International Journal of Recent Advances in Multidisciplinary Research
Vol. 01, Issue 01, pp.014-019, July 2014

Full Length Research Article

A NEURAL NETWORK AND FUZZY LOGIC APPROACH FOR THE CONTROL OF AN ACTIVE POWER FILTER

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ARTICLE INFO

Article History:
Received 13th April, 2014
Received in revised form
14th May, 2014
Accepted 28th June, 2014
Published online 25th July, 2014

Keywords:

Power Quality,
Active Power Filter,
Harmonics distortion,
Reactive power,
Adaline.

ABSTRACT

In this paper a three-phase shunt active filter is used to compensate current harmonics, reactive power in three-phase distribution network system. In order to improve its performances, a Neural Network and Fuzzy Logic approaches are used to control this device. The first controller called Adaptive Linear Neural Network (ADALINE) is used with the direct method in order to identify precisely the necessary currents to reduce the harmonics and to compensate reactive power. The neural network inputs are based on a decomposition of the measured currents. This decomposition is also based on the Fourier series analysis of the current signals and Least Mean Square (LMS) training algorithm to carry out the weights. In this case, three ADALINE are used to extract the fundamental component of the distorted line current directly from the abc axis (the three phase space). The second controller is the fuzzy logic controller, used to regulate the DC link capacitor voltage. This approach has the advantage to eliminate the PLL and Concordia, Park or Clark transformations method. Speed and accuracy of this approach results in improving the performance of the APF. All of the studies have been carried out through detail digital dynamic simulation using the MATLAB/Simulink Power System Toolbox.

INTRODUCTION

Nowdays there has been a rapid increase in the number of power electronic loads resulting in alarming levels of harmonic distortion in the distribution systems. These harmonics circulate in the electrical network, disturb the correct operation of the components and even it may damage them. Shunt Active Power Filters (SAPFs) are recognized solutions to compensate for harmonic distortions, to correct the power factor and to recover the balance in power distribution systems by injecting compensating currents [1, 2]. One important factor which influences the performance of the active power filters is the speed and accuracy of the detection tool for the power line harmonic currents.APF can be used with different control strategies. One of the most widely used is based on the conventional Instantaneous Power Theory (pq method) initiated by Akagi [1]. It works in the ✔ ꞓ-reference frames, calculate the real and imaginary instantaneous powers and separate their alternative parts from their continuous parts. The alternative parts of the powers are then used to deduce the compensation currents. This principle has been efficiently achieved through neural approaches in [3, 4, 5]. The major disadvantages of a bloc identification-based pq method are essentially as follows [6]:

- It is not effective under distorted and unbalanced mains voltages conditions.
- The time delays introduced by pass filters, which are used to separate the average and oscillating parts of powers, degrades the dynamic performance of active filter;
- This method requires more computational calculation.

Recently, Artificial Neural Networks (ANNs) have been successfully applied to power systems [2]. With their learning capabilities, ANNs are able to take into account time-varying parameters [7, 8]. Inserted in an APF scheme, they can appreciably improve its performance compared to the one obtained with traditional methods. Several methods have been proposed in [3] where ADALINE neural networks have been used to on-line learn the expressions of the signals, i.e., either instantaneous powers or currents. The Adaline is a simple and fast architecture which is suitable for on-line applications. In this paper, a neural network and fuzzy logic controllers are proposed to ameliorate the performances of an active power filter. The adaptive neural network is used in the open-loop,

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extracts with high precision the fundamental components of the distorted line current signal directly from the abc axis and the output of the ADALINE is compared with distorted supply current to obtain the reference current. The fuzzy logic controller is used in closed-loop to maintain the DC bus voltage at the reference value. The output of the closed-loop and the open-loop is summed to construct the modulating signal as shown in figure 1. This modulating signal is used to generate the PWM pulses to be fed into the active power filter to generate the compensating currents. Thus the power quality will be maintained.

Proposed Control Strategy

The main function of the controller is to create the PWM switching signals for the connected VSI. Figure 1 shows the schematic diagram of the proposed control strategy for the shunt active power filter. The proposed control system consists of two control loop, an open-loop and a closed-loop control system. In the open loop system, the I_{Sh} harmonic signal is obtained from the output of the current ADALINE and then its value is summed by $-V_S \cdot u_{dc}$, the output u_{dc} of the fuzzy logic controller is used to maintain the dc-side voltage at its reference value [13, 14]. The opposite of this signal is used as a current reference signal. The sum of the open loop control signal (ADALINE current reference signal) and the closed-loop control signal (FLC for regulating dc-side voltage) is used as the modulating signal of the three phases PWM control strategy to create the PWM switching pattern for the switches of the VSC.

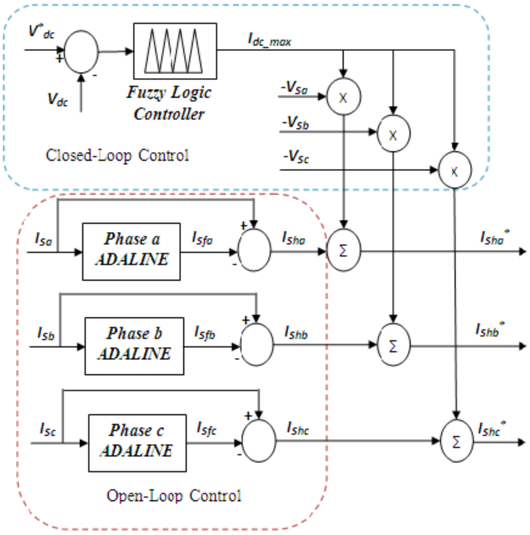


Figure 1. The proposed control strategy

In this section we describe the ADALINE approach specially the direct method and FLC design for active power filter system.

Adaptive Linear Neural Networks Principe

The ADALINE is an algorithm having N input in the form of vector and a signal output, when its main applications are in the adaptive filtering and prediction signals. The output of the ADALINE is a linear combination of its inputs. An ADALINE in block diagram form is depicted in Figure 2.

The input to the ADALINE is the vector $X = [X_0 \; X_1 \; X_2 \; \dots \; X_n]$, Where X_0 is the bias term, it set to 1.

The ADALINE has a weight vector $W = [W_0 \; W_1 \; W_2 \; \dots \; W_n]$, and its output can be, simply written as $Y = W^T X = W_0 + W_1 X_1 + W_2 X_2 + \dots + W_n X_n$. The weight adjustment, or adaptation, is performed during the training process of the ADALINE using a nonlinear adaptation algorithm.

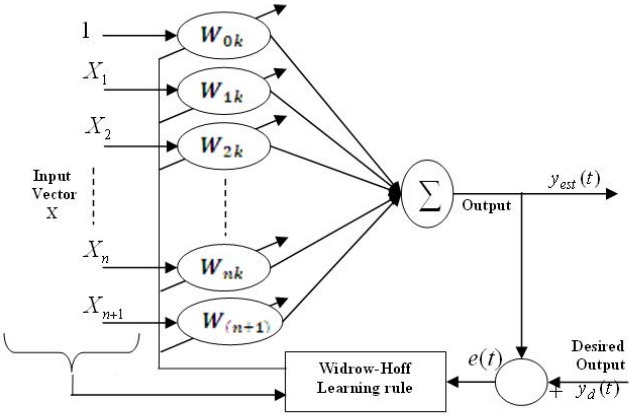


Figure 2. Adaline Network

To update the weight vector and minimize the mean square error between the desired signal output $y_d(t)$ and the estimate output $y_{est}(t)$, the Widrow-Hoff learning delta rule is used [12, 13, 14]:

$$W(k+1) = W(k) + \alpha \left[\frac{e(k) \cdot X(k)}{X^T(k) \cdot X(k)} \right]$$

Where:

k: Time index of iteration,
$W(k)$: Weight vector at time k,
$X(k)$: Input vector at time k,
$e(k) = y_d(k) - y_{est}(k)$: Error at time k,
α: Learning parameter,

We use this principle and apply it to the ***direct method.***

Adaline as Harmonic Estimator *(The Direct Method)*

The ADALINE has been used to identify the current harmonics reference in a distorted waveform [9, 13, 14]. In our application, the direct method ADALINE is used and carried out in the space of the currents (the three phase space), measuring the current of the three phases of the electrical supply network. So, three ADALINE are used in this approach, each one can be decomposed into Fourier series in the following way [12, 13, 14]:

$$I_S(t) = I_{Sf}(t) + I_{Sh}(t) = I_{11}\cos(wt - \alpha) + I_{12}\sin(wt - \alpha) + \sum_{n=2}^{N} I_{n1}\cos n(wt - \alpha) + I_{n2}\sin n(wt - \alpha) \quad (1)$$

In this expression, I_S represent the current source, I_{Sf} is the fundamental component of current source and I_{Sh} is the harmonics current.

Where:

$$I_{Sf}(t) = I_{11}\cos(wt-\varphi) + I_{12}\sin(wt-\varphi) \qquad (2)$$

And

$$I_{Sh} = \sum_{n=2..n} I_{n1}\cos n(wt-\varphi) + I_{n1}\sin n(wt-\varphi) \qquad (3)$$

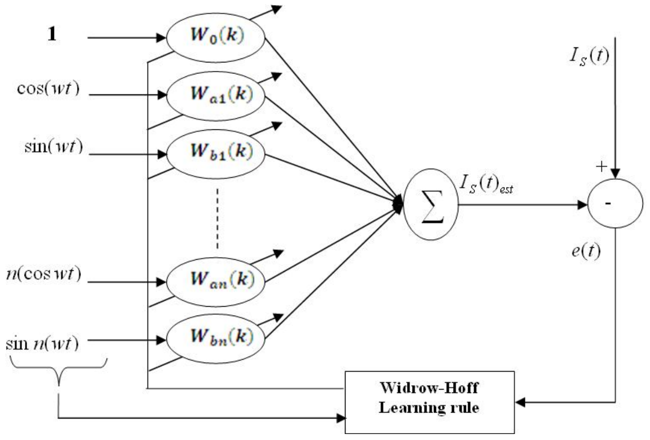


Figure 3. Design of the Adaline network for harmonic distortion identification (direct method)

When, w is the fundamental frequency, φ the phase between current and load voltage, I_{11} and I_{12} the cosine and sine frequency components of fundamental current, and I_{n1}, I_{n2} the cosine and sine frequency components of the harmonics current; the identification of the harmonics components is done with an Adaline for each phase. As show by figure 3, [12, 13]. The expression of the current, depicted by (1), can be written as a linear combination which can be learned by an Adaline network:

$$I_S(t) = W^T \cdot x(t) \qquad (4)$$

Where:

W^T : Is the ADALINE weight vector.
$x(t)$: Is the network input vector

$$W^T = [I_{11} \quad I_{12} \quad \ldots\ldots \quad I_{n1} \quad I_{n2}] \qquad (5)$$

And

$$x(t) = [\cos(wt-\varphi) \quad \sin(wt-\varphi) \quad \ldots\ldots \quad \cos n(wt-\varphi) \quad \sin n(wt-\varphi)] \qquad (6)$$

The amplitude of continuous component of the fundamental current will be determined by the weight $W_0(k)$ of a first neural network ADALINE multiplying by $\cos(wt)$ and $\sin(wt)$ as follows [13]:

$$I_{Sf} = I_{11}\cos(wt) + I_{12}\sin(wt) \qquad (7)$$

Once the fundamental current is determined, the harmonic current can be obtained by subtraction of the currents networks and that obtained by ADALINE algorithm; this current is given by the following equation:

$$I_{Sh}(t) = I_S(t) - I_{Sf}(t)$$
(8)

These harmonics current $I_{Sh}(t)$ of one phase will be injected thereafter in opposition phase in the electrical network via a control device (VSI).

Design of DC Bus Fuzzy Logic Controller

The voltage of the DC bus should be maintained at a desired value, to compensate the losses in the active filter. Voltage control of DC bus is achieved by adjusting a small amount of real power flowing into the dc capacitor. Several methods have been used in this case (PI, PID, RST controllers). We utilize in our application the fuzzy logic control algorithm of an active power filter in a closed loop, the dc-bus capacitor voltage is sensed and then compared with the desired reference value [15, 16, 17, 18]. The error signal $e(t)$ and a change of error signal $\Delta e(t) = e(t) - e(t-1)$ are used as inputs for a fuzzy logic controller as shown in Figure 4 [16]. The output of the fuzzy controller estimates the magnitude of peak reference current $I_{dc\_\max}$. This current takes response of the active power demand of the non-linear load for harmonics and reactive power compensation. This peak reference current multiplied with a voltage system (V_{S-abc}) synchronizing output for determining the reference current as shown in Figure 1.

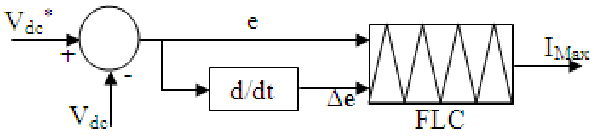


Figure 4. Fuzzy logic Controller

In order to convert the crisp variables into linguistic variables, we use the following seven fuzzy sets, which are: NL (negative big), NM (negative medium), NS (negative small), Z (zero), PS (positive small), PM (positive medium), NL (positive big) [20, 21, 22, 23]. The fuzzy logic controller characteristics used in this section are: Seven fuzzy sets for each input $(e, \Delta e)$ and output I_{Max} with triangular and trapezoidal membership functions.

- Fuzzification using continuous universe of discourse.
- Implications using Mamdani's 'min' operator.
- Defuzzification using the 'centroid' method.

Membership functions used for the input and output variables used here are shown in Figure 5. As both inputs have seven subsets, a fuzzy rule base formulated for the present application is given in Table 1. [17, 19, 20, 21, 22, 23].

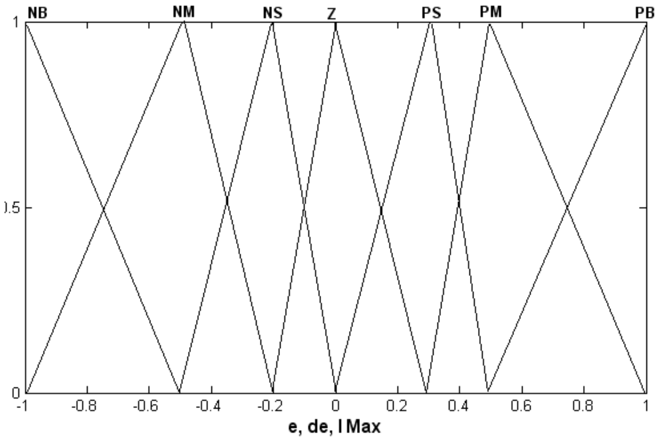


Figure 5. Membership function for the inputs and the output variables

Table 1. Fuzzy Inference table

e de	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	NL	NM	NS	ZE	PS	PM	PL

Simulation Result and Analysis

In order to evaluate our approach based on an adaptive Linear Neural Networks and fuzzy logic controller, a digital simulation is carried out. This study examines an electrical distribution networks having a three-phase voltage source, a nonlinear loads that generate harmonics and shunt active power filter. The main parameters of the system are listed in Table 2.

Table 2. Main parameters of the simulated system

Phase to neutral source voltage	$240\sqrt{2}$ V, $50Hz$
Source impedance	$R_S = 3.5m\Omega$; $L_S = 0.05\mu H$
Filter impedance	$R_C = 0.82m\Omega$; $L_C = 0.1mH$
Load impedance	$R_{L1} = 1.5\Omega$; $R_{L2} = 3\Omega$; $L_L = 6mH$
DC side capacitance	$C = 8mF$
DC-bus voltage reference	$V_{dc}^{*} = 850V$

The converter is tested with a firing angle of 20° and the nonlinear load is changed at $t = 0.125s$. Each on ADALINE is used to estimate the fundamental current, and the subtraction of this current and the current network gives the reference current and the fuzzy logic controller is used to maintain the value of the DC voltage at a fixed value. The performances of the proposed technique are given in Figure 6 and Figure 7, illustrating the steady state and transient behavior of the system. Load current without compensation (only one phase current is represented for the clearness) and its harmonics spectrum, source currents and its harmonics spectrum after compensation (Figure 6: a, b) respectively, the active power filter current and its reference (Figure 6: c), the current and voltage source (Figure 6: d), the DC capacitor voltage (figure 6: e), and the active and reactive power with compensation are shown (Figure 7).

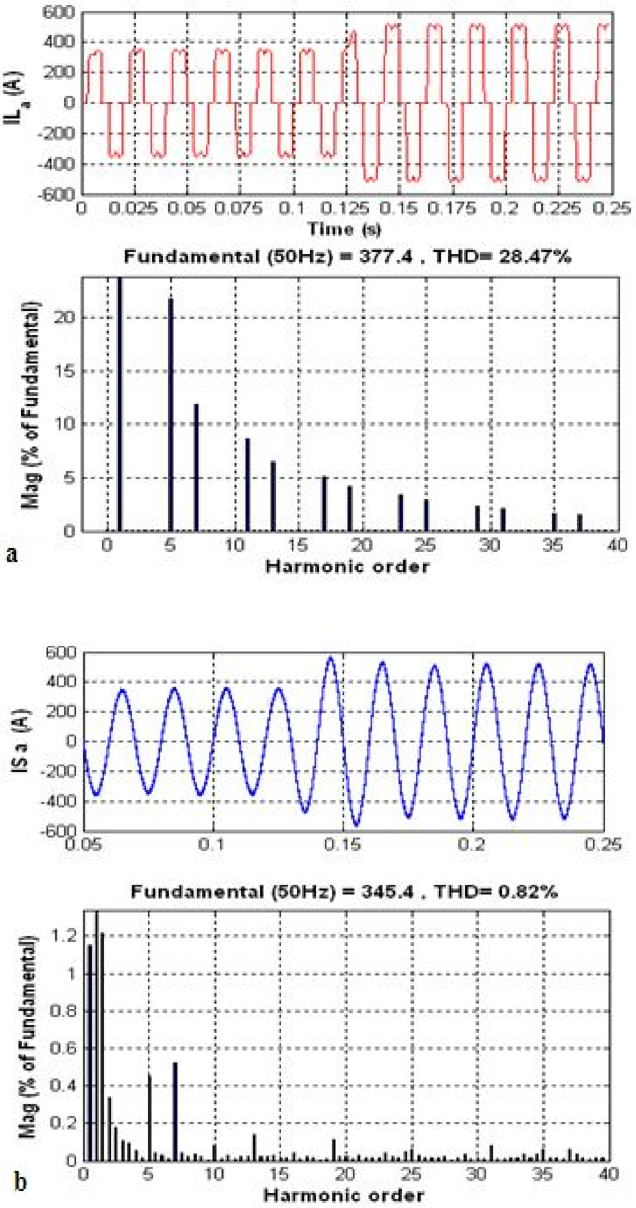
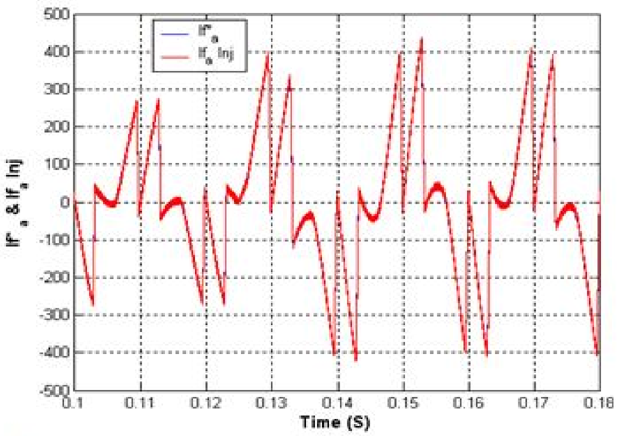


Figure 6. Load and source current and its harmonics spectrum. a) Before compensation (THD=28.47%), b) After compensation (THD=0.82%)



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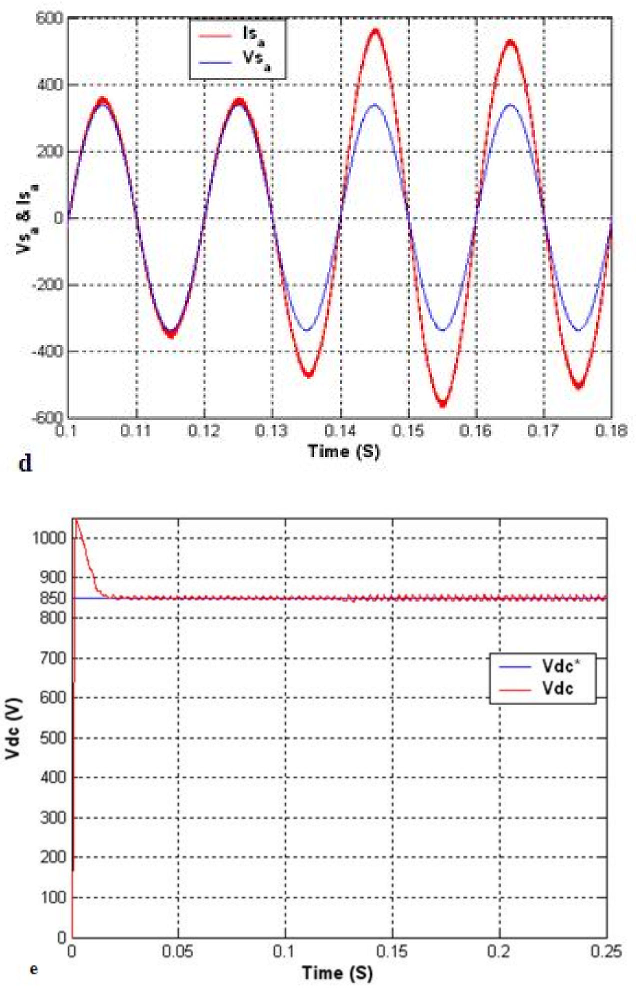
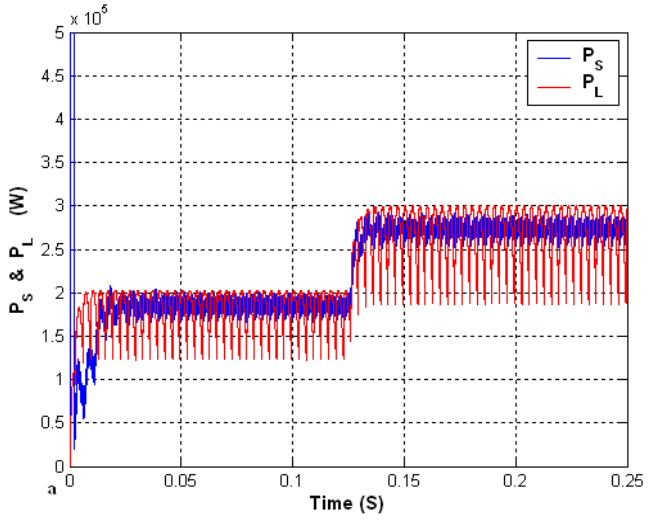


Figure 6. Simulation Results, c) reference and compensation current by active power filter, d) voltage and current source waveforms before compensation, e) the DC capacitor voltage

The proposed compensation technique of the active power filter reduces the harmonics generated by the nonlinear load and thus results in a sinusoidal current and in phase with the source voltage, under load change, where it can be seen that the total harmonic distortion (THD) and the power factor (PF) are both excellently improved before and after load change. The Total Harmonic Distortion (THD) parameter, are reduced after compensation from 28.47% to 0.82%. Therefore, there is a better reduction in harmonic distortion with this approach. By using the fuzzy logic controller in a closed- loop control, the DC-bus voltage is maintained at the desired value when the load changes with excellent response. It can be observed also in Figure 7 where the active and reactive power is depicted. The reactive power is almost canceled, and the real power drawn from the AC source is practically free of the alternating part of the load power.



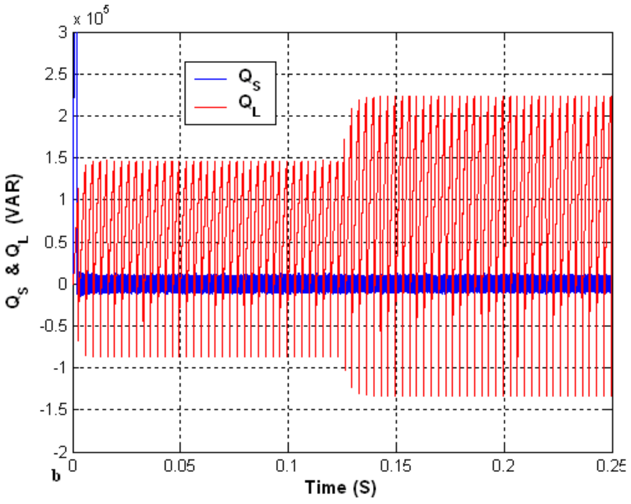


Figure 7. The Instantaneous, active and reactive power. Simulation Results

Conclusion

The shunt active power filter is basically used to compensate harmonics, produced in the case of a nonlinear load, and reactive power. In this paper, we have presented the simulation results, using the Matlab/Simulink, Power System. The reference current's identification is accomplished by an approach based on an Adaptive linear neural network (ADALINE direct method). The Fuzzy logic controller (FLC) is used to keeps the DC voltage at the desired value and to minimize the DC voltage fluctuation, reducing the voltage variation ΔV_{dc} and settling time.

The proposed control approach based shunt active power filter can compensate a highly distorted line current by creating and injecting appropriate compensation current. In the test cases simulated for different non linear loads, the THD of the supply current is improved to less than 5% with the proposed approach. The performances reached by the proposed method are better than those obtained by more traditional techniques as mentioned in the introduction. The first investigations, presented here, of the control algorithm prove its effectiveness and its high dynamics. It will be completed in a future work by using other artificial techniques and by considering others PAF configurations for comparative study.

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