

Fig. 1 Proposed shunt active filter topology.

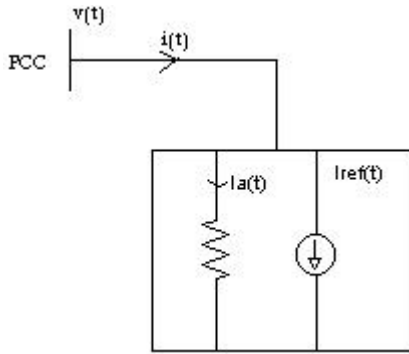


Fig. 2 Nonlinear load connected to the grid. Current components.

This part of the real load absorbs the active current which is ideal current and represents only a part of total current flowing through the metering section. This current has the same waveform of voltage and is always in phase with it.

The parameter R of the ideal load has been calculated by this equation:

$$R = \frac{V_1}{I_{R1}} = \frac{V_1}{I_1 \cos \phi_1} \quad (1)$$

Where V_1 and I_1 are the fundamental value of the voltage and current at the PCC and ϕ_1 is the displacement angle between them. I_{R1} represents the part of the fundamental current which is in phase with the fundamental voltage.

The ideal active current is:

$$i_A(t) = \frac{v(t)}{R} \quad (2)$$

And the reference current is defined as:

$$i_{REF}(t) = i(t) - i_A(t) \quad (3)$$

Where $v(t)$ and $i(t)$ represent voltage and current waveform at the PCC before compensation.

Let's consider a traditional current reference:

$$i_{REF_{trad}}(t) = i(t) - I_1 \cos \phi_1 \sin(\omega t + \theta_1) \quad (4)$$

Where θ_1 represents the phase angle of the fundamental voltage.

It is possible to show that the new current reference has a lower harmonic content. In fact considering the Fourier series of the voltage $v(t)$, it can be shown:

$$i_{REF}(t) = i(t) - \frac{v(t)}{R} = \quad (5)$$

$$i(t) - \sum_{k=1}^{\infty} \frac{V_k}{R} \sin(k\omega t + \theta_K) =$$

$$i(t) - \sum_{k=1}^{\infty} I_{Rk} \sin(k\omega t + \theta_K) =$$

$$i(t) - \sum_{k=1}^{\infty} I_k \cos \phi_k \sin(k\omega t + \theta_K) =$$

$$i(t) - I_1 \cos \phi_1 \sin(\omega t + \theta_1) - \sum_{k=2}^{\infty} I_k \cos \phi_k \sin(k\omega t + \theta_k)$$

$$= i_{REF_{trad}}(t) - \sum_{k=2}^{\infty} I_k \cos \phi_k \sin(k\omega t + \theta_k)$$

Since the principle of superposition can be applied.

3. REFERENCE CURRENT CALCULATION

To design the control system and harmonic reference current generator, the dq transformation method is used to achieve harmonic cancellation. The following three element matrix vectors are expressed by using dq transformation matrix $T(\theta)$ and inverse dq transformation matrix $T^{-1}(\theta)$

$$f_{dq} = T(\theta) f_{abc} \quad f_{abc} = T^{-1}(\theta) f_{dq}, \quad (6)$$

Where the f variable denotes the current or voltage quantities and the transformation matrix is given as,

$$T = \frac{2}{3} \begin{bmatrix} \sin(\theta) & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (7)$$

Fig.3 shows a technique taking dq transformation from stationary to synchronous reference frame and having low pass filters to obtain average values. A low pass filter can eliminate all harmonic currents except dc component. This component used for fundamental current calculation.

The three phase nonlinear load currents can be expressed as follows, The detail equations for phase-a are derived.

$$i_a = i_a^1 + i_a^h \quad (8)$$

$$= \sqrt{2} I_a^1 \sin(\omega t - \beta_a^1) + \sqrt{2} \sum_{h \neq 1} I_a^h \sin(h\omega t - \beta_a^h)$$

Where i_a^1 is a fundamental component, i_a^h ($h=1,2,3,\dots$) is a harmonic component such as 3rd, 5th, 7th, etc on the stationary abc frame, and β_a^1, β_a^h are the displacement power factor angles for fundamental and harmonics, respectively. Taking the dq transformation for the above currents,

$$i_{dq}^e = [i_d^e \quad i_q^e \quad i_n^e]^T = T(\theta) [i_a \quad i_b \quad i_c]^T = T(\theta) i_{abc} \quad (9)$$

D and Q components on the synchronous reference frame are separated as,

$$i_{dq}^e = \begin{bmatrix} i_d^e \\ i_q^e \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} i_{d,a}^e + i_{d,b}^e + i_{d,c}^e \\ i_{q,a}^e + i_{q,b}^e + i_{q,c}^e \end{bmatrix} \quad (10)$$

Again each component is divided into fundamental and harmonic components as,

$$i_{d,j}^e = i_{d,j}^{e1} + i_{d,j}^{eh} \quad (11)$$

$$i_{q,j}^e = i_{q,j}^{e1} + i_{q,j}^{eh}$$

Where $i_{dq,j}^{e1}$ ($j=a, b, c$) comes from the fundamental component i_j^1 and $i_{dq,j}^{eh}$ from the harmonics i_j^h . In [10] S. Kim shows the reference current calculated by:

$$i_d^{e1} = \frac{\sqrt{2}}{3} (I_{d,a}^{dc} + I_{d,b}^{dc} + I_{d,c}^{dc}) - \frac{\sqrt{2}}{3} \times$$

$$\left(\sqrt{I_{d,a}^{dc2} + I_{q,a}^{dc2}} \tan(2\omega t - \beta_a^1) + \right.$$

$$\left. \sqrt{I_{d,b}^{dc2} + I_{q,b}^{dc2}} \tan(2\omega t + \frac{2\pi}{3} - \beta_b^1) + \right.$$

$$\left. \sqrt{I_{d,c}^{dc2} + I_{q,c}^{dc2}} \tan(2\omega t - \frac{2\pi}{3} - \beta_c^1) \right)$$

$$i_q^{e1} = \frac{\sqrt{2}}{3} (I_{d,a}^{dc} + I_{d,b}^{dc} + I_{d,c}^{dc}) - \frac{\sqrt{2}}{3} \times$$

$$\left(\sqrt{I_{d,a}^{dc2} + I_{q,a}^{dc2}} \tan(2\omega t + \frac{\pi}{2} - \beta_a^1) + \right.$$

$$\left. \sqrt{I_{d,b}^{dc2} + I_{q,b}^{dc2}} \tan(2\omega t + \frac{7\pi}{6} - \beta_b^1) + \right.$$

$$\left. \sqrt{I_{d,c}^{dc2} + I_{q,c}^{dc2}} \tan(2\omega t - \frac{1\pi}{6} - \beta_c^1) \right)$$

Where I_{dq}^{dc} denote dc component of $i_{dq,j}^e$. The dc component can be obtained through a simple first order low pass filter. A displacement power factor angle obtained as:

$$\beta_j^i = \tan^{-1} \left(-\frac{I_{q,j}^{dc}}{I_{d,j}^{dc}} \right) \quad (14)$$

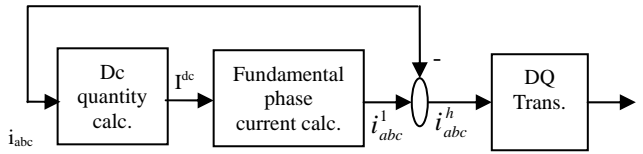


Fig. 3 Block diagram of estimate reference current.

4. FUZZY LOGIC BASED CONTROL TECHNIQUE

Fuzzy logic has rapidly become one of the most successful of today's technologies. It offers a methodology for handling of qualitative, inexact and imprecise information in a systematic and rigorous way. Fuzzy logic based controllers can be employed with good results if the system to be controlled has unknown, ill-defined or non linear dynamics. Unlike in usual control methods, the design and tuning of a fuzzy based controller doesn't need establishing any mathematical model of the controlled plant. On the contrary, what we need to design fuzzy logic algorithms are understanding the mechanics behind a behavior of the controlled system, end identifying the system dynamics in terms of measure of input/output changes are essential parts of the fuzzy algorithms design [9].

Fuzzy logic may serve as a very effective tool to handle some of PWM inverters and electrical drivers because they have discrete time varying and/or nonlinear dynamic mathematical representation. The internal structure of the fuzzy controller is shown in Fig. 4. Here, the input variables are the current error and slope of the reference current. To convert these numerical input variables into linguistic variables, the

following four fuzzy levels or sets are chosen as: NL (negative large), NS (negative small), PS (positive small), PL (positive large).

The fuzzy controller is characterized as follows:

- 1- Four fuzzy sets for each input and five fuzzy sets for output.
- 2- Bell shape membership functions
- 3- Fuzzification using Gaussian curve membership function
- 4- Implication using Mamdani's 'min' operator.
- 5- Defuzzification using the 'centroid' method.

The output variable is the duty cycle that defines the sampling period portion assigned to the first switch driven in respect of the full sampling period. The fuzzy labels chosen to define the duty cycle are very small (VS), small (S), medium (M), big (B) and very big (VB).

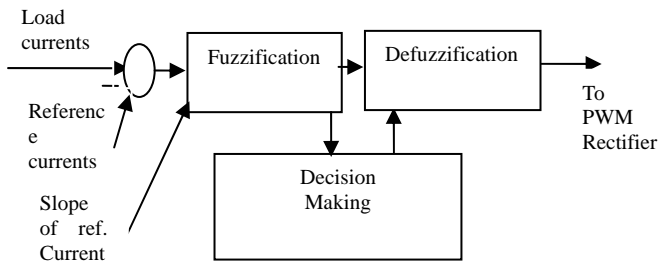


Fig. 4 Internal structure of the fuzzy controller.

Fig. 5 shows the normalized bell membership functions used in fuzzification.

The set of fuzzy control rules is shown in Table (1). Each rule is described as

$R_i : \text{If } x \in \text{current error AND } y \in \text{slope of current reference}$

Then $z \in \text{duty cycle}$

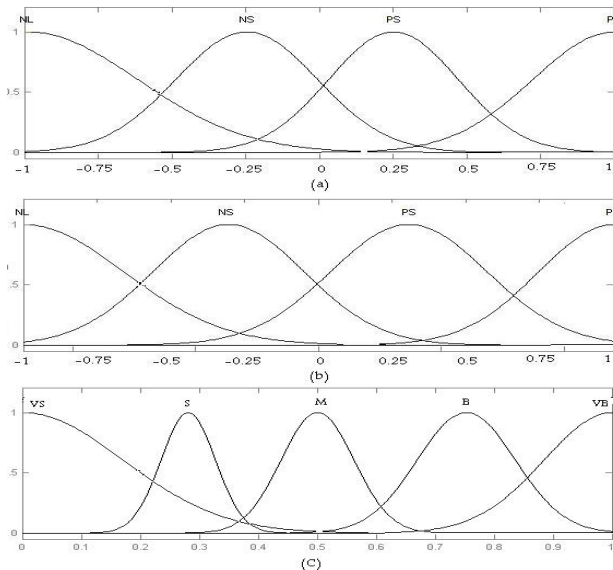


Fig. 5 Normalize membership function.

a: current error b: slope of reference current c: Duty cycle.

Table (1) Fuzzy rules for duty cycle.

Duty cycle		Current error			
		NL	NS	PS	PL
Reference Current slope	NL	VB	V	VS	VB
	NS	VB	M	S	VB
	PS	VB	S	M	VB
	PL	VB	VS	B	VB

5. SIMULATION RESULTS

Fig. 6 shows the system configuration of the three phase PWM rectifier with the function of active power filter.

The parameters of the system analyzed were:

main : $V_{s_{rms}} = 220V$, $R_s = 0.1\Omega$, $L_s = 0.5mH$,

Passive filter : $R_c = 0.1\Omega$, $L_c = 0.66mH$

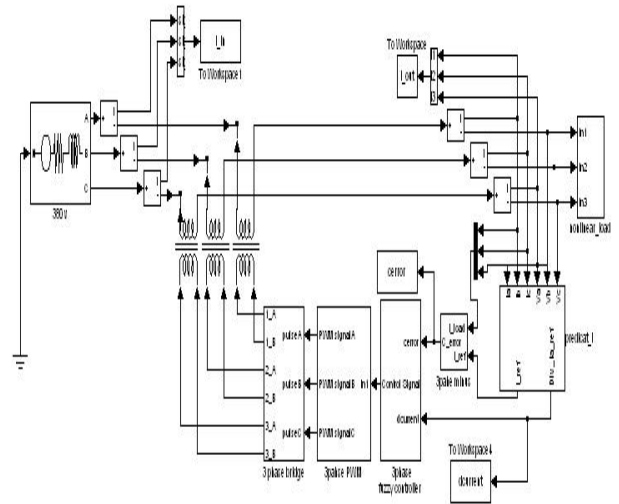


Fig. 6 System configuration of the three phase APF-PWM rectifier.

Figs (7), (8) Show the simulation results of the proposed shunt active power filter controlled by fuzzy logic.

Fig. (7) shows the response of the fuzzy controller: The main Voltage (V_{sa}), The load current (I_{la}) and source current (I_{sa}) and filter current (I_{fa}) are presented here. The filter is switched on at 20ms.

The harmonic contents for load current and source current are shown in Fig. (8).

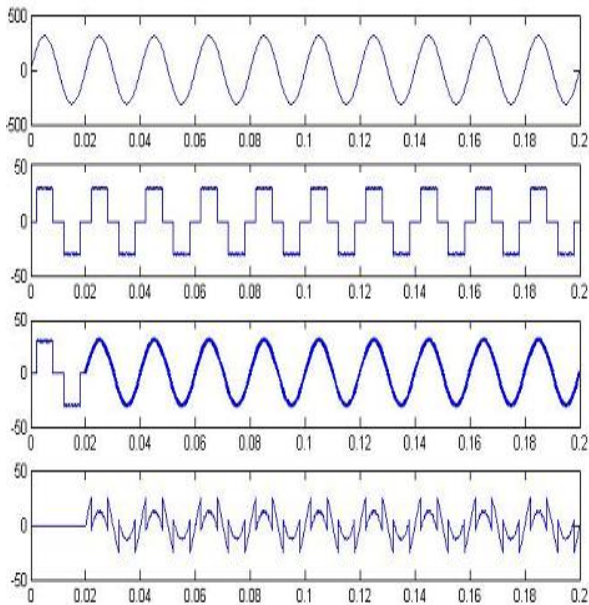


Fig. 7 Switch-on response of fuzzy logic controlled shunt active filter.

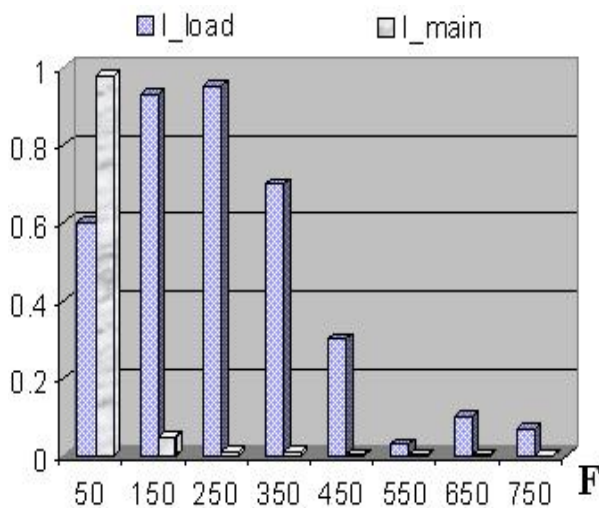


Fig. 8 Normalize Harmonic contents for load and source currents.

6. CONCLUSION

In this paper, three phase active power filters with fuzzy logic control are introduced. This novel control has a high accuracy, good speed and provides a faster response to fast load changes. The proposed control

method eliminates the need of calculating the harmonics and reactive current components. This technique only needs to sense the three phase load currents. It can be seen that performance of the filter don't affect by the supply distortion and source currents are nearly sinusoidal after compensation. The proposed system tested using computer simulations.

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