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A Novel Current Controller Technique for Three Phase Shunt Active Power Filter

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Abstract:
In this paper a novel control algorithm is implemented for three phase shunt active power filter based on fuzzy logic controller. Harmonics is the predominant power quality issues which have adverse effect on the power system. The most of power quality issues in power system is created by non linear loads. The shunt active power filter is extensively employed to eliminate harmonic current and reactive power compensation. The performance of shunt active power filter depends on the control strategy used for the shunt active filter. Hysteresis Current Controller is widely used due to its simplicity, fast and accurate response and ease in implementation but this leads to high switching losses and injects high frequency harmonic into the system due to its variable switching frequency. This paper provides the frame work for fuzzy based adaptive hysteresis current controller based SAPF which overcomes the problem of hysteresis current control scheme. The proposed control algorithm is found to be superior to meet IEEE 519 standard recommended on harmonics levels. The simulation results, obtained using Matlab/Simulink shows the effectiveness of proposed control algorithm of the three phase shunt active power filter.

***Keywords**: Harmonics, Voltage Source Inverter (VSI), Shunt Active Power Filter (SAPF), Harmonic Distortion, Hysteresis Current Control (HCC), Adaptive Hysteresis Current Control (AHCC), Fuzzy Logic Controller (FLC)*

1. Introduction

Now a days, Power quality issues are becoming increasingly important to electricity consumers at all levels of usage. But the quality of power has degraded due to sensitive power electronic equipment such as information technology equipment, power electronics such as variable speed drives, programmable logic controller, energy efficient lighting, switching power supplies and non-linear loads widely used in industrial, commercial and domestic applications leading to large amount of harmonic current into the power system. These nonlinear currents flow through the impedance of the electrical system which produce an additional voltage distortion. The presence of harmonics in the power system cause greater power loss in distribution, interference problem in communication system and sometimes causes failure of operation of electronic equipments which are more and more sensitive because it contains microelectronic controller operation of electronic equipments which are more and more sensitive because it contains microelectronic controller systems, which work with very low energy levels. It is noted that non-sinusoidal current results in many problem such as low power factor, low energy efficiency, electromagnetic interference (EMI), excessive neutral current in three phase wire line, overheating of devices like transformer, rotating electrical machines, distortion of line voltage etc.

Traditionally passive LC filters were used to compensate harmonic currents because of their low cost and simple operation. But it suffers from several demerits like fixed compensation, resonance problem, electromagnetic interference and bulkiness [1]. Due to these problem faced with the passive filters makes their applications limited and may not be able to meet future requirements of a particular Standard. Due to recent advances in the field of power electronics makes the use of active power filters (APF) as flexible solution for harmonic current compensation. The purpose of an active power filter is to generate harmonic currents having the same magnitude but opposite phase with harmonic current produced by the nonlinear loads and to ensure that the supply current consist of only fundamental component of current. The active filter topology can be connected in series for compensation of voltage harmonic and in parallel for compensation of current harmonic. Most of the industrial applications need current harmonic compensation so the shunt active filter is more popular than series active filter. The shunt active filter has the ability to balanced the mains current sinusoidal after compensation regardless of whether the load is non linear, balanced or unbalanced [2].

The IGBT based Voltage Source Inverter (VSI) bridge with common DC bus capacitor structure is an attractive topology to solve harmonic current problems. The shunt active filter is a pulse width modulated (PWM) voltage source inverter (VSI) that is connected in parallel with the load [3]. Here voltage source inverter is chosen in place of current source inverter due to simple circuit and better filtering of load current [1] . It can be used to compensate unbalanced currents, current harmonics, and reactive power. The mains current obtained after compensation are sinusoidal and in phase with the supply voltages [4].
The performance of APF is basically depends on the design of VSI, type of the firing circuit and methods used for calculating the reference current. There are several control algorithms and performance analysis were implemented using shunt active filter [5]. but in terms of quick current controllability and easy implementation hysteresis band current control method has the highest rate among other current control strategy such as sinusoidal PWM.

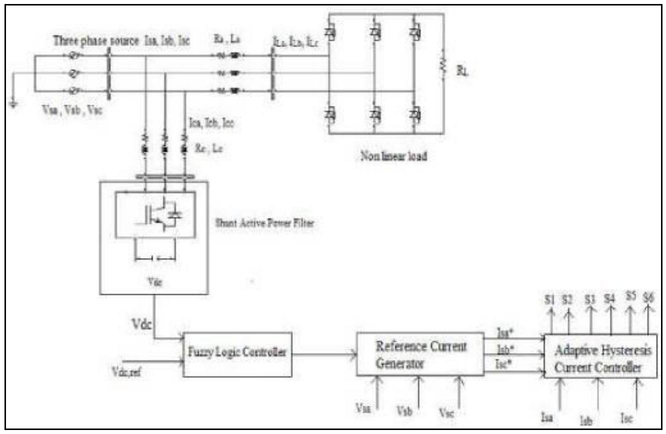


Figure 1: Basic system with nonlinear load and Shunt Active Power Filter

In most PWM applications the switching frequency varies in time with operating point and conditions. In increasing inverter operation frequency helps to get a better compensating waveform. But there are device limitations and increasing the switching frequency cause increasing switching losses, audible noise and EMI related problems. The range of the frequencies used is based on a compromise between these two factors [6]. The control of switching frequency is realized by introducing an adaptive hysteresis band current control algorithm. The adaptive hysteresis band current controller changes the hysteresis bandwidth as a function of reference compensator current variation to optimize switching frequency and THD of supply current [3]. The fuzzy based control does not require accurate mathematical model, can work with imprecise input, can handle non linearity and are more robust than other conventional non linear controller [5]. This paper proposes a fuzzy based adaptive hysteresis current controller.
In the active filter design it is necessary to maintain constant DC voltage across the capacitor connected to the inverter because energy loss associated to conduction and switching of the diodes and IGBTs of the inverter in APF, which tend to reduce the voltage across the DC capacitor. Generally, PI controller is used to control the DC bus voltage but it requires precise linear mathematical model which is difficult. It also fails to operate satisfactorily under parameter variations, non-linearity and load disturbances [3]. In this paper a fuzzy logic controller for D.C voltage control is proposed.

2. Determining APF Reference Current Compensation

Active power filter compensation strategy requires that the source currents need to be balanced, undistorted, and in phase with the positive-sequence source voltages. The goals of the shunt APF controls are

- Unity source power factor at positive sequence fundamental frequency.
- Minimum average real power consumed or supplied by the APF.
- Harmonic current compensation.
- Neutral current compensation.

To achieve these goals, the desired three-phase source currents must be in phase with the positive-sequence component of fundamental source voltage [6].

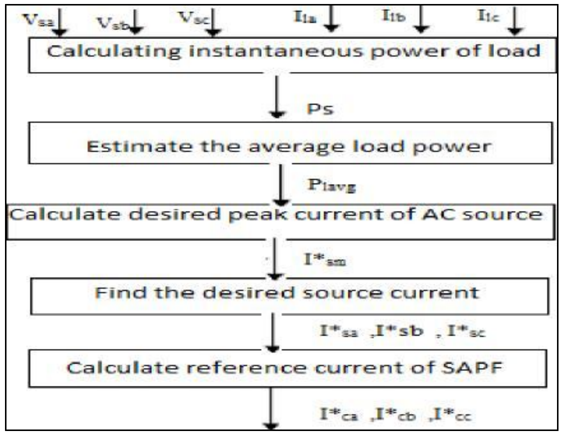


Figure 2: Flow chart of control algorithm

Active power filter compensating current are determined by sensing load current, DC bus voltage and peak value of ac source. The instantaneous value of AC source voltage can be represented as :

$V_{sa}(t) = V_{sm}.sin(wt)$

$V_sb(t) = V_{sm}.sin(wt-120)$ (1) [1]

$V_{sc}(t) = V_{sm}.sin(wt+120)$

The basic function of the proposed shunt active filter is to eliminate harmonics and compensation of current unbalance and reactive power of load. The instantaneous power is given by

Pload(k) = Vsa(k)Ila(k) + $_{Vsb(k)Ilb(k)}$ + $_{Vsc(k)Ilc(k)}$ (2) [1]

The average load power is obtained by passing $_{Pload(k)}$ to low pass filter.

$$P_{lavg} = \frac{1}{n}\sum_{k=1}^{n} P_{load(k)}$$ (3) [1]

In order to compensate harmonics and reactive power of load the current in the inductor to decrease. Once the current

The average active power of AC source can be represented asby the inverter to the inductor and this causes the current to increase and the cycle repeats.

$P_s = 3/2 . Vsm\ I^*smp = Plavg$ (4) [1]

The first component of AC side current from average power of load is given by

$I^*smp = 2/3(Plavg / Vsm)$ (5) [1]

The desired peak current of AC source can be calculated by DC capacitor voltage regulator where difference between reference value and actual value is given by

$V^*cdc = Vdcref - Vcdc$ (6) [1]

This $_{V*cdc}$ will be given to controller to obtain $_{I*smd.}$ The desired peak current of AC source can be given as

$I^*sm = I^*smp + I^*smd$ (7) [1]

The AC source current must be sinusoidal and in phase with source voltage. Therefore the desired current of AC source can be calculated by multiplying peak source current with unity sinusoidal signal. The unity signal are obtained as

$U_a = Vsa / Vsm$

$Ub = Vsb / Vsm$ (8) [1]

$U_c = Vsc / Vsm$

The desired source current is given as

$I^*sa = I^*sm \times Ua$

$I*sb = I^*sm\times Ub$ (9) [1]

$I^*sc = I^*sm\times Uc$

Finally, the reference current of active filter can obtained by subtracting load current from reference source current as

$I^*ca = I^*sa – Ila$

$I^*cb = I^*sb - Ilb$ (10) [1]

$I^*cc = I^*sc - Ilc$

The obtained reference current will be given to switching circuit of adaptive hysteresis current controller for producing necessary PWM pulse to the voltage source inverter. The voltage source inverter act as a controlled current source closed loop and produces exact reference current waveform at the output.

3. Adaptive Hysteresis Current Control

Hysteresis current controller generates required triggering pulses by comparing the error signal with that of hysteresis band and it is used for controlling the VSI so that output current generated from filter will follow the reference current waveform. The switches are controlled asynchronously to ramp the current through the inductor up and down so that it follows the reference current [5]. When the current through the inductor exceeds the upper hysteresis limit a negative voltage is applied by the inverter to the inductor. This causes The switching logic for phase a is given as follows:

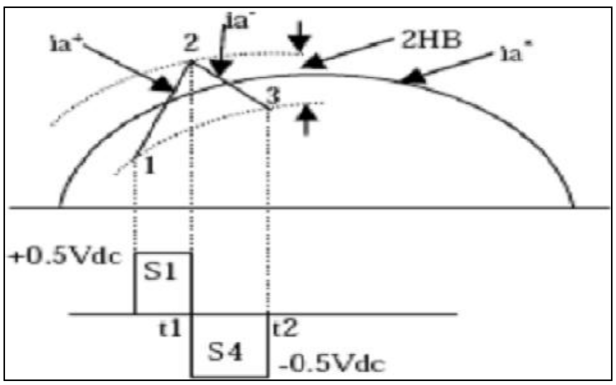
The hysteresis current control is easiest method to implement but it produces a varying modulation frequency of power converter which results in increasing losses. To avoid this problem adaptive hysteresis current controller with variable hysteresis band is recommended where variable hysteresis band for each phase is defined so that switching frequency remains almost constant. It consists of hysteresis around reference line current. The difference between reference line current Iref and measured line current I is referred as δ [1].

δ = I - Iref

If δ > HB, upper switch is OFF (S1 = 0) and lower switch is ON (S4 = 1).

If δ < -HB, upper switch is ON (S1 = 1) and lower switch is OFF (S4 = 0).

Similarly, the switching logic for phase b and c can be find. The value of line inductance of shunt active power filter and capacitor voltage are main parameter for determining the rate of change of line currents. In hysteresis current control the switching frequency does not remain constant throughout switching operation but varies along with rate of change of line current.



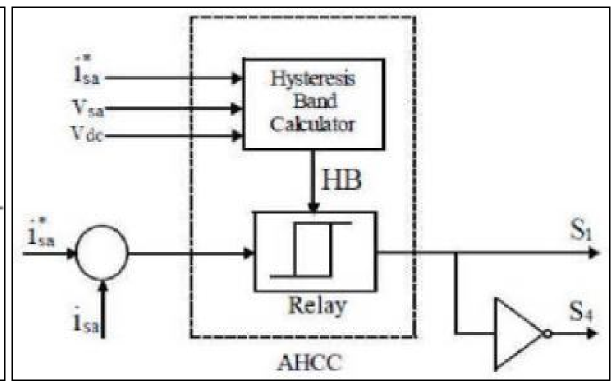


Figure 3: Current controller switching [1] Figure 4: Adaptive Hysteresis Current Control [11]

The following equation can be written from switching intervals t1 and t2

$\frac{di_a^+}{dt} = \frac{1}{L}(0.5V_{dc} - V_s)$ $\frac{di_a^+}{dt} = \frac{1}{L}(0.5V_{dc} - V_s)$	[1] [1]

From geometry we can write

$$\frac{di_a^+}{dt}t_1 - \frac{di_a^*}{dt}t_1 = 2HB \qquad (13)[1]$$

$$\frac{di_a^-}{dt}t_2 - \frac{di_a^*}{dt}t_2 = -2HB \qquad (1\ 5)$$

$t1 + t2 = T_c = 1/f_c$ (15) [1]

On adding equation (13) and (14) , we get

Subtracting eq. (14) from (13), we get	
$\frac{di_a^+}{dt} t_1 - \frac{di_a^-}{dt} t_2 - (t_1 - t_2) \frac{di_a^*}{dt} = 4HB$	(17) [1]
Substituting eq. (12) in (17) , we get	
$\frac{di_a^+}{dt}(t_1 + t_2) - (t_1 - t_2)\frac{di_a^*}{dt} = 4HB$	(18) [1]

Substituting eq. (12) in (16) and solving we get

$(t_1 - t_2) = \frac{\frac{di_a^*}{dt}}{f_c(\frac{di_a^+}{dt})}$	(19) [1]

Substituting eq. (19) in (18), we get

$$HB = [\frac{0.125Vdc}{Lfc}[1 - \frac{4L^2}{Vdc^2}\left(\frac{Vs}{L} + m\right)^2]] \quad (20)\ [1]$$

Where $m = di^*_a/dt$ is the slope of command current waveform [1]. From the above eq. hysteresis band can be calculated.

4. Proposed Hyteresis Band Current Control

To improve the active power filter performance without precise knowledge of the parameters, the shunt active filter can be implemented with a fuzzy logic controller. Which senses DC link capacitor voltage and compared with desired reference voltage Vdc,ref . The error signal e = Vdc,ref - Vdc and change of error signal is passed through fuzzy logic controller. The output of fuzzy logic controller limits magnitude of peak reference current Imax . This current takes care of active power demand of non linear load and distribution system losses. The switching signal is generated by comparing actual current with reference current using adaptive hysteresis current control [14].

Fuzzy logic uses fuzzy set theory, in which a variable is a member of one or more sets, with a specified degree of membership. Fuzzy logic allow us to emulate the human reasoning process in computers, quantify imprecise information, make decision based on vague and in complete data, yet by applying a “defuzzification” process, arrive at definite conclusions.

The FLC mainly consists of three blocks

- Fuzzification
- Inference
- Defuzzification

$\frac{di_a^+}{dt} t_1 + \frac{di_a^-}{dt} t_2 = -\frac{1}{f_c}\frac{di_a^*}{dt} = 0$	(16) [1]	The details of the above processes are given below. *A. Fuzzification*

The fuzzy logic controller requires that each input/output variable which define the control surface be expressed in fuzzy set notations using linguistic variables instead of numerical variables. The linguistic values of each input and output variables divide its universe of discourse into adjacent intervals to form the membership functions. The member value denotes the extent to which a variable belong to a particular level. The process of converting input/output variable (numerical value) to linguistic variables is termed as Fuzzification.

- *Inference*

  The behavior of the control surface which relates the input and output variables of the system is governed by a set of rules. A typical rule would be If x is A Then y is B. When a set of input variables are read each of the rule that has any degree of truth in its premise is fired and contributes to the forming of the control surface by approximately modifying it. When all the rules are fired, the resulting control surface is expressed as a fuzzy set to represent the constraints output. This process is termed as inference.

- *Defuzzification*
  Defuzzification is the process of conversion of fuzzy quantity into crisp quantity. There are several methods available for defuzzification. The selection of method is a compromise between accuracy and computational intensity. The most prevalent one is centroid method, which utilizes the following formula:

$$\frac{\int \mu(x)\,x\,dx}{\int \mu(x)\,dx} \quad \text{............ (1)[4]}$$

Where μ is the membership degree of output x.

5. Simulation Result

This section represents the details of simulation carried out to demonstrate the effectiveness of the proposed control strategy for three phase shunt active power filter. The test system consist of three phase voltage source and three phase diode bridge rectifier with resister as a non linear load. The SAPF is connected to test system through an inductor. The basic parameters used in the test system are Vs = 127V, F = 50Hz, Rs = 1Ω, Ls = 0.25mH, Lf = 2.5mH, reference dc voltage Vdc(ref) = 220V, Cdc = 300μF, switching frequency = 12kHz, Load resistance Rl = 50Ω.

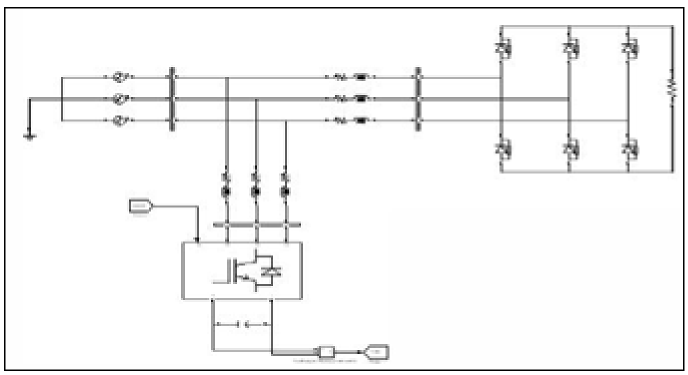


Figure 5: SAPF with proposed control algorithm

The source current and load current waveform with proposed fuzzy adaptive hysteresis current control method is shown below

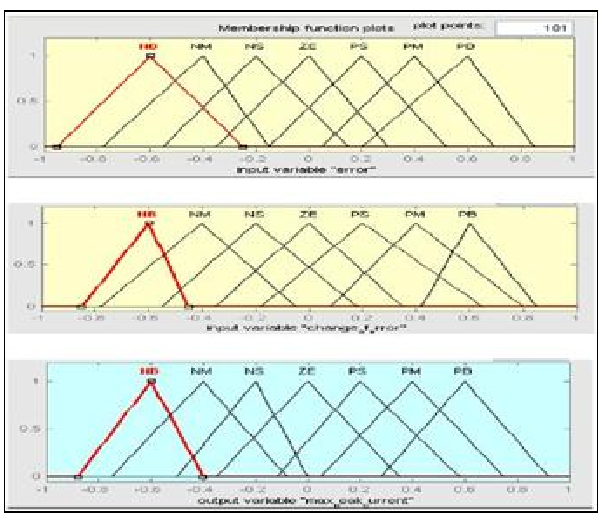


Figure 6 :(a)input variable error (b)input variable change of error (c) Output variable max. Peak current

The waveform of source current and load curent without filter is shown below:

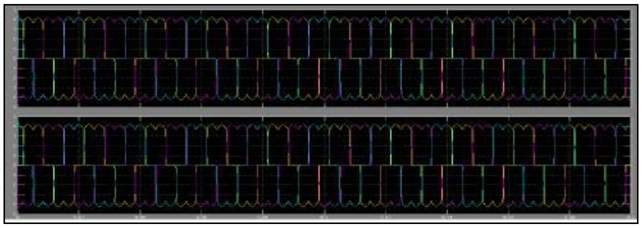
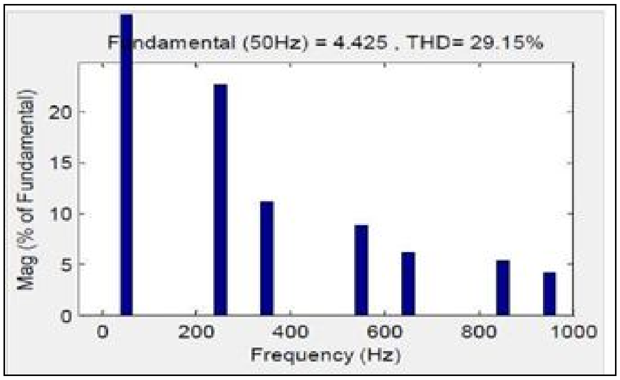


Figure.7: source current and load curent without filter(R,Y,B)

The total harmonic distortion (THD) of the distorted line current without filter is 29.15% as shown in fig for phase R.



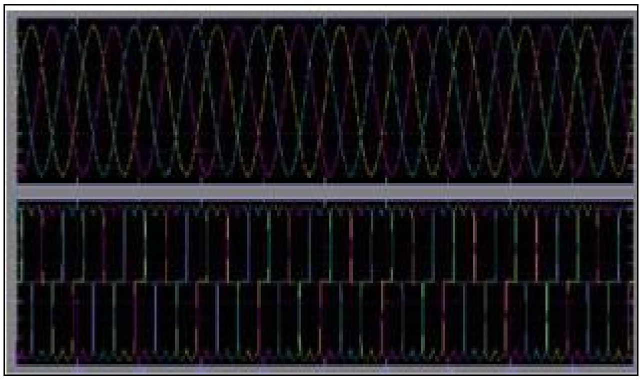


Figure .8: Frequency spectrum of line current without filter(R)
Figure 9: source current and load current(R,Y,B)

The compensating current to be generated by proposed fuzzy adaptive hysteresis current control method is shown below:

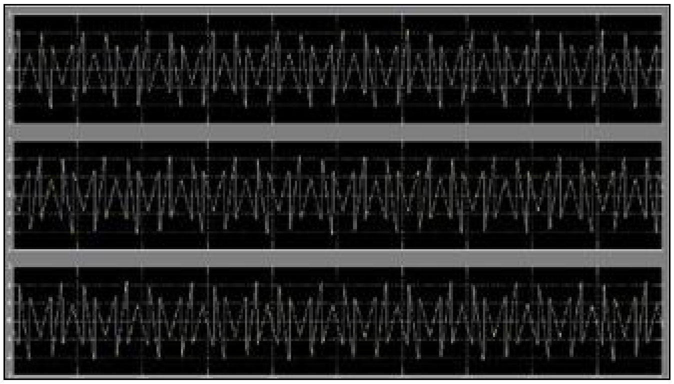


Figure 10: compensating current (R,Y,B)

The total harmonic distortion of the distorted line current with proposed fuzzy adaptive hysteresis current control is 0.50% as shown in fig. below:

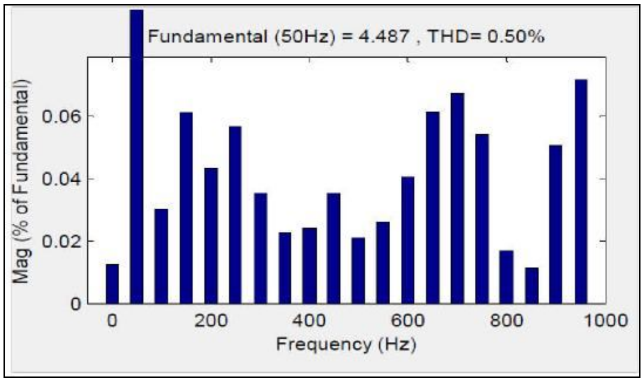


Figure 11: Frequency spectrum of line current(R) with fuzzy ahcc

The result of the simulation can be summarized in table for different compensating methods:

Method	THD in %		
	R phase	V phase	B phase
Without Filter	29.15	29.14	29.14
With HCC	1.11	1.08	1.09
With AHCC	1.02	1.01	1.02
With Fuzzy HCC	0.51	0.50	0.50
With Fuzzy AHCC	0.50	0.50	0.50

The total harmonic distortion (THD) of distorted line current with proposed method is reduced to 0.50% as compared to 29.12% without filter for R phase. The result shows the effectiveness of the proposed fuzzy adaptive hysteresis current control method for three phase shunt active power filter for reducing line harmonics well below the IEEE 519 standards.

6. Conclusion

This paper has presented a fuzzy based adaptive hysteresis current control technique for three phase shunt active power filter. The shunt active power filter was simulated using MATLAB/SIMULINK and the performance was analyzed in a sample power system with a source and three phase diode bridge rectifier with resistance as a non linear load. The Fuzzy based adaptive hysteresis control has fast response and keeps switching frequency nearly constant with good quality of filtering. The simulation result shows the effectiveness of the proposed fuzzy based adaptive hysteresis control which reduces harmonic distortion below the IEEE 519 standard.

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