A FUZZY ADAPTIVE HYSTERESIS BAND CURRENT CONTROL FOR SINGLE PHASE SHUNT ACTIVE POWER FILTERS

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REZUMAT. În ultimii ani, filtrarea activă a devenit o tehnologie importantă în compensarea armonicilor şi puterii reactive în sistemele electrice monofazate. Totuşi, performanțele filtrelor active depind de metoda de extragere a curentului de referință şi tehnica PWM utilizată. În această lucrare se propune un nou regulator cu histerezis adaptiv controlat cu logică Fuzzy. În urma simulării se observă că frecvența de comutație este menținută constantă, iar distorsiunea totală şi puterea reactivă au valori mult mai mici decât în cazul regulatoarelor clasice cu histerezis.

Cuvinte cheie: filtre active de putere, logica fuzzy, armonici, reglator cu histerezis.

ABSTRACT. Over the recent years, active filtering has become a mature technology for harmonic mitigation and reactive power compensation in single phase systems. However, the performance of the active filter depends on the reference current extraction methods and the PWM technique used. In this paper, a new fuzzy adaptive hysteresis band controller is proposed for active power filters. The results of the simulation study are found quite satisfactory in order to keep the switching frequency constant, eliminate current harmonics and reactive power in single phase electrical systems.

Keywords: active power filters, fuzzy logic, harmonics, hysteresis band.

1. INTRODUCTION

With the increasing number of power electronics based equipment come the real problem of harmonic distortion. The harmonic distortion results in deterioration of current and voltage waveforms, power losses, aging of materials, excessive heating in rotating machines, significant interference and equipment damage risk.

In order to avoid these undesirable effects, conventionally passive LC filters have been used, but they are ineffective due to large size, resonance, fixed compensation characteristics and inability to adapt to network variation.

The shunt active power filters (APF) are being used for over 20 years to mitigate voltage and current harmonics and to compensate reactive power, without the drawbacks of the passive LC filters.

The performance of active power filters depends on the harmonic detection method, current control method and the dynamic characteristics of the power converter circuit. Up to date, there are various current control methods and PWM techniques. The hysteresis band current control is very popular due to its simplicity of implementation, fast transient response, suitable stability and high accuracy. However, a conventional hysteresis band current control with fixed band has the disadvantages of variable switching frequency, consequently increasing switching losses, audible noise, sub-harmonics and difficulties to design the input filter.

Moreover, in order to keep a high efficiency and safety in the APF operation, the switching frequency and the DC source voltage, which are highly relevant to the current control method used, must be as low as possible. To overcome these problems, adaptive hysteresis band current control had been proposed in [1-4].

This paper presents a new technique, with the hysteresis band implemented with Fuzzy logic.

Computer simulations using Matlab Simulink and Fuzzy Logic toolboxes had been carried out to demonstrate the effectiveness of the proposed fuzzy logic adaptive hysteresis band current control.

2. ANALYTICAL MODEL FOR RESIDUAL STRESSES CONSIDERATION

Figure 1 presents the shunt active power filter topology, connected in parallel with the source and various loads. Typically, the shunt APF is a current controlled voltage source inverter which cancels current harmonics and exchanges the necessary reactive power required by the nonlinear load, by injecting the compensating current in the point of common coupling (PCC).

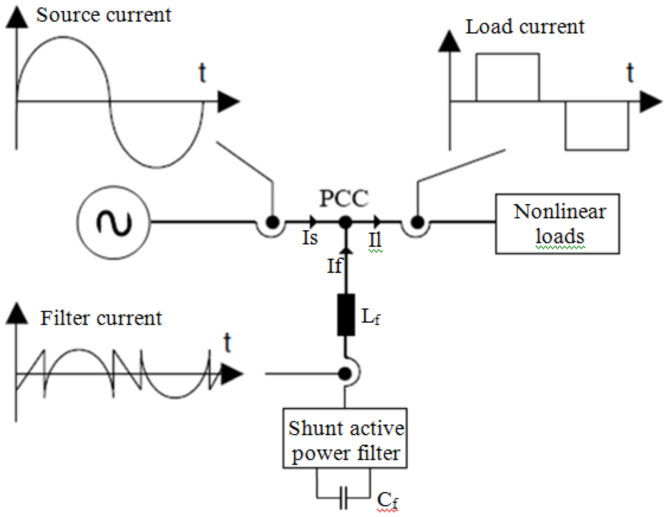

Fig. 1. Shunt APF principle.

According to (1), the APF should produce a current as close as possible to the reference one, which it is usually obtained by subtracting the fundamental component of the load current from the load current. The compensating current is equal but opposite to the harmonic components of the load current.

$$i_f = i_{load} - i_1 \tag{1}$$

In this paper, the current reference extraction is based on the instantaneous non-active power theory presented by Fryze [5].The current is divided into two parts. The first part, i_a, is the active current in phase with the voltage and with amplitude I_a. The second part, i_r, is the residual current. The two currents can be defined as in (2) and (3):

$$i_a(t) = \frac{P(t)}{U^2(t)} u(t) \tag{2}$$

$$i_r(t) = i(t) - i_a(t) \tag{3}$$

The reason of this division is that if i_r is compensated using the shunt APF, the source will see a pure resistive load in the PCC, the power factor will be equal to unity, and the source current harmonics free.

Thereby, from (2) and (3) can be obtained the APF reference current, i_f^*, (4):

$$i_f^*(t) = i_{load}(t) - \frac{\frac{1}{T}\int_{t-T}^{t} u(\tau) i_{load}(\tau) d\tau}{\frac{1}{T}\int_{t-T}^{t} u^2(\tau) d\tau} u(t) \tag{4}$$

where: u(t) represents the PCC voltage and T represents the time of interest, which for an ideal power system, with sinusoidal voltages and currents is 1/50 or 1/60.

3. PROPOSED CONTROL SCHEME

The conventional hysteresis band current control technique has proven to be most suitable for controlling APF line current. The hysteresis band (HB) current controller decides the switching logic pattern of APF, according to:

If $i_f < (i_f^* - HB)$ upper switch is OFF, lower switch is ON.

If $i_f > (i_f^* + HB)$ upper switch is ON, lower switch is OFF.

The switching frequency of this hysteresis band current control depends on how fast the current changes from the upper limit to the lower limit of the hysteresis band or vice versa. By increasing the switching frequency, one can get a better compensating current waveform at the cost of increased switching losses, audible noise, sub-harmonics and difficulties to design the input filter.

In order to overcome these drawbacks, various adaptive hysteresis band current controls were proposed [1-4]. This paper proposes a fuzzy adaptive hysteresis band current control where the hysteresis band is determined by the fuzzy logic controller.

The design of the adaptive hysteresis band current control depends only on two main parameters. One of them is the instantaneous current at a certain sample period (n, n-1), while the other is the value of the current change during this period. This way, the control algorithm uses the previous switching cycles to forward estimate the future compensating current [6].

The variable hysteresis band for each sampling instant is presented in figure 2, and is as follows:

$$H(n) = k_1 i_f(n) + k_2 \Delta i_f(n) \tag{5}$$

$$\Delta i_f(n) = i_f(n) - i_f(n-1) \tag{6}$$

where: H(n) represents the hysteresis band at the nth sampling instant, $i_f(n)$ represents the APF current at nth sampling instant, $\Delta i_f(n)$ is the current change at the nth instant, and $i_f(n-1)$ is the current at the (n-1)th sampling instant. Variable k_1 and k_2 are calculated by the fuzzy logic controller.

From to (5) and (6) it can be seen that at each sampling period the band is updated according to the value of the actual filter current and current change. Based on this new fuzzy HB calculation, the current of the APF follows the reference current better, resulting in less harmonic distortion in the ac mains, as we will indicate in the simulation results.

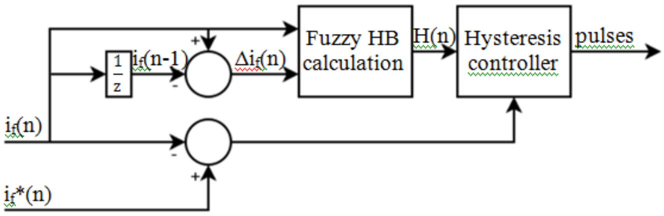

Fig. 2. Proposed fuzzy adaptive hysteresis band current control.

The variable HB made to control the switching frequency constant is the output of the fuzzy controller. The inputs of the fuzzy controller are the filter current $i_f(n)$ at the nth sample and the current change $\Delta i_f(n)$ at the n^{th} instant. Therefore, a rule base is needed to satisfy (5). Figure 3 and 4 shows the normalized triangular membership functions of the inputs and output variables, where NL (negative large), NS (negative small), Z (zero), PS (positive small), PL (positive large), VS (very small), S (small), M (medium), L (large), VL (very large) are the chosen linguistic codes. As both inputs, $i_f(n)$ and $\Delta i_f(n)$, have five membership functions, the number of possible combination is 25, and the fuzzy rule base formulated for the APF control is shown in table I.

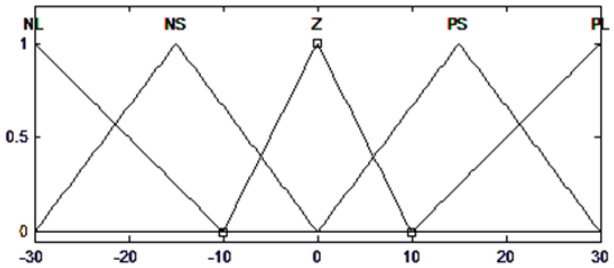

Fig. 3. Membership functions for input variables $i_f(n)$ and $\Delta i_f(n)$.

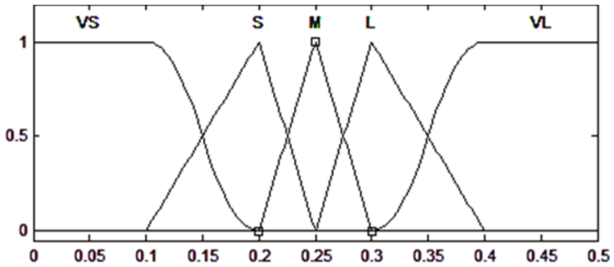

Fig. 4. Membership functions for output variable HB(n).

Table 1

Fuzzy control rule table

Δi_f \ i_f	NL	NS	Z	PS	PL
NL	VS	S	S	M	M
NS	S	S	S	M	M
Z	L	L	VL	L	L
PS	M	M	S	S	S
PL	M	M	S	S	VS

4. SIMULATION RESULTS

This section presents the simulation results carried out to demonstrate the effectiveness of the proposed fuzzy controlled hysteresis band for the APF to reduce the harmonics and reactive power.

The test consists system is a single phase voltage source and two uncontrolled rectifiers, first a permanently connected RC load and then a RL load which connects at half simulation time. The filter is connected to the system through the inductor L_f.

The values of circuit elements used in the simulation are: V_s=220V, f_s=50Hz, R_s=0.01Ω, L_s=0.1mH, L_f=2mH, C_f=2000μF, V_{DC}=500V.

First, we examine the source current waveform in the absence of the APF, for both load configurations, as shown in figure 5. The total harmonic distortion (THD) is 92.06% for the RC load and 68.84 for both loads, with very high 3rd, 5th and 7th harmonics. The reactive power is high, as shown in figure 6.

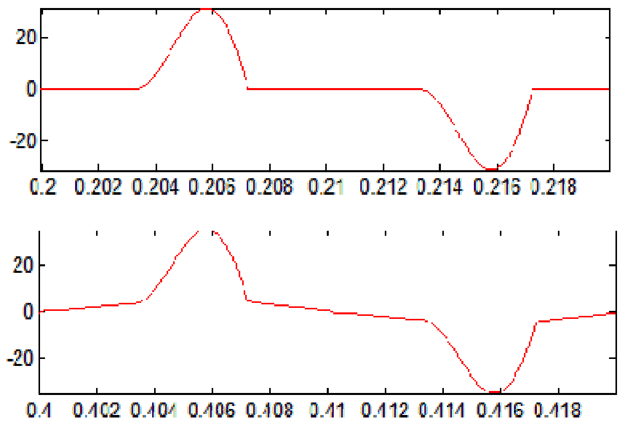

Fig. 5. Source current without active power filter – top with RC load, bottom with RC and RL loads.

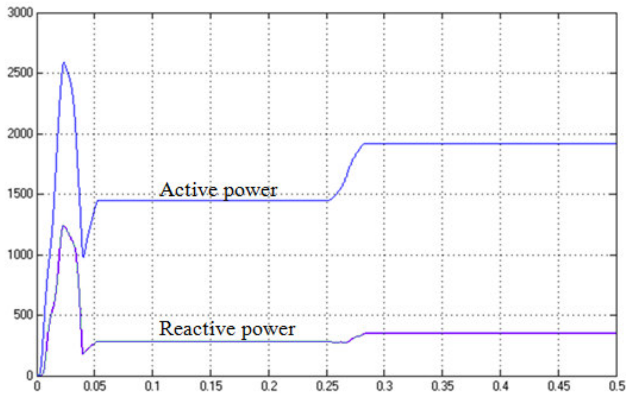

Fig. 6. Active and reactive power without filtering.

Next, the active power filter is connected, but with fixed hysteresis band (HB=0.5A) current control. Figure 7 shows the filtered source current for both load configurations, with the THD decreased to 4.16%, respectively to 2.99%. The reactive power is shown in figure 8, and it drops down close to 0.

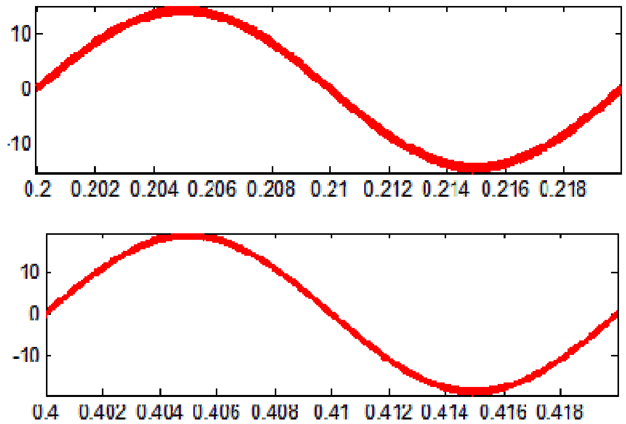

Fig. 7. Source current with active power filter with fixed hysteresis band – top with RC load, bottom with RC and RL loads.

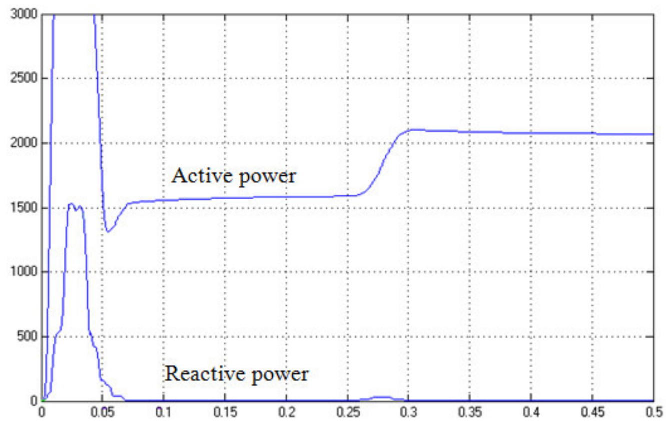

Fig. 8. Active and reactive power with APF with constant HB.

To further improve the performances of the system, the last test was made with the proposed Fuzzy adaptive hysteresis band current controller. Figure 9 shows the source current, with a THD of only 2.22%, respectively 1.64%. It can be seen that the source current is practically sinusoidal and smoothed comparing to figure 7, thus the performance of the active filter with the proposed control algorithm is found to be excellent.

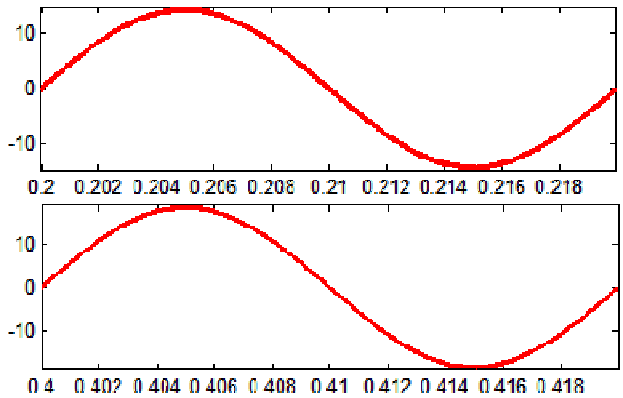

Fig. 9. Source current with proposed Fuzzy adaptive hysteresis band active power filter – top with RC load, bottom with RC and RL loads.

Figure 10 shows a comparison between the harmonics spectrum of the source current with the fixed hysteresis band APF and proposed fuzzy adaptive hysteresis band APF.

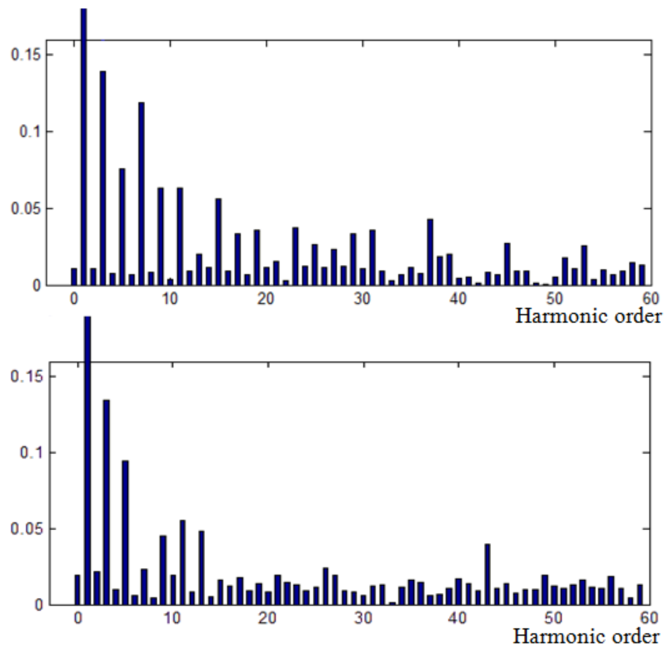

Fig. 10. Harmonic spectrum of the source current – top with fixed hysteresis band APF, bottom with proposed fuzzy adaptive hysteresis band APF, in the case of both loads connected.

5. CONCLUSIONS

Fixed hysteresis band current control techniques is proven to be most suitable for controlling active power filters line current, at the cost of variable switching frequency. In order to overcome the drawbacks of variable switching frequency, various adaptive hysteresis band current control were proposed.

This paper presents a new fuzzy adaptive hysteresis band current control for shunt active power filter. The simulations of the proposed system were carried in Matlab Simulink environment.

The simulation results verify the proposed method, with a quick response time, switching frequency nearly constant and good quality of filtering.

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