COMPARISON OF FUZZY LOGIC AND PROPORTIONAL CONTROLLER OF SHUNT ACTIVE FILTER COMPENSATING CURRENT HARMONICS AND POWER FACTOR

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Abstract: *The paper describes and compares the application of fuzzy logic controller and proportional controller to a three phase shunt active power filter used to compensate harmonic current and reactive power of nonlinear loads simultaneously.*
The proposed scheme uses a pulse width modulation (PWM) technique to generate the switching signals to the active filter, p-q theory for harmonic current identification and fuzzy logic and P controllers for active filter current and DC capacitor voltage control. The performance of fuzzy logic controller is compared with a conventional P controller. The dynamic behavior of fuzzy logic controller is found to be better than the conventional P controller.

Key words: *Fuzzy logic control, P controller, Harmonics, Reactive powercompensation, PWM control, Shunt active power filter.*

1 – Introduction

Power converters are the main source of harmonic distortion and are largely used in industrial applications and result in low power factor, reducing the efficiency of the power system. Active power filter (APF) have been widely studied and used to eliminate harmonics and compensate reactive power [1-4]. Many methods of active power filter control techniques such as conventional P and PI controller are used to control the APF. It is very difficult to design a control technique that is able to follow current peaks with a limited switching frequency. The scheme using proportional controller for the generation of a reference current requires precise linear mathematical models, which are difficult to obtain under load disturbance and parameters variation.

Recently, fuzzy logic controllers have been introduced in power electronics field [5,6,7,8,9,10]. The advantage of fuzzy logic controllers over the proportional P controllers is that, it is based on a linguistic description and does not need an accurate mathematical model of the system.
It is possible with a fuzzy logic to design a control system that can follow the reference current even when high peaks occur. The fuzzy control can also maintain the DC voltage capacitor constant. The present paper proposes a shunt active power filter that compensates harmonic current and reactive power simultaneously using two control techniques P and fuzzy logic controllers. The PWM technique is employed to generate the inverter switching signals and the *p-q* theory [4] for harmonic current identification. MATLAB power system blocks are used to carry out the simulation work.
The basic principle of APF is illustrated in Fig.1.

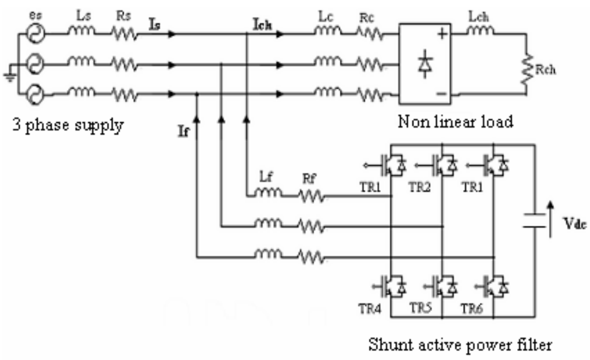


Fig.1. The active power filter operation

2 - Reference current calculation

Several methods were proposed for the identification of the harmonic current references. Mainly, the methods based on the FFT (Fast Fourier Transformation) in the frequency domain, and the methods based on instantaneous power calculation in the time domain. In this study, we retained the *p-q* theory method allowing the compensation of harmonic currents, unbalanced currents and reactive power.

The reference currents (harmonic currents) identification is based on α-β transformation to obtain real and imaginary powers.

The voltages (V_{S1}, V_{S2}, V_{S3}) and currents (I_{S1}, I_{S2}, I_{S3}) are transformed into bi-phased systems according to the following:

$$\begin{bmatrix} X\alpha \\ X\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} X1 \\ X2 \\ X3 \end{bmatrix} \quad (7)$$

The instantaneous active and reactive powers of the system are calculated as follows:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{pmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{pmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad (8)$$

Instantaneous powers are composed of a constant part which corresponds to fundamental and of a variable part due to harmonic currents.

$$\begin{bmatrix} Ih\alpha \\ Ih\beta \end{bmatrix} = \frac{1}{V_{s\alpha}^2 + V_{s\beta}^2} \begin{bmatrix} Vs\alpha & -Vs\beta \\ Vs\beta & Vs\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (9)$$

3 – Harmonic Currents Control using PWM

This control implements initially a controller which starts from the difference between the injected current (active filter current) and reference current (identified current) that determines the reference voltage of the inverter (modulating wave). This reference voltage is compared to a triangular or a tooth saw wave at high frequency (carrier frequency) in order to determine the gating signals. The general block diagram of control currents is shown in Fig.3.

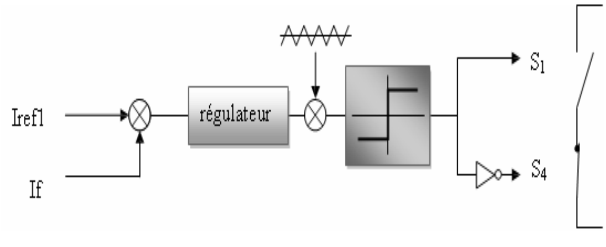


Fig.2. PWM synoptic block diagram of currents control

4- Presentation of the two control techniques

a- Using P Controller

- Shunt active filter current control

By neglecting the effects of the C_{dc} capacity and resistances of the passive filter of the injected current I_{inj} (reference current), the relation characterizing this current can be written as follows:

$$L_f \frac{d}{dt} I_{inj} = V_f - V_s \quad (13)$$

ΔI_f *the* difference between the current of reference and the measured current

$$\Delta I_f = I_{ref} - I_{inj} \quad (14)$$

From equations (13) and (14), we obtain:

$$L_f \frac{d}{dt} \Delta I_f = (V_s + L_f \frac{d}{dt} I_{ref}) - V_f \quad (15)$$

The first term of the right part of the relation (15) can be defined as a standard reference voltage (V_{fref}), the equation below is obtained:

$$V_{fref} = V_s + L_f \frac{d}{dt} I_{ref} \quad (16)$$

Second term is the voltage drop of L_f (inductance), when it is crossed by a current equal to the reference current. This term must be performed by a regulator of current illustrated in Fig.3.

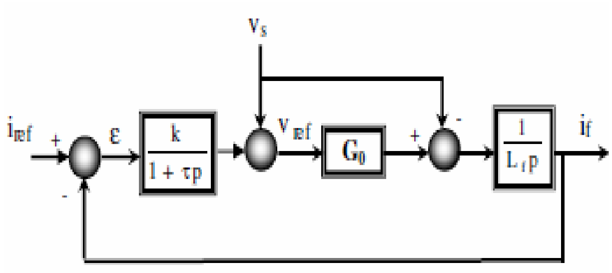


Fig.3. PWM synoptic block diagram of currents control

- DC voltage control

The capacitor average voltage (V_{dc}) has to be maintained at a fixed value. The main cause of its variation is the active filter losses (switches and output filter). The energy storing capacitor voltage control must be done by the adjunction in reference currents of active fundamental currents.

The output controller *Pc* is added to the distorted active power $\tilde{p}$ giving an active fundamental current that corrects V_{dc}. The power P_c represents the active power required to maintain V_{dc} voltage equal to the value of the desired reference voltage (V_{dcref}). The used controller is a simple proportional controller (K_c).

A first order filter is added at the proportional controller output in order to filter distortions at 300Hz. Neglecting inverter commutation losses and the storing energy in the output filter inductance, the relation between the power absorbed by the active filter and the voltage across the capacitor is as follows:

$$P_c = \frac{d(\frac{1}{2}C_{dc} \times V_{dc}{}^2)}{dt} \quad (10)$$

Noting that equation (10) is a non linear relation. For low variations of V_{dc} voltage around its reference V_{dcref}, it can be linearized through the following relations:

$$p_c = c_{dc} \times V_{dcref} \frac{d(V_{dc})}{dt} \quad (10)$$

$$\Rightarrow V_{dc}(s) = \frac{P_c(s)}{V_{dcref}\, c_{dc} S} \quad (12)$$

The control loop of dc voltage can be represented as shown in Fig.4.

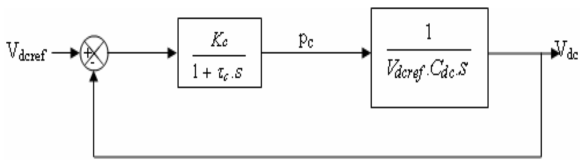


Fig.4. dc voltage control block.

b- Fuzzy Control Application

Fuzzy logic serves to represent uncertain and imprecise knowledge of the system, whereas fuzzy control allows taking a decision even if we can't estimate inputs/outputs only from uncertain predicates. Fig. 5 shows the synoptic scheme of fuzzy controller, which possesses two inputs (the error (*e*), ($e = i_{ref} - i_f$) and its derivative (*de*)) and one output (the command (*cde*)).

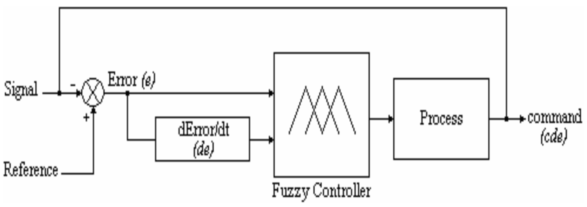


Fig.5. Fuzzy controller synoptic diagram

- Active power filter current control

The objective is to get sinusoidal source currents in phase with the supply voltages at the common coupling point.

This step consists on replacing the conventional controllers (P, PI…) by fuzzy logic controllers. The main characteristics of the fuzzy control are:

- Three fuzzy sets for each input (*e, de*) with Gaussian membership functions,
- Five fuzzy sets for the output with triangular membership functions,
- Implications using the 'minimum' operator, inference mechanism based on fuzzy implication containing five fuzzy rules,
- Defuzzyfication using the 'centroïd' method.

The establishment of the fuzzy rules is based on the error (*e*) sign, variation and knowing that (*e*) is increasing if its derivative (*de*) is positive, constant if (*de*) is equal to zero, decreasing if (*de*) is negative, positive if ($i_{ref} > i_f$), zero if ($i_{ref} = i_f$), and negative if ($i_{ref} < i_f$), fuzzy rules are summarized as following:

1. If (*e*) is zero (Z), then (*cde*) is zero (Z).
2. If (*e*) is positive (P), then *(cde*) is big positive (BP).
3. If (*e*) is negative (N), then (*cde*) is big negative (BN).
4. If (e) is zero (Z) and (de) is positive (P), then (*cde*) is negative (N).
5. If (e) is zero (Z) and (de) is negative (N), then (*cde*) is positive (P).

- DC capacitor voltage control

Among the various available powers filter controllers IP, RST, hysteresis, adaptive control and fuzzy logic controller.

In this application, the fuzzy control algorithm is implemented to control the DC side capacitor voltage based on DC voltage error $e(t)$ processing and its variation $\Delta e(t)$ in order to improve the dynamic performance of APF and reduce the total harmonic source current distortion.

The determination of the membership functions depends on the designer experiences and expert knowledge. It is not easy to choose a particular shape that is better than others.

A triangular membership function has the advantages of simplicity, easy implementation, and suitable for this application.

In the design of a fuzzy control system, the formulation of its rule set plays a key role in improving the system performance. The rule table contains 49 rules as shown in Table 1, where (LP, MP, SP, ZE, LN, MN, And SN) are linguistic codes (LP: large positive; MP: medium positive; SP: small positive; ZE: zero; LN: large negative; MN: medium negative; SN: small negative).

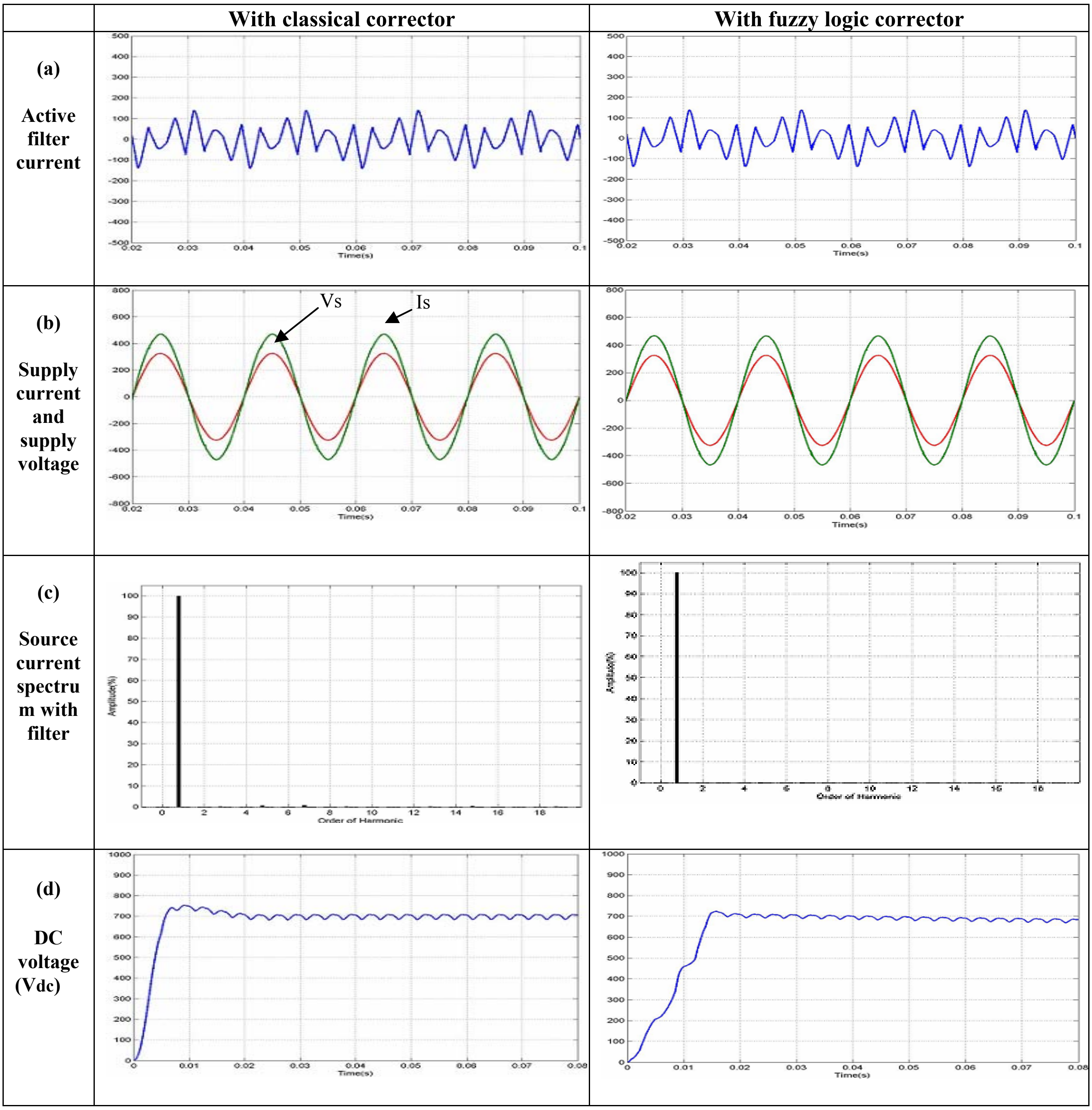
Table.1. Fuzzy control rule table

e / Δe	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

5 - Simulation

The active power filter consists of a voltage-source inverter with a DC side capacitor (C_{dc}) and six IGBT semiconductor switches. The inverter is connected to the power system through filter inductor L_f.

Computer simulation of this system has been carried out using Matlab/Simulink software. Simulation is performed for two cases: shunt active power filter with the classic proportional controller and fuzzy logic controller.



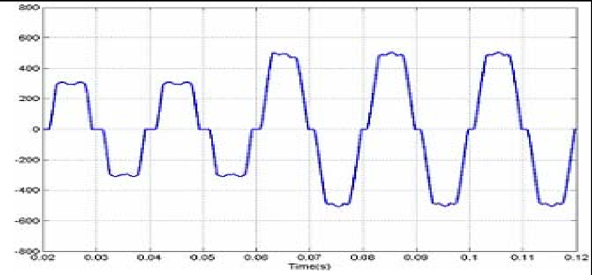
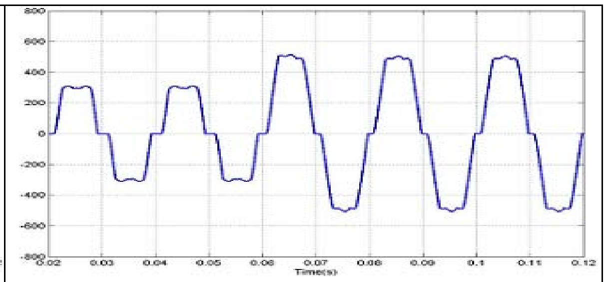
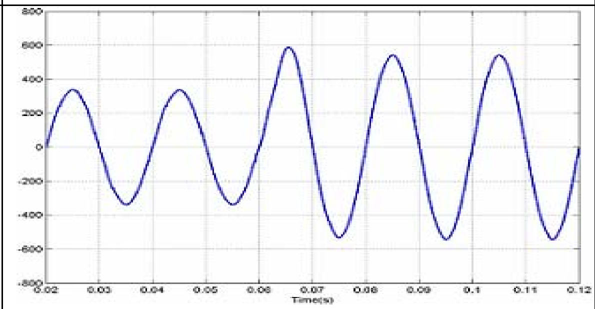
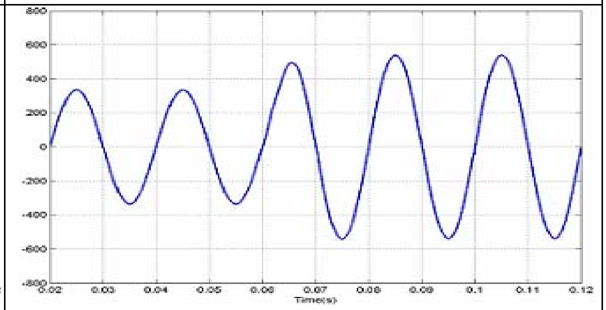
(e) **Load current**		
(f) **Supply current**		
THD%	**1.32%**	**0.98%**

Fig.6. Results of comparison of fuzzy logic controller and P controller techniques

6 - Results and discussions

Shunt active filter performances are related to current references quality, *p-q* theory is used for harmonic currents identification and calculation. This method is very important.

The line current without active filter is given in Fig. 6.a. The line current and voltage for continuous mode using P and Fuzzy controller are given in Fig. 6.b, resulting in unity power factor.

From Fig.6, PI and Fuzzy controllers give good regulation of the DC voltage,

The supply current THD is equal to 1.32**%**, using P controller, whereas for fuzzy controller the supply current THD is equal to 0.98%.

7 - Conclusion

In this paper a fuzzy logic control of shunt active power filter based on *p-q* theory to identify reference currents and PWM to generate switching signals have shown high AF performances in reducing harmonics, and power factor correction.

The obtained results show that DC capacitor voltage and the harmonic currents control are very important. Application of fuzzy logic in the control loops makes easy the choice of decoupling inductance values and the storage capacity.

With these types of control, the active filter can be adapted easily to other more severe constraints, such as unbalanced conditions.

The shunt active filter for the three-phase circuit is simulated and the THD measured verifies the reduction of harmonics to a very low level when the fuzzy logic control is employed.

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