads.

A ratio of the amplitude of the harmonic component after compensation to that before compensation is another criteria for evaluating the effectiveness of the compensation. This ratio, for harmonic components of two types of the loads (residential complex & compact fluorescent lamps), from zero (DC component) up to 39^{th} order, is calculated and shown in figures 6 (a) and (b), respectively.

In the residential complex case, the harmonic components have been reduced after compensation, but have not been completely suppressed. The fluorescent lamps load is more critical. In this case, as mentioned in section 3, the harmonic content varies extremely. Consequently, a notable number of harmonic components have been amplified, as shown in Fig. 6(b).



(a)

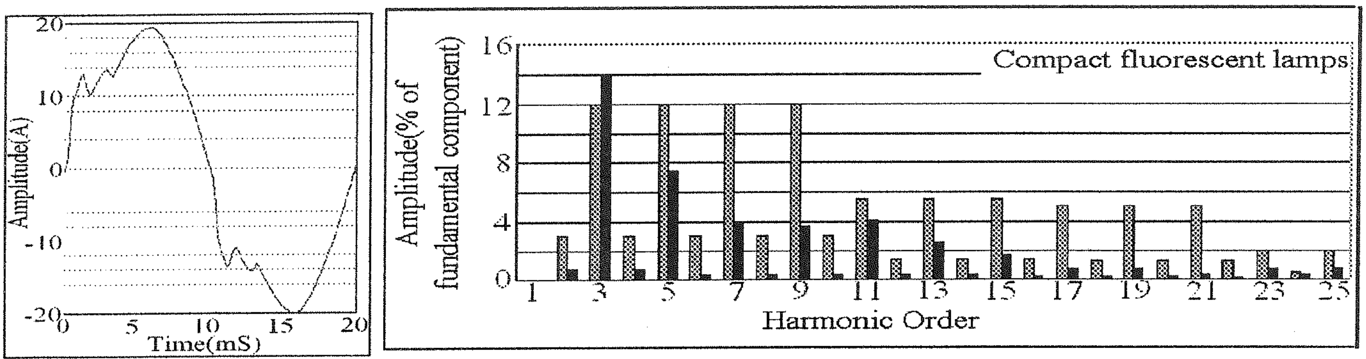


Figure 2: One period of the loads currents. (a) Waveforms (b) Harmonic components

PC: Samples of the load current show that nearly all the harmonic amplitudes are above the standard levels. Also, THD (total harmonic distortion) amount is 100% (the permitted range is 15%). But, harmonic amplitudes variations are small.

Resistance Welding Machine: The machine draws current during 11 periods after turning on and then turns off automatically. Load current during a period is discontinuous. Most of the load current harmonics exceed the standard ranges, and even order harmonics exist in the wave, too. The harmonic amplitudes are nearly fixed except for switching instants.

Residential Complex: Sampling has been carried out during 24 hours intervals at several times. Load harmonic content is noticeable, particularly when the lift is working. Amplitudes variations are observed at high order harmonics, where the amplitudes are very small.

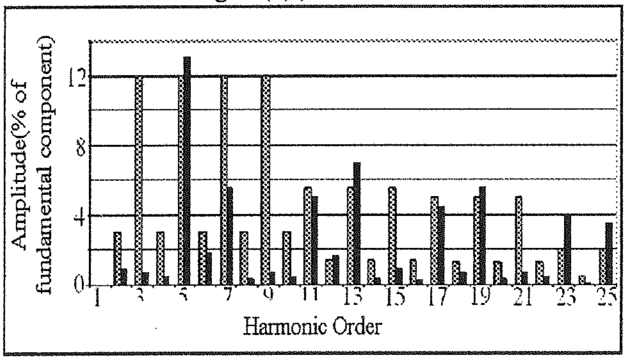
Electrical Machines Lab: The load consists of a big solid state rectifier that supplies the dc motor lab tables. 5th order harmonic, as well as THD, is greater than the permitted ranges.

Compact Fluorescent Lamps: Most of the load harmonics are under the standard limits, but a few of even order harmonics exceed the permitted ranges. Also, amplitudes vary extremely.

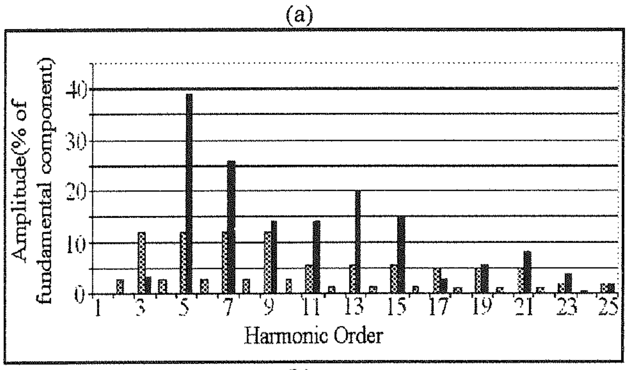
4. 4. EVALUATION OF FILTER PERFORMANCE

A. A. Immediately injected compensating current

It is assumed that the DSP needs 400μs for reference signal production, and compensating current is injected into the supply network immediately after this time delay. Therefore, a phase delay (φ_n) equal to $n\omega\tau$ will appear at each harmonic, where n, ω and τ are the harmonic order, the fundamental angular frequency and the delay time, respectively (see appendix). Consequently, the load current harmonics will not be compensated completely. Remaining harmonics for two types of loads (electrical machine lab and P.C.), are presented in Fig. 3. As it can be seen, the amplitudes are decreased, but are not completely filtered. In addition, amplitudes of some harmonics are increased and exceed the standard ranges. (for example, 5^{th}, 13^{th}, 19^{th}, 23^{rd} harmonics in Fig. 3 (a) , and 3^{rd}, 5^{th}, 7^{th}, 11^{th}, 13^{th} harmonics in Fig. 3 (b)).



(a)



(b)

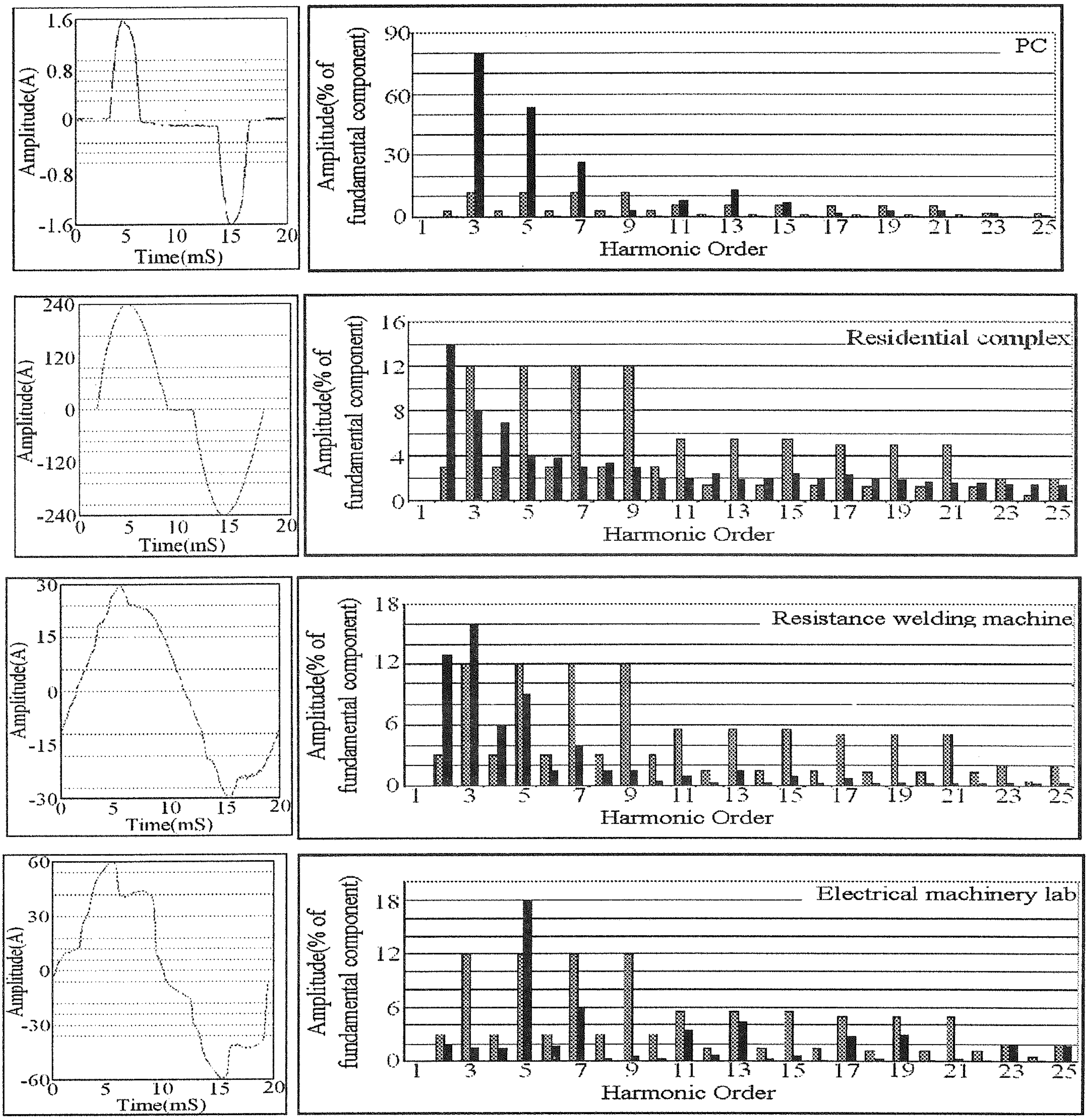
Figure 3: Remained source current harmonics with delayed current injection.
(a) Electrical machine lab,
(b) P.C.

B. B. Injection of the compensating current after one period

In this condition, the compensating current is injected into the grid without phase shifting, but with one period delay, in order to prevent the phase shifts in compensating current components. It is observed that the effect of this delay is negligible on compensation for loads, which have low harmonic contents compared to their fundamental component. Fig. 4 shows the ratio of the load harmonics to the fundamental component for 250 periods of the residential complex current.

samples are transferred to a PC and analyzed by FFT (fast Fourier transform) algorithm. Number of samples in one period is 128 and, due to the apparatus memory limitation, and 250 periods of the network current (equal to 5 seconds) are sampled in each time.

Fig. 2 shows the currents of the studied loads in time and frequency domains. Light colored bars present the standard levels and dark bars show the harmonic components of the loads current. Following points should be noticed for each load:



semiconductor switches of the inverter

This delay, for modern DSP controlled active filters with enhanced time domain control strategies such as instantaneous reactive power control (IRP), is normally about 100-400μs [13-16]. Consequently, it is usually impossible to inject the compensating current into the network at the right instant [17,18]. Time delay causes phase differences between the load harmonic components and the components of the injected compensating current. This harmonic-order -related phase shifting,particularly when compensation for the high order harmonics is required, reduces the effectiveness of the filter. Even, some of the source current harmonic components may be increased instead of reduction [19].

One of the most popular solutions proposed in the literature, referred to as "predictive control method", is to inject the compensating current in the next network period succeeding the period in which sampling and processing stages are accomplished [20,21]. So, the phase shift, arising from the time delay in calculating the reference current, will not happen. In fact, the compensating current which is supplied to the network, in this manner, is calculated according to the harmonic distortion of the previous period [22].

In the frequency domain methods, which need a set of time samples of a whole period, one period delay is unavoidable [23,24]. Moreover, due to the computational burden, the calculation delay is not negligible. Thus, the compensating current must be injected into the network after two periods [25,26].

However, if the nonlinear load distortions after one or two periods differ largely, the correcting current can not completely cancel the harmonics of the load current. This paper aims to reveal this fact. Several nonlinear loads are studied for this purpose. These are either industrial or domestic, and single or cumulative loads. A personal computer (P.C.) is used as domestic load and a resistance welding machine as industrial type. The considered cumulative loads are: a residential complex, an electrical machines lab and a set of compact fluorescent lamps.

The principles of shunt active filter are briefly described in section 2. Harmonic contents of the nonlinear studied loads are presented in section 3. Compensation performance of the filter, with time delays in injecting the compensating current, is simulated and the remaining harmonics of the supply current after applying the compensating current are calculated and shown in section 4.

2. GNERAL SHUNT ACTIVE FILTER

Fig. 1 (a) shows a basic system configuration of a general active filter, which is used to actively shape the source current, i_s into the sinusoid. The load is assumed to be a diode rectifier and the waveforms of the load, the source and the filter are shown in Fig. 1 (b).

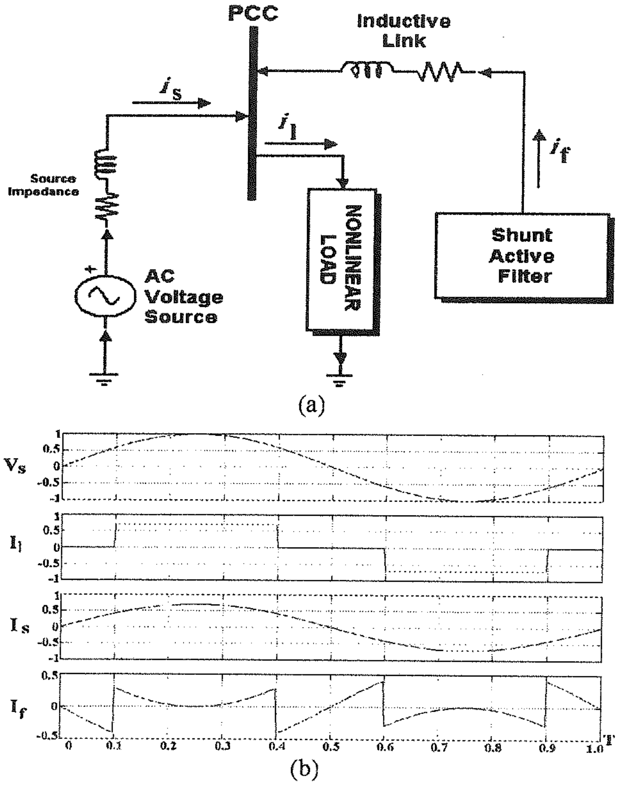


Figure 1: Basic principle of a shunt active power filter.
(a) System configuration
(b) Waveforms

The instantaneous current of the nonlinear load, i_l can be represented by three components as follows:

$i_l = i_{1a} + i_{1r} + i_h$ (1)

where, i_{1a} is the value of the active fundamental load curent, i_{1r} is the reactive fundamental component, and i_h denotes the harmonic content of the load current. In order to make the source to supply a pure sinusoidal in-phase current, the active filter should inject a compensating current, with instantaneous value given by:

$i_f = i_{1r} + i_h$ (2)

Therefore, considering the basic configuration shown in Fig. 1(a), the source current can be expressed as:

$i_s = i_l - i_f = i_{1a}$ (3)

It is obvious that, for realizing a perfect compensation, the instantaneous value of the active filter current should be exactly equal to the instantaneous value of the non-active portion of the load current. This means that the filter should have an accurate and fast response, particularly in the case of the time-varying nonlinear loads. In other words, fast computation of the reference signal is generally required for the purpose of complete compensation.This fact explains why the control scheme is the heart of the active filter [27].

3. HARMONIC SPECIFICATIONS OF THE LOADS UNDER STUDY

Sampling of the loads currents is done by a power quality analyzer apparatus in specific time intervals. Then

Effects of Load Harmonics Variations on Performance of Shunt Active Filters

Mojtaba Pishvaei[i], Seyyed-Hamid Fathi[ii], George B. Gharehpetian[iii]

ABSTRACT

This paper presents the study of shunt active filters which inject compensating current into the network with time delays. It is shown that the performance of the filter is influenced by the variations of the nonlinear load harmonic contents. Measurement results are obtained from several industrial and domestic loads. The samples of the load currents are analyzed by fast Fourier transform. The delay in the compensating current injection is simulated by Matlab software and harmonics of the source current after compensation are compared with the standard permitted harmonic levels (IEEE 519). It is shown that the compensation is not completed for nonlinear loads and, in some cases, does not satisfy the standard requirements. Thus, it is concluded that before selecting a control strategy for the active filter (even, before selecting an active filter for compensation purpose), behavior of the nonlinear load must be studied and inspected from harmonic content variations point of view.

KEYWORDS

Nonlinear load, harmonic content, shunt active filter, current harmonics compensation, reference signal production

1. INTRODUCTION

Nonlinear loads, particularly modern power electronic switching devices, are widely utilized in power transmission and distribution systems. These loads generate a large amount of harmonic current that may pollute the power system, causing problems such as transformer overheating, rotary machine vibration and power waste, voltage quality degradation, destruction of electric power components, malfunctioning of measurement and monitoring devices[1]. In order to prevent the problem of harmonic pollution, many harmonic limitation standards, such as IEEE 519[2] and IEC-3-2[3] have been established.

The harmonic distortion generated by nonlinear load can be suppressed by using of passive or active filter. Conventionally, passive filters have been used to solve the problem in the industrial power systems due to their low cost. However, passive filters have disadvantages such as sensitivity to the variations of power system impedance and frequency, the risk of series/parallel resonance, and limitation of performance to a few tuned harmonics [4].

Among the different new technical options available to improve power quality, active power filters (introduced in 70's) have proved to be an important and flexible alternative to compensate for current and voltage disturbances in power distribution systems [5].

The active filter introduces current or voltage components, which cancel the harmonic components of the nonlinear loads or supply lines, respectively. Different active power filters topologies have been introduced, and many of them are already in the market, among them shunt active filters are the most preferred [6,7]. This filter consists of a VSI (voltage source inverter), an ac-link inductor, measurement and sampling devices, analog/digital signal processor and controller [8]. The control of the active filters is realized using discrete analog and digital devices or advanced microelectronic devices, such as single-chip microcomputers, digital signal processors (DSP's), etc.[9]. However, due to inherent delay in digital control schemes, an active filter spends time to do following stages: [10-12]

-sampling and data conditioning

-data processing and producing reference signal

-producing adequate switching commands for power

[i] Mojtaba Pishvaei is Phd student in the Faculty of Electrical Engineering, Amirkabir University of Technology, Tehran, Iran (e-mail: mojtaba pishvaei @ yahoo.com).

[ii] Seyyed-Hamid Fathi is with the Faculty of Electrical Engineering, Amirkabir University of Technology, Tehran, Iran (e-mail: fathi@aut.ac.ir).

[iii] George B. Gharehpetian is with the Faculty of Electrical Engineering, Amirkabir University of Technology, Tehran, Iran (e-mail: grptian @aut.ac.ir).