2. System Description

Active power filters have been under research and development for more than three decades and have found successful industrial applications with varying configurations, control strategies, and solid-state devices. However, this is still a technology under development, and many new contributions and new control topologies have been reported in the last few years. It is aimed at providing a broad perspective on the status of APF technology to researchers and application engineers dealing with power quality issues.

Shunt active filters are inverters driven to compensate for both fundamental reactive power and harmonic distortion. As shown in Figure 1, The block diagram of an active filter. The performance of the shunt active filter depends on the reference compensating current detection algorithm and the current control technique used to drive the gating pulses of the active power filter switches to generate compensating current that should be injected into the power system to mitigate the current harmonics and compensate the reactive power .

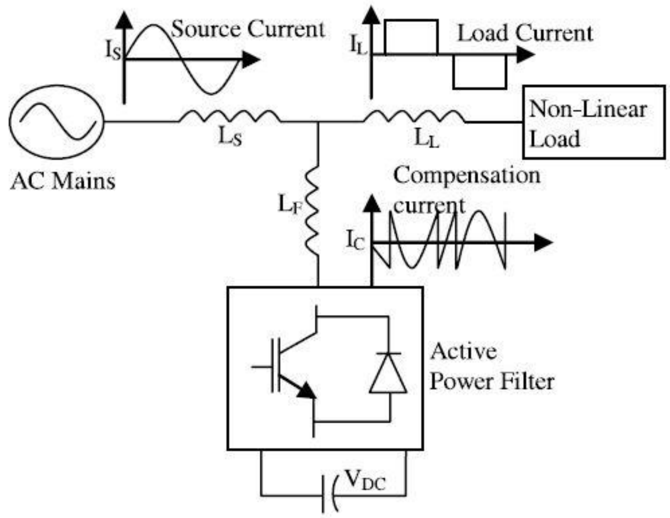


Figure 1. Basic configuration of a shunt active filter

3. Control Strategy

The proposed control strategy can be divided in three parts. The first part is the harmonic isolator (reference current generation). It consists in generating the harmonic current references using the STF. The identification method of harmonics used is the method of instantaneous power.

This theory based on instantaneous values in three-phase power systems with or without neutral wire, and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms called as Instantaneous Power Theory or Active-Reactive (p-q) theory which consists of an algebraic transformation (Clarke transformation) of the three-phase voltages in the a-b-c coordinates to the α-β coordinates, followed by the calculation of the p-q theory instantaneous power components by eliminating the DC component of the instantaneous active power (corresponding to the fundamental component of load current) using a selective Filter STF, so the harmonic components can be identified.

3.1 Principle of Self-tuning filter

To date, the STF has only been applied to three-phase APF systems in an effort to combat the effects of non-ideal grid voltages. In the following, we first introduce the STF, then show how it can be adapted to single-phase APF control systems.

Hong-sock Song had presented in his PhD work the recovery of the equivalent transfer function of the integration in the synchronous references frame SRF by [4]:

$$v_{xy}(t) = e^{jwt} \int e^{-jwt}\, u_{xy}(t)dt \qquad (1)$$

Where v_{xy} and u_{xy} are the instantaneous signals, respectively before and after integration in the synchronous reference frame. Equation (1) can be expressed by the following transfer function after Laplace transformation.

$$H(s) = \frac{v_{xy}(s)}{u_{xy}(s)} = k\frac{s+j\omega}{s^2+j\omega^2} \quad (2)$$

A constant k is introduced in the transfer function H(s) in this paper to obtain a STF with a cut-off frequency w_c, so Eq. (2) becomes

$$H(s) = \frac{v_{xy}(s)}{u_{xy}(s)} = \frac{(s+k)+j\omega_c}{(s+k)^2+\omega_c{}^2} \quad (3)$$

By replacing the input signals $u_{xy}(s)$by $x_{\alpha\beta}(s)$ and the output signals $v_{xy}(s)$ by $\hat{x}_{\alpha\beta}(s)$, Eqs. (4) and (5) can be obtained.

$$\hat{x}_\alpha(s) = \frac{k}{s}[x_\alpha(s) - \hat{x}_\alpha(s)] - \frac{\omega_c}{s}\hat{x}_\beta(s) \quad (4)$$

$$\hat{x}_\beta(s) = \frac{k}{s}[x_\beta(s) - \hat{x}_\beta(s)] - \frac{\omega_c}{s}\hat{x}_\alpha(s) \quad (5)$$

The block diagram of the STF tuned at the pulsation w_c is depicted in Fig. 2 while the frequency response of the STF versus different values of the parameter k

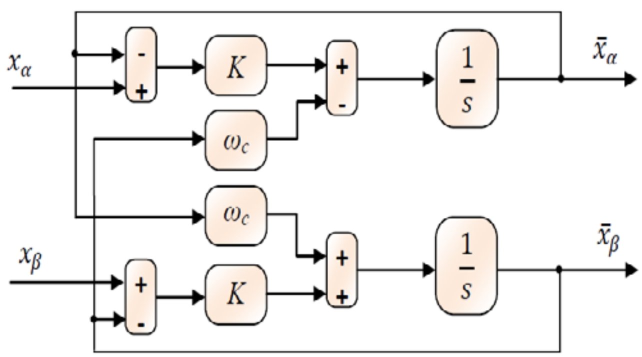


Figure 2. Self Tuning Filter tuned at the pulsation ω_c

3.2 Harmonic isolator

The load currents, i_{La}, $i_{Lb}$and i_{Lc} of the three-phase three wire system are transformed into the α-β axis (Fig. 3) as

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (6)$$

As is known, the currents in the α-β axis can be respectively decomposed into DC and AC components by

$$i_\alpha = \bar{i}_\alpha + \tilde{i}_\alpha \quad (7)$$
$$i_\beta = \bar{i}_\beta + \tilde{i}_\beta \quad (8)$$

Then, the STF extracts the fundamental components at the pulsation ω_f directly from the currents in the α-β axis.
The α-β harmonic components of the load currents are computed by subtracting the STF input signals from the corresponding outputs. The resulting signals are the AC components, $\tilde{i}_\alpha$ and $\tilde{i}_\beta$
, which correspond to the harmonic
components of the load currents i_{La}, $i_{Lb}$and i_{Lc} in the stationary reference frame.
For the source voltage, the three voltages v_{sa}, v_{sb} and $v_{sc}$are transformed to the α-β reference frame as follows:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (9)$$

Then, we applied the STF to these α-β voltage components. This filter allows suppressing the harmonic components of the distorted mains voltages and consequently leads improves the harmonic isolator performances.

After the computation of the fundamental component $\tilde{v}_{\alpha\beta}$and the computation of the harmonic currents $\tilde{i}_{\alpha\beta 0}$, we calculate the alternative instantaneous real power $\tilde{p}(t)$ and the instantaneous imaginary power $\tilde{p}(t)$ as follows:

$$\tilde{p}(t) = \tilde{i}_\alpha \tilde{v}_\alpha + \tilde{i}_\beta \tilde{v}_\beta \qquad (10)$$

$$q(t) = \tilde{i}_\beta \tilde{v}_\alpha - i_\alpha \tilde{v}_\beta \qquad (11)$$

And so we identify harmonics and reactive power at the same time. The references of current in the α-β reference frame are calculated by:

$$i^*_\alpha = \frac{\bar{v}_\alpha}{\bar{v}_\alpha^2 + \bar{v}_\beta^2}\ (\tilde{p} + p_c) - \frac{\bar{v}_\beta}{\bar{v}_\alpha^2 + \bar{v}_\beta^2}\tilde{q} \qquad (12)$$

$$i^*_\beta = \frac{\bar{v}_\beta}{\bar{v}_\alpha^2 + \bar{v}_\beta^2}\ (\tilde{p} + p_c) - \frac{\bar{v}_\alpha}{\bar{v}_\alpha^2 + \bar{v}_\beta^2}\tilde{q} \qquad (13)$$

Where: p_{dc} is a small amount of active power absorbed from or realised to the DC capacitor so as to regulate the DC bus voltage. Then the filter reference current in the 1, 2, 3 coordinates are defined by:

$$\begin{bmatrix} i^*_{fa} \\ i^*_{fb} \\ i^*_{fc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix} \qquad (14)$$

Fig. 3 below describes the identification scheme

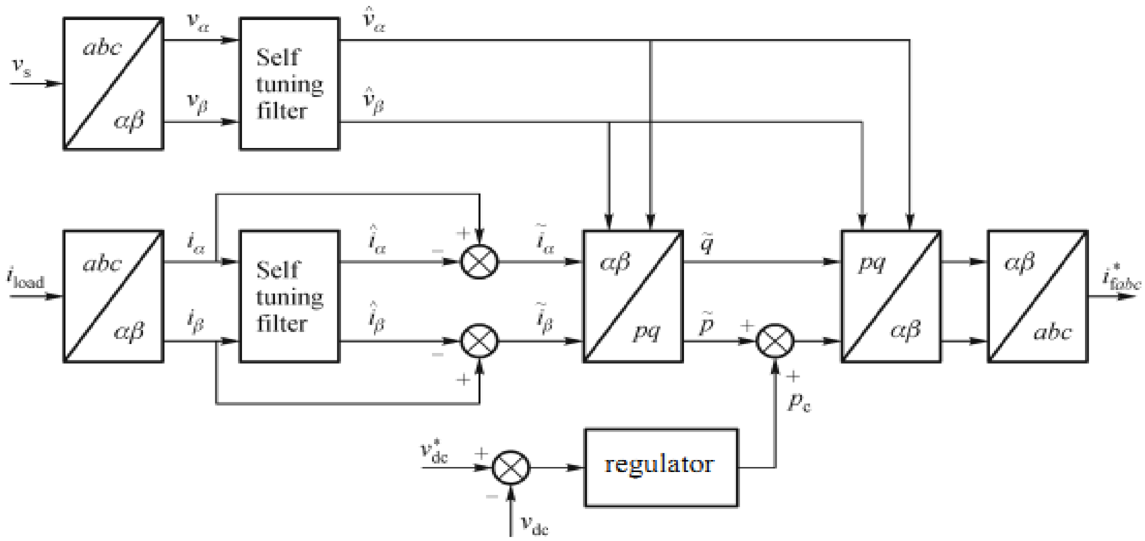


Figure 3.Block diagram of the harmonic isolator

3.3 DC-bus voltage control

The active filter regulates the dc capacitor voltage by itself without any external power supply. When the active filter is controlled to produce a fundamental voltage being in phase with the fundamental leading current of the passive filter, an active power formed by the leading current and the fundamental voltage is delivered to the dc capacitor. A proportional plus integral PI control is used for the control algorithm.

The PI controller consists of a proportional term and an integral term. Proportional value determines the reaction to the current error; the Integral determines the reaction based on the sum of recent errors. $K_p$and K_i are the proportional and the integral gains of the dc bus voltage PI controller.

Here the values of proportional and integral gain taken as $K_p = 150$=10, $K_i = 0.1$. PI controller has been widely used for DC bus voltage regulation in shunt active power filters. This operation has been performed by comparing the real DC bus voltage of the active power filter with a reference DC bus voltage.

4. Modelling and implementation fuzzy hysteresis band current control

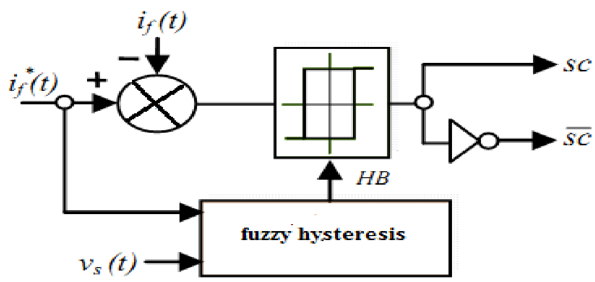
The hysteresis-band current control technique has been confirmed to be the most suitable for all the applications of current controlled VSIs in grid connected systems and active power filters. The hysteresis-band current control is characterised by unconditioned stability, very fast response and good accuracy. On the other hand, the basic hysteresis technique also exhibits several undesirable features, such as asymmetrical switching frequency that causes acoustic noise and difficulty in designing input filters.

The concept of fuzzy logic was introduced in the year 1965, since then fuzzy logic has become a powerful computation paradigm. Numerous fuzzy control applications have been observed in the literature.

An adaptive hysteresis band current control technique can be programmed as a function of the active filter and supply parameters to minimize the influence of current distortions on the modulated waveform. The hysteresis band value can be implemented with a fuzzy logic controller. In this case, the supply voltage wave, $v_s(t)$, and main current reference slope, $\frac{di_f}{dt}$ can be selected as input variables to the fuzzy controller, and the hysteresis band hysteresis band magnitude (HB) as an output variable .

Fig. 4 shows a block diagram of the adaptive hysteresis band current control

(a)



(b)

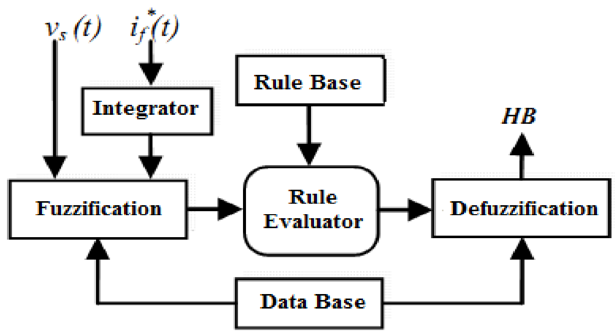


Figure 4. (a) Block diagram of fuzzy hysteresis-band current control , (b) Fuzzy logic controller.

The following step is to determine the linguistic values of each variable and fuzzy rule. The membership functions of the input and the output variables are shown in Fig. 5. Here, the triangular membership functions are chosen because the parametric functional description is the most economic one [10]. Each input and output variable is transformed into linguistic size, with seven fuzzy subsets which is sufficient and satisfactory: negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM) and positive big (PB).

The resulting rules are presented in Table 1.

$v_s(t)$ / $\frac{dif}{dt}$	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

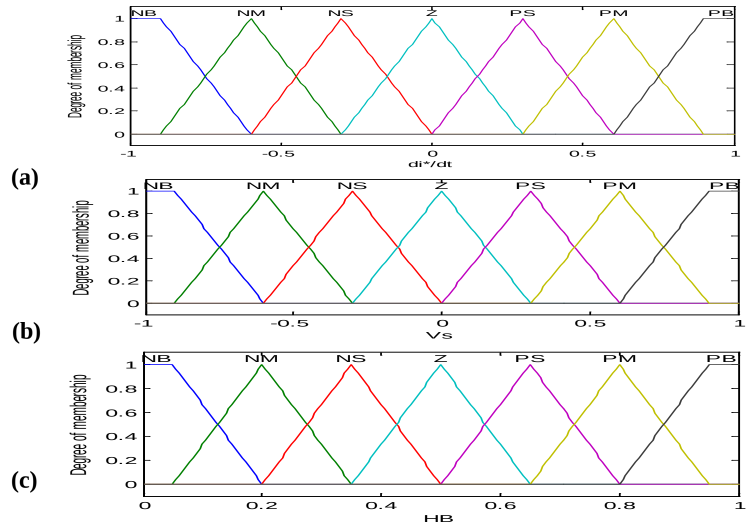


Figure.5. Membership functions for input variables and output variable (a) input e,(b) input de,(c) output h

Thus the variable bandwidth and the nearly constant switching frequency are controlled by the Fuzzy logic rules. And actual currents of APF are controlled to track the reference currents better and have fewer ripples.

5. Simulation and results

This section introduce the details of simulations that have been implemented using MATLAB/SIMULINK, to shows the performance of the proposed adaptive hysteresis band controller for SAPF are presented in comparison with results of both conventional hysteresis band controller and fuzzy hysteresis band controller for SAPF.

Initially, the system is simulated without the SAPF. Fig. 6 The THD has been estimated to 21.6 %.

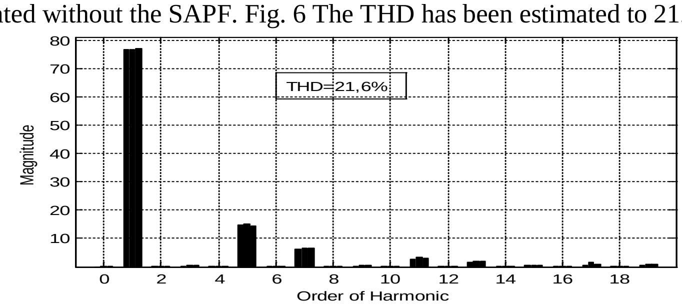


Figure 6. Supply current FFT without SAPF.

Fig. 7 shows the performance characteristics of the active power filter application using classical hysteresis band control with STF theory, illustrating the steady state and transient behavior of the system. As it can be seen, from this figure the source currents become sinusoidal and the source harmonic current is significantly reduced.

The THD is dropped from 21.6% to 2.5 % as shown in Fig. 8.the DC-bus voltage practically keeps its reference value (Fig. 9).

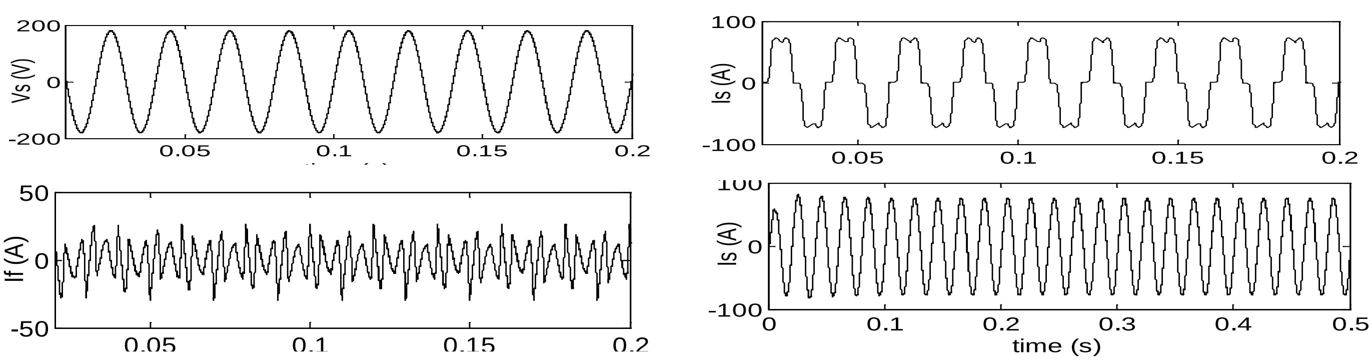


Figure7.Active power filter steady-state performance for harmonic current with STF theory using classical hysteresis band control

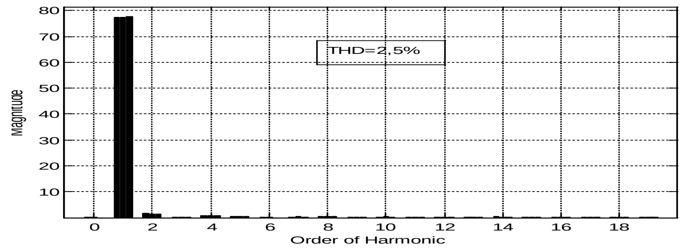


Figure 8. Supply current FFT (fixed hysteresis control)

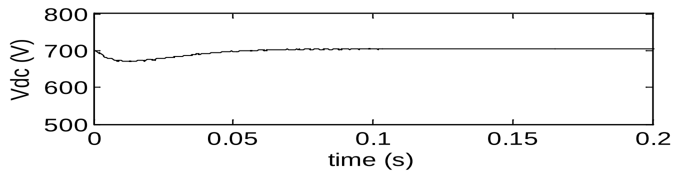


Figure 9. DC-bus voltage response

Fig.10. represents the performance characteristics of the active power filter application using fuzzy hysteresis band control with STF theory. The controllers are explicitly shown which has been given to the inverter for the optimal switching states.

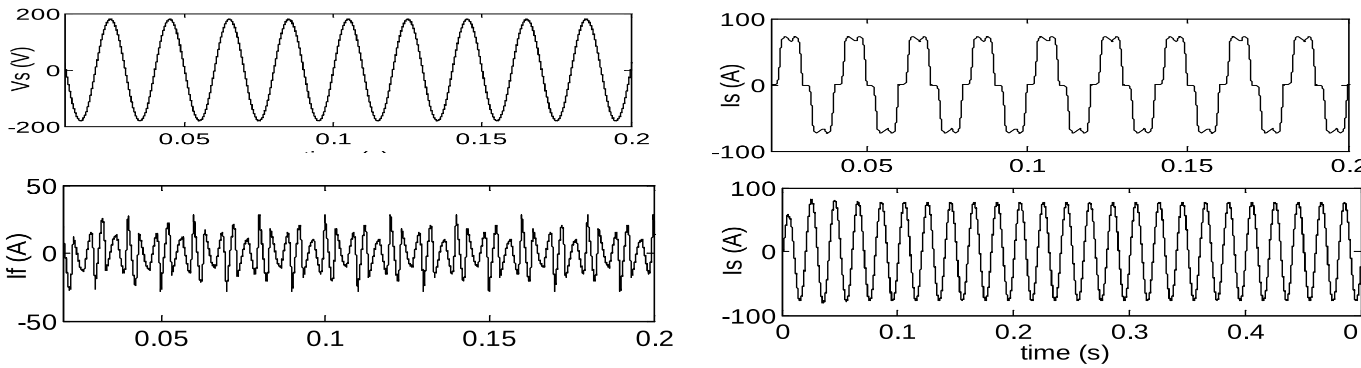


Figure 10.Active power filter steady-state performance for harmonic current with STF theory using fuzzy hysteresis band control

The supply current FFT for fuzzy hysteresis band current control is shown in Fig. 11

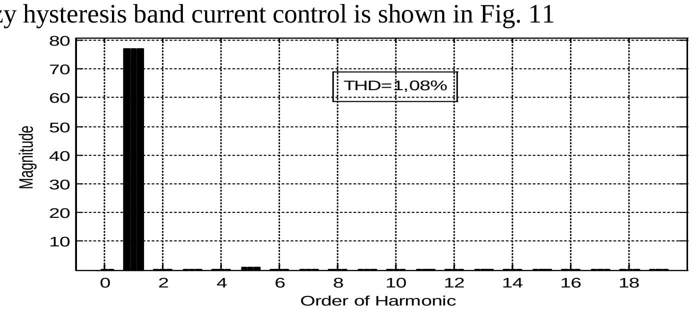


Figure11 Supply current FFT (fuzzy hysteresis control)

Total Harmonic Distortion (THD) parameter, are reduced after compensation from 21.6% to 1.08% . Therefore, there is a better reduction in harmonic distortion with this approach. By using the fuzzy logic controller in hysteresis control. It can be observed also in Figure11.This control algorithm presents high performances.

In the case of a fixed or fuzzy hysteresis band control. Current peaks are more important than those produced by adaptive or fuzzy band controls, and the switching frequency changes many times per cycle. As a result, the switching losses are increased, and current source contains excessive harmonics.

6. Conclusions

The work presented in this paper makes a significant contribution to the identification and control strategies in order to improve the SAPF performance. The novel approach which is based on intelligent techniques has been proposed. The performance of the proposed fuzzy hysteresis band was verified through simulation studies with Matlab and confronted with classical techniques. The complete SAPF structure has been implanted to compensate harmonics caused by nonlinear loads.
At this level, comparative studies between both the fuzzy hysteresis band and the conventional fixed band current control method used to extract the harmonic component of the load current to produce reference currents; (STF theory) have been accomplished.
The conventional fixed hysteresis band current control achieves fast response but generates excessive current ripples because the modulation frequency varies within one band. With the fuzzy hysteresis current control method, the band can be easily implemented with fuzzy logic to keep the modulation frequency nearly constant and to achieve good
quality filtering.

APPENDIX

Table 2. System rating details

Parameters	Value
Supply	220V, 50Hz, Rs = 0.35ohm, Ls =0.2mH
Load	RL = 4ohm, LL = 2.5mH
SAPF	L = 3mH, Cdc= 2000μF, Vdc =700 V

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