ENHANCE PERFORMANCE PREDICTIVE CURRENT CONTROL FOR SHUNT ACTIVE FILTER USING FIVE LEVEL CASCADED H-BRIDGES

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Abstract: In this paper we propose an APF based on five-level cascaded inverter to compensate reactive power and suppresses harmonics drawn from a diode rectifier supplying RL load. The technique proposed for extraction harmonic current is balancing capacitor voltages presented a perfect compensation, a current predictive control is used for the correct operation of inverter and compensation demands. The results simulation using Matlab Simulink have demonstrated perfect performances obtained by the shunt filter active associated with cascade inverter the that the proposed shunt active power filter with predictive current controller have produced a sinusoidal supply current with low harmonic distortion and in phase with the line voltage.

Key words: Shunt active filter, five-level inverter, PI controller, Predictive controller, Harmonic extraction algorithm.

1. Introduction

Recently the power electronics based nonlinear loads are increased tremendously in the distribution network. These include, switched mode power supplies, variable speed drives, uninterrupted power supplies etc. These nonlinear loads create harmonics or current distortion problem in the supply side of the distribution system. The harmonic induce malfunctions of sensitive equipment, over voltage by resonance and harmonic voltage drop across the network impedance, and these significantly deteriorate the power quality in the distribution system. Traditionally, passive filters are used to eliminate harmonics and improve power quality of the distribution system. But it fails to work because of certain limitation like fixed compensation, resonance problem and bulky in nature. In order to overcome the above mentioned limitations, a new set of compensators based on power electronics technology has been introduced in the market. One of the important set of such compensators is called active power filters. Basic principle of active power filter is proposed by Gyugyi and Strycula in the year 1976 [1], [2].

Generally active power filters, it acts as a harmonic current source which injects an anti-phase but equal magnitude of the harmonic and reactive load current. As a result components of harmonic currents contained in the load current are cancelled and the source current remains sinusoidal and in phase with the respective phase to voltage, in recent years, the APF has been based on cascaded multilevel converter [3].

The term multilevel was introduced by Nabae , al. , multilevel inverter obtains a desired output voltage from several levels of input DC voltage sources. With an increasing number of DC voltage sources, the inverter voltage output waveform level increases. The multilevel inverters have more advantages which include lower semiconductor voltage stress, better harmonic performance, low Electro Magnetic Interference (EMI) and lower switching losses [4]. The cascaded H-bridge configuration of multilevel inverters is widely used because of its ability to generate near sinusoidal output waveforms, modular structure, simple power circuit and high reliability. The cascaded H-bridge inverter is an ideal choice for APF [5]. The objective of this study is to show the performance advantages of predictive current control technique for five level cascaded converter used as an APF by MATLAB/SIMULINK tools.

2. Basic configuration of the active power filter

Shunt active filter acts as a current source injecting equal but opposite harmonic and quadrature components of load current at the point of common coupling (figure 1). In effect, the system views the nonlinear load together with the active filter as an ideal resistor.
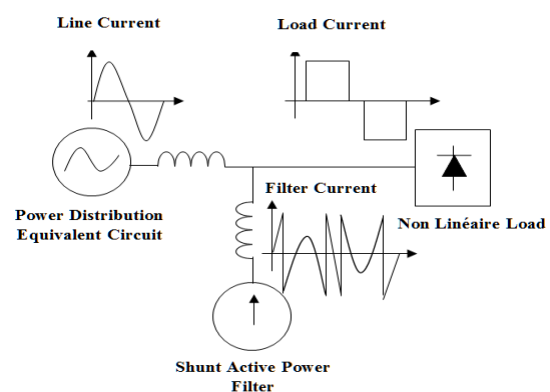

Fig1. Shunt active filter operating principle

In this paper, we present a comparison study between two control methods, associated with a shunt APF based on three-level inverter. The first method is based on the conventional regulator PI and the second method is based on predictive current control. Therefore, the APF must compensate current harmonics and the reactive power in balanced and unbalanced network cases. For that it is necessary to see the evaluation of the apparent power of the shunt APF necessary for compensation of perturbations that will allow us to judge the filter of view point energetic and technique.

Compensation of Harmonic Currents; The active power P_{ch}, the reactive power Q_{ch} and the power deforming D_{ch} composed the apparent power of a non-linear load (S_{ch}), which is indicated by the following equation:

$$S_{ch} = \sqrt{P_{ch}^2 + Q_{ch}^2 + D_{ch}^2} = 3. V_s I_{n-ch} \qquad (1)$$

With:

V_s : The mains voltage connecting point

I_{n-ch}: The current of the nonlinear load

The apparent power of the active filter (S_f) compensating the harmonic current I_h, is given by the following equation:

$$S_f = \sqrt{D_{ch}^2} = 3. V_s I_h \qquad (2)$$

This harmonic current I_h is to be created by the active filter, it can be written as follows:

$$I_h = \sqrt{I_{n-ch}^2 - I_{fon}^2} \qquad (3)$$

With I_{fon} is the fundamental current consumed by the nonlinear load.

The fundamental current and the load current according to the forward current of the non-linear load Id can be written as follows:

$$I_{n-ch} = \sqrt{\frac{2}{3}} I_d \;, I_{fon} = \frac{\sqrt{6}}{\pi} I_d \qquad (4)$$

By deferring Relations (3) and (4) in those of (1) and (2), the power ratio (τ_h) is given by:

$$\tau_h = \frac{S_f}{S_{ch}} = \frac{0.24 I_{d-\alpha}}{\sqrt{\frac{2}{3}} I_d} \qquad (5)$$

$$I_{d-\alpha} = \frac{U_d. \cos\alpha}{R_d}; \; U_d = \frac{3\sqrt{6} V_s}{\pi} \qquad (6)$$

Based on expressions (5) and (6), the final expression of τh is given by the following equation:

$$\tau_h = \left(\frac{\sqrt{\pi^2 - 9}}{\pi}\right). \cos\alpha \approx 0.3 \cos\alpha \qquad (7)$$

The following figure shows the variation of the power ratio (τ_h) of the shunt APF with respect to that of the non-linear load, depending on the ignition angle of the thyristors (α).
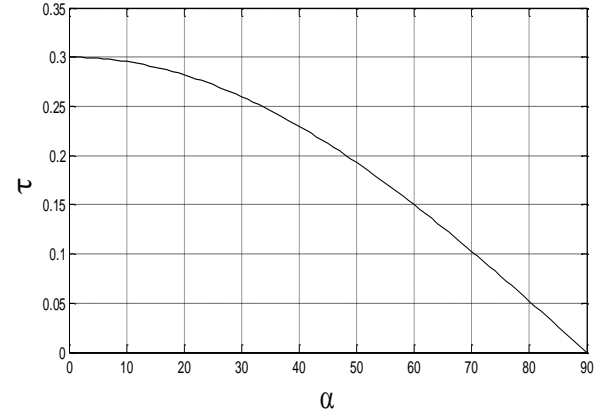

Fig. 2. Variation of the power ratio τ_h depending on the ignition angle (α)

Compensation of Harmonic Currents and Reactive Power; In this second study, we are interested to the calculation of the ratio of the apparent powers when the harmonic currents and the reactive power consumed by the non-linear load are compensated. In this case, the ratio of the apparent powers τ_{hr} is given by the following relationship:

$$\tau_{hr} = \frac{S_f}{S_{ch}} = \frac{\sqrt{Q_{ch}^2 + D_{ch}^2}}{3. V_s. I_{n-ch}} \qquad (8)$$

This last relation can also be rewritten as follows:

$$\tau_{hr} = \frac{\sqrt{(3. V_s. I_h)^2 + + (3. V_s. I_{fon}. \sin\alpha)^2}}{3. V_s. I_{n-ch}} \qquad (9)$$

By deferring the relationships (3) and (4) these in (6) and (9), the expression of the power ratio (τ_{hr}) is given as follows:

$$\tau_{hr} = \cos\alpha \sqrt{1 - \frac{9}{\pi^2}\cos\alpha^2} \qquad (1\ 0)$$

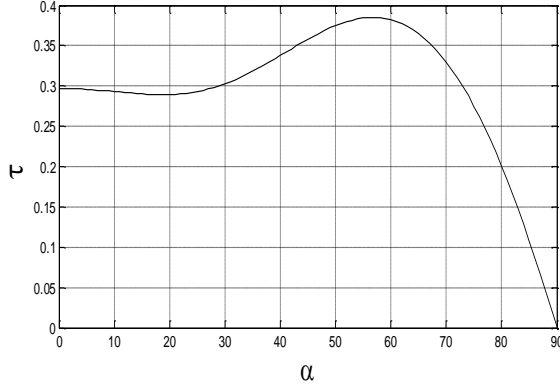Figure 3 gives the graphical representation of the power ratio (τ_{hr}) based on the ignition angle.

Fig .3. Power ratio for compensating harmonic currents and reactive power

The active power filter gives the maximum of the power $S_f \approx 52\% \, S_{ch}$ for an angle $\alpha = 42°$. For an angle $\alpha = 0$, one finds the same power ratio as that obtained in the previous compensation case $S_f \approx 30\% \, S_{ch}$.

Compensation of Harmonic Currents and Reactive Power in the Unbalanced Network Case; The compensation of harmonic currents and reactive power is realized for an unbalanced network. The current imbalance is represented only by the inverse sequence current I_i of the non-linear load. The new power ratio (τ_{hri}) is given as:

$$\tau_{hri} = \frac{S_f}{S_{ch}} =$$
$$\frac{\sqrt{(3.V_s.I_h)^2 + \left(3.V_s.I_{fon}.\sin\alpha\right)^2 + (3.V_s.I_i)^2}}{3.V_s.I_{n-ch}} \qquad (11)$$

By deferring the relationships (3) and (4) in equation (11), the expression of the power ratio is obtained as follows:

$$\tau_{hri} =$$
$$\sqrt{\cos\alpha^2 . \left[1 - \frac{9}{\pi^2}(1 - \sin\alpha^2)\right] + \frac{9}{\pi^2}\left(\frac{I_i}{I_{fon}}\right)^2} \qquad (12)$$
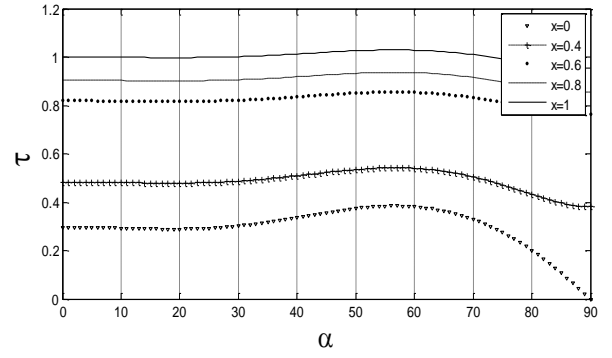
Posing: $x = \frac{I_i}{I_{fon}}$

Fig.4. Variation of the power ratio τ_{hri} in the case compensating harmonic currents and reactive power with an unbalanced network

Figure 4 represents the variation of the power ratio (τ_{hri}) depending on the ignition angle (α). The power ratio is given for various values of the reverse current rate ($x = \frac{I_i}{I_{fon}}$). It is noted firstly that the power ratio increases nearly linearly with the increased rate of the reverse current. For $x = 0$, the same curve as in the case of balanced system is obtained. In the rest of the article, the considered nonlinear load is a diode rectifier with R-L load.

2.1 Proposed five-level cascaded H-bridge inverter

The term multilevel began with the three-level inverter; is considered as a solution for semiconductor power device-rating limitations for high-power, high-voltage application , however, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries; sources can be used as the multiple dc voltage sources. Multilevel inverters have three types. Diode clamped multilevel inverters, flying capacitor multilevel inverters and cascaded H-bridge multilevel inverter. Because the cascaded multilevel inverter has advantages over the other two inverter types cited in [5], is chosen for the presented work. In this paper the proposed five level cascaded inverter a standard three leg; components of one phase include in table 1 and figure 5 shows the five level inverter used for active power filter application.

Table1
number switches of one phase

Types of multilevel inverter	Number of switches	Number of diodes	Number of capacitors
Diode	8	12	4

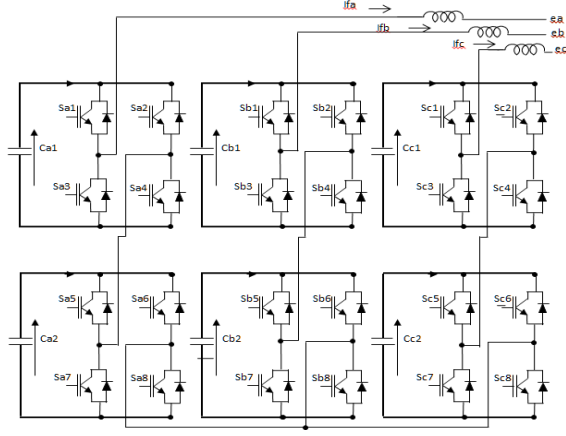|			
clamped			
Flying capacitor	8	/	10
Cascaded H bridge	8	/	/

Fig .5. Five level Cascade H-Bridge inverter

The circuit figure.5 consists of eight main switches in two series connected H-bridge configuration S1~S4, and S5~S8. The number of dc sources are two so the output voltage of the cascaded multilevel inverter is $2 * V_{dc}$. The output waveforms of multilevel inverters are in a stepped waveform therefore they have reduced harmonics compared to a square wave inverter.

Each separate dc source is connected to a single-phase full-bridge, or H-bridge inverter. Each inverter level can generate three different voltage outputs,$+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S1, S2, S3, and S4. To obtain $+V_{dc}$, switches S1 and S2 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S3 and S4. By turning on S1 and S2 or S3 and S4, the output voltage is 0. Similarly S5 and S6 for $+V_{dc}$, switches S7 and S8 are turned on for $-V_{dc}$. The ac outputs of each of the different full bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. As given below.

Table 2
.the switching states of five level cascade inverter

Switches turn on	Voltage level
S1,S2	$+V_{dc}$
S1,S2,S5,S6	$+2V_{dc}$
S4,S2,S8,S6	0
S3,S4	$-V_{dc}$
S3,S4,S7,S8	$-2V_{dc}$

3.   Current control techniques

3.1 Harmonic Current Extraction

The capacitor voltage control technique has many advantages; the number of sensors is minimized compared with techniques proposed in [6].

It has a low computational burden, does not require sensing of the load or active filter currents, but the supply current which means fewer sensors than for other techniques. This technique is based on power balance where the supply real power is equal to the load real power plus the inverter losses. To maintain power balance, the capacitor must instantaneously compensate for the difference between the supply and the load power. So controlling five level [5] capacitor voltages (Figure 6) using three proportional-integral (PI) controllers, results in outputs that are proportional to the instantaneous changes in power balance. Multiplying each output by the corresponding per-unit voltage of the supply currents.
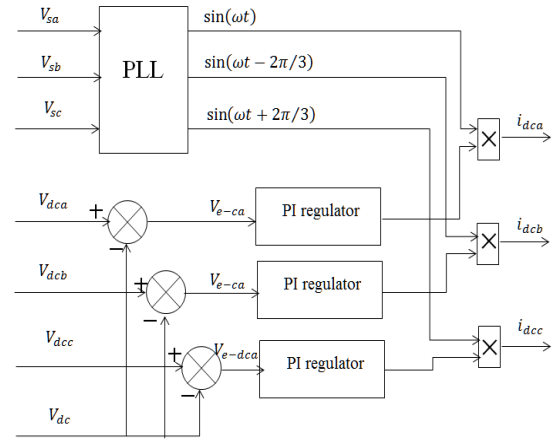

Fig .6. Capacitor voltage control

3.2 Predictive current control

Fig .3 represent, the three phase active filter consists of two H-bridges in cascaded method for 5-level output voltage [6],[7],[8],[9], the capacitor voltage is maintained constant using PI-controller. As in [10],[11],[12],[13], measured supply currents and voltages of the common coupling point, are used to predict the reference output voltage of the inverter, required to make the measured current reach its reference at the next sampling instant. The predicted inverter output voltages are used to obtain the switching decision of the inverter switches. In figure.7, the equation relating the shunt APF current, the inverter output voltage and the common coupling point voltage is given as:

$$v_x = L_x \frac{di_{fx}}{dt} + e_x \qquad (13)$$

Where x represents the phases a, b or c, Lx is the interfacing inductance, v_x is the APF output voltage for the x phase, e_x is the phase voltage of the CCP and i_{fx} is the phase APF current. The inductor resistance is neglected. Equation (13) can be represented in the discrete form as follows:

$$v_x^*(n+1) = L\left(\frac{i_{fx}^*(n+1) - i_{fx}(n)}{T_s}\right) + e_x \quad (14)$$

Where $i_{fx}^*(n+1)$ and $v_{fx}^*(n+1)$ are the phase APF common coupling point results in the corresponding reference current and the predicted output voltage references respectively, at the sampling instant (n+1) and Ts is the sampling time. Using Kirchhoff's current law at the CCP:

$$i_{fx}(n) = i_{Lx}(n) - i_{sx}(n) \quad (15)$$

Where $i_{Lx}(n)$ and $i_{sx}(n)$ are the phase load and supply currents respectively at the sampling instant (n). Since the sampling instant (n+1) is not available, $i_{fx}^*(n+1)$ is replaced by $i_{fx}^*(n)$. This introduces one sampling time delay which becomes less significant as the sampling frequency increases. The reference current of the shunt APF can be expressed as:

$$i_{fx}^*(n) = i_{Lx}(n) - i_{sx}^*(n) \quad (16)$$

Substituting (15) and (16) into (14) gives:

$$v_x^*(n+1) = L_x\left(\frac{i_{sx}(n) - i_{sx}^*(n)}{T_s}\right) + e_x(n) \quad (17)$$

Equation (17) represents the predicted inverter output voltage expressed in terms of the reference and the actual supply currents.
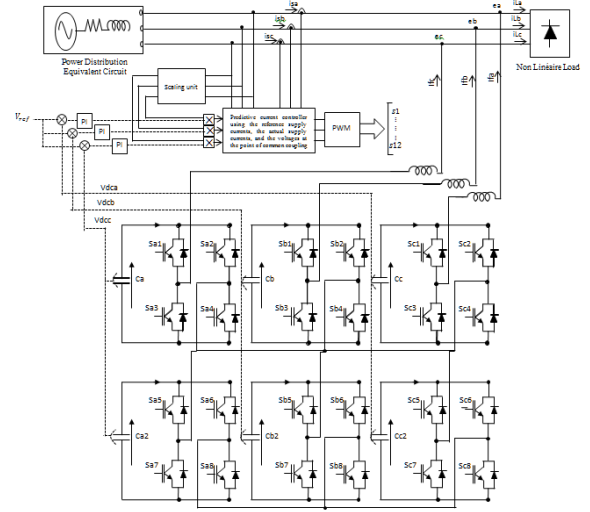

Fig .7. Five-level cascade inverter based a shunt active power filter

Table 3
The system parameters

Parameter	Value
Supply voltage	400 V
Load impedance	R=12 Ω,L=20mH
vdc	420 V
Cdc	8.8mH
f	5000Hz

4. Simulation results

A number of simulation results with two type control, control by PI and second by predictive current was presented. In fig is connected in parallel with nonlinear load RL case α =0, has to be compensated by the APF
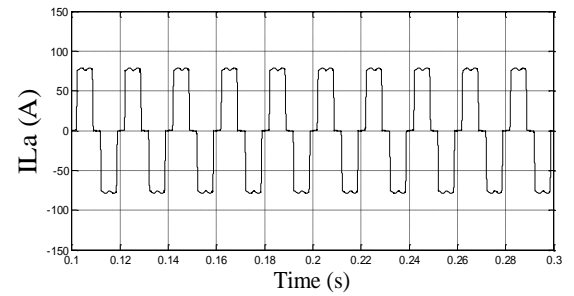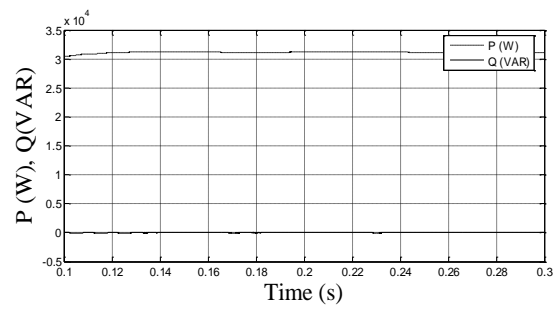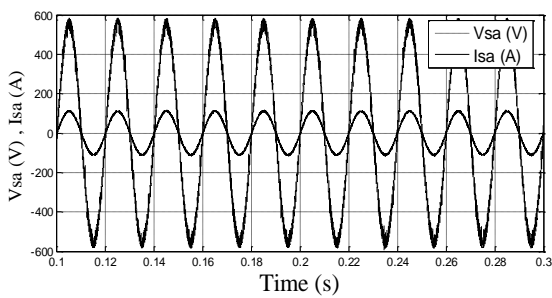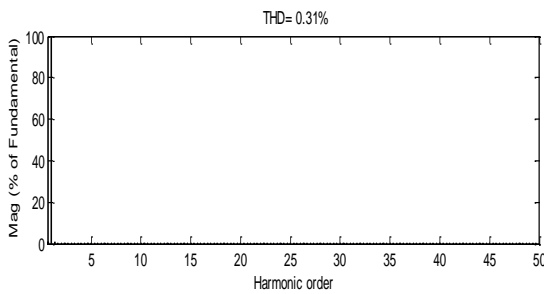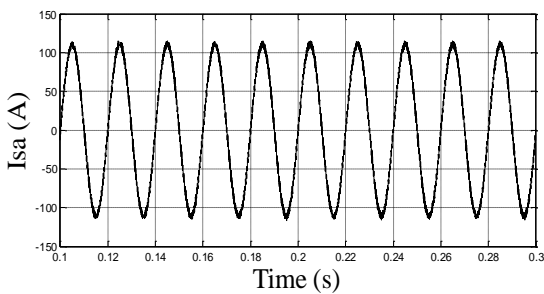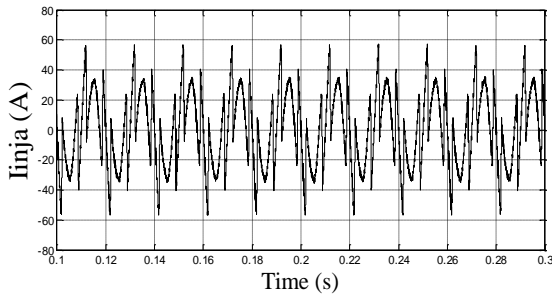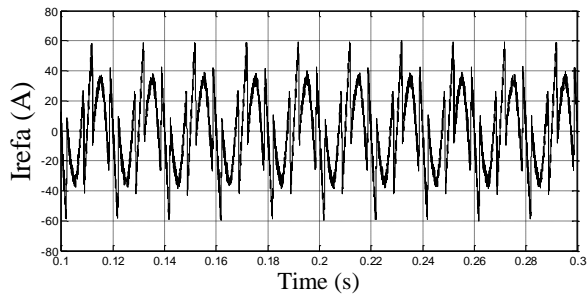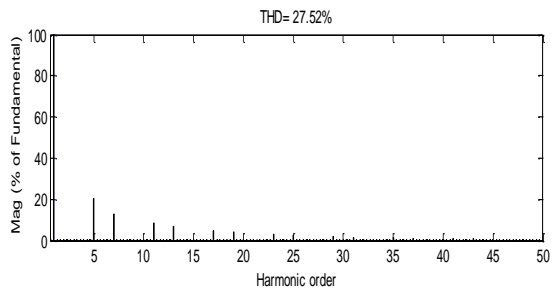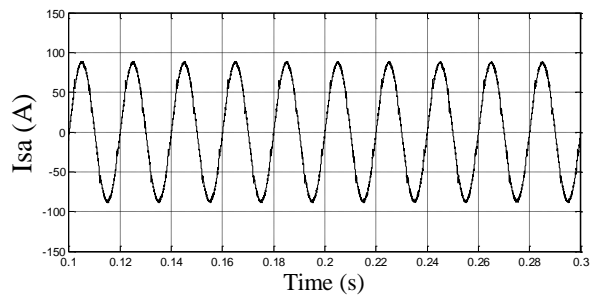
Fig .8. Load phase current; Frequency spectrum of the load phase current; Injected current; Reference current; Source current; Frequency spectrum of the source phase current, Source voltages with source current

For we see your performance command predictive controlled shunt active filter. We compared with controller pi.
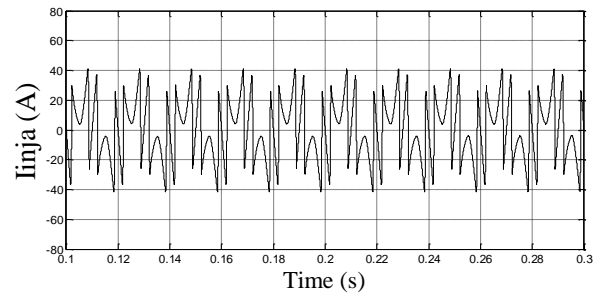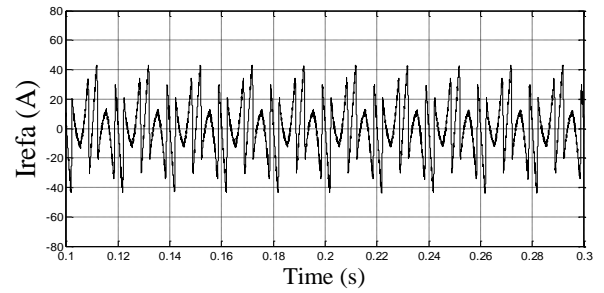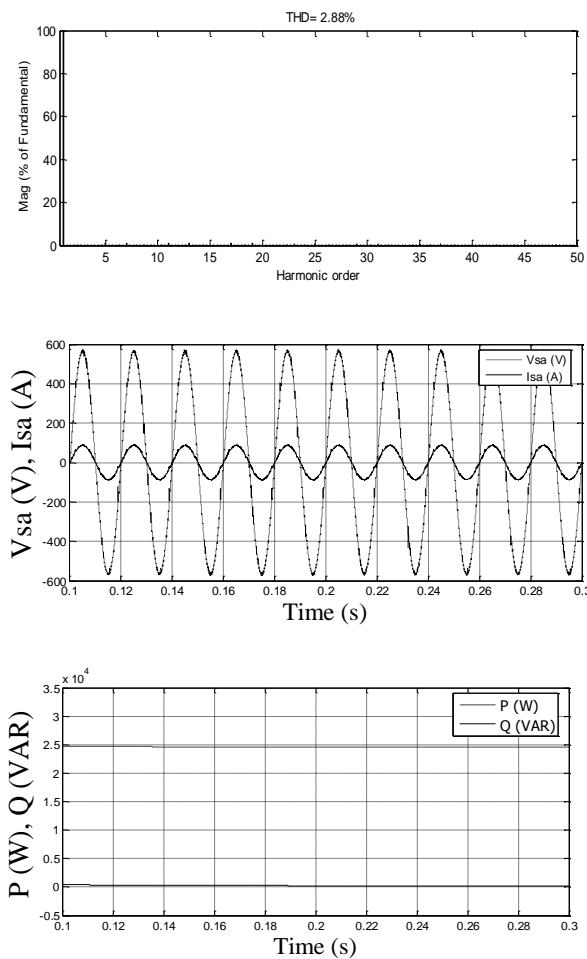
Fig. 9. Load phase current; Frequency spectrum of the load phase current; Injected current; Reference current; Source current; Frequency spectrum of the source phase current, Source voltages with source current

The simulation results with two methods of control Pi and predictive current control are presented in figure 8, figure 9. The active filter produces multilevel voltages that generate a current to cancel the harmonic contents source current (THD=27.52%) these results show that supply currents always remain sinusoidal (THD=0.31%) compared with simulation resulted by conventional regulator PI (THD= 2.88%). From this results simulation, it can be seen that the voltage and current are in phase. Therefore, this figure describes the proper power factor compensation by presented system.

The presented simulation results show the validity and effectiveness of presented structure FAP, with five levels cascaded inverter to compensate current harmonic and reactive power.

Conclusion

In this paper simulation a predictive current control applied in shunt active filter associated five level inverter show the main advantages of this method of control are the negligible harmonic distortion obtained and very low switching frequency operation This control structure features design simplicity, as well as superior dynamic performance to large signal disturbances,

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