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PERFORMANCE ENHANCEMENT OF SHUNT ACTIVE POWER FILTER WITH FUZZY AND HYSTERESIS CONTROLLERS

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ABSTRACT

This paper proposes fuzzy and hysteresis controllers based three phase Shunt Active Power Filter for current harmonic compensation to improve the performance of 3ϕ supply system feeding non- linear loads. The Shunt Active Power Filter is used to eliminate current harmonics. The dc link control strategy is based on the fuzzy logic controller. Gating pulses for the Shunt Active Filter is generated using Hysteresis current controller based Pulse width modulation technique. The proposed model is simulated in MATLAB/SIMULINK. Simulation results show that the dynamic behavior is better than the conventional Proportional- Integral (PI) controller and is found to be more robust for changes in load.

Keywords: *Shunt Active Power Filter(SAPF), Fuzzy Logic Controller(FLC), Hysteresis current controller, Harmonics, Total Harmonic Distortion (THD).*

1. INTRODUCTION

In Modern Electrical systems, there has been a sudden increase of non-linear loads due to SMPS, ASDs, Electrical Ballast, Rapid advancements in the power electronics technology have resulted in the usage of various power electronics equipment for both industrial and commercial applications. Equipment using power electronic devices are residential appliances like TVs and PCs , business and office equipment like copiers, printers etc, industrial equipment like Programmable Logic Controllers (PLCs), Adjustable Speed Drives (ASDs), rectifiers, inverters and so on. This widespread use of power electronics equipment pollutes the power system with harmonic currents due to its nonlinear nature. Harmonics causes several problems in power system and consumer products such as heating of the electrical equipment, trip of circuit breaker, capacitor damage, eddy current loss, communication interference, effect on transformer, malfunction of solid state devices and damage of sensitive electronic equipment [2].Hence, it is necessary to reduce the dominant harmonics below 5% as specified in IEEE 519 harmonic standard.

There are two approaches in the mitigation of power quality problems. The initial approach of load conditioning, which ensures that the equipment is made minimum sensitive to power disturbances, allowing the operation under significant voltage distortion. The other solution is to install line-conditioning systems that suppress or counteract the power system disturbances. Some of the power quality improvement solutions that have evolved over the years are fixed capacitors, switched capacitor banks, synchronous condensers, static VAR compensators, passive and active power filters etc. Passive filters work well if the harmonics of interest are well known and relatively invariant over time. However, the passive filter must be tuned to the frequencies of the harmonics to be removed and when the harmonics changes the filter effectiveness is reduced. If multiple harmonics are to be removed, the passive filter will require multiple stages, increasing size and cost. Passive filters can also produce harmonics due to resonance between the filter and source impedance [2].

For overcoming the drawbacks of passive filters and reducing power quality problems number of attempts have been made on the design, analysis and optimal control development of Active Power Filter (APF).APF is a power electronic device that can dynamically suppress harmonics and compensate reactive power regardless of the changes of their frequencies and amplitudes[9]. Active filters act as a harmonic attenuation device. The capacity and performance of the active power filter is determined by the choice of components and the execution of the power circuit.

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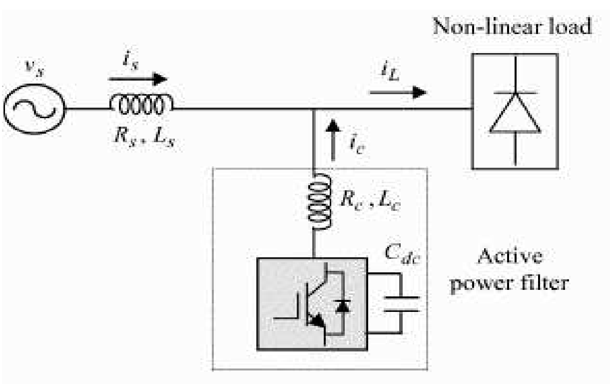
Controlling the active filter involves making the choice between open loop and closed loop current control. In open loop mode, the harmonic currents are measured on the load side of the active filter, which are used to calculate the required compensating current to be injected into the network. In closed loop control, the resulting current in the network is measured and the active filter injects a compensating current in order to minimize it. The open loop control system is easier to implement but is less efficient and require higher accuracy current sensors. The closed loop control is more precise. The reference current generator, and the control system are the two most important parts of an active filter. Earlier, thyristors,bipolar junction transistors and power MOSFET's were used for active filter fabrication. Later Gate Turn Off thyristors (GTO's) were employed to develop active filters. Recently Insulated Gate Bipolar Transistors (IGBT's) are used for the same. The compensating current is created by a three phase IGBT bridge which is controlled by the control circuit. The IGBT bridge uses a dc voltage source in the form of a capacitor and the generated voltage is coupled to the supply system through reactor.

2. BASIC COMPENSATION PRINCIPLE

The basic compensation principle of a shunt active power filter is shown in Figure 1. It is controlled to draw / supply a compensating current i_c from / to the utility, so that current harmonics gets cancelled on the AC side and makes the source current almost sinusoidal.



Figuer1: Shunt Active Power Filter- Basic Compensation Principle

Figure 2 shows the different waveforms. Curve A is the load current waveform and curve B is the desired mains current. Curve C shows the compensating current injected by the active filter containing all the harmonics to make mains current sinusoidal.

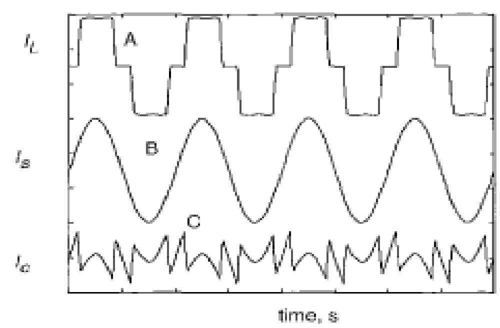


Figure 2: Shunt active power filter waveforms of load, source and desired filter current.

Shunt Active Power Filter is a pulse width modulated VSI that is connected in parallel with the load. Shunt active power filters compensate current harmonics by injecting equal-but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase-shifted by 180° [10]. The principal components of the SAPF are the VSI, a DC energy storage device and the associated control circuits. The performance of a SAPF depends mainly on the technique used to compute the reference current and the control method used to inject the desired compensation current into the line.

The first step of operation of SAPF is to generate the reference current. There are mainly two methods namely time domain and frequency domain methods for reference current generation [3]. The frequency domain methods include, Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), and Recursive Discrete Fourier Transform (RDFT) based methods. The frequency domain methods require large memory, computation power and the results provide during the transient condition may be imprecise.On the other hand, the time domain methods require less calculation and are widely followed for computing the reference current. The two mostly used time domain methods are synchronous reference (d-q-0) theory and instantaneous real-reactive power (p-q) theory[4].

The DC side capacitor serves two main purposes: (i) it maintains a DC voltage with small ripple in steady state, and (ii) serves as an energy storage element to supply real power difference between load and source during the transient period. In the steady state, the real power supplied by the source

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should be equal to the real power demand of the load plus a small power to compensate the losses in the active filter. Thus, the DC capacitor voltage can be maintained at a reference value.

Generally, PI controller is used to control the DC bus voltage of SAPF. The PI controller based approach [15] requires precise linear mathematical model which is difficult to obtain. Also, it fails to perform satisfactorily under parameter variations, non-linearity, and load disturbances. This paper proposes a fuzzy logic control for DC bus voltage control. The advantages of FLC's over the conventional controllers are: it does not need accurate mathematical model, it can work with imprecise inputs, it can handle nonlinearity, it is more robust than conventional nonlinear controllers [13].

There are several current control strategies for a SAPF namely PI control, Average Current Mode Control (ACMC), Sliding Mode Control (SMC) [12] and hysteresis control[17,18]. Among the various current control techniques, hysteresis control is the most popular one for active power filter applications. It is broadly used because of its ease and inherent peak current limiting capability without much information about system parameters. Hysteresis current control is a method of controlling a voltage source inverter so that the output current is generated which follows a reference current.

3. PROPOSED CONTROL METHOD FOR SHUNT ACTIVE POWER FILTER

In this work, Shunt Active Power Filter based on fuzzy and hysteresis control is proposed. The block diagram representation of the proposed control technique for the SAPF is shown in Figure 3.The performance of the active filter mainly depends on the methodology adopted to generate the reference current and the control strategy adopted to generate the gate pulses. The control strategy is implemented in three stages. In the first stage, the essential voltage and current signals are measured to gather accurate system information. In the second stage, reference compensating currents are derived. Fuzzy logic controller is used for DC bus voltage control and reference current generation. In the third stage, the gating signals for the solid-state devices are generated using Hysteresis Current controller based Pulse Width Modulation (HCPWM) method.

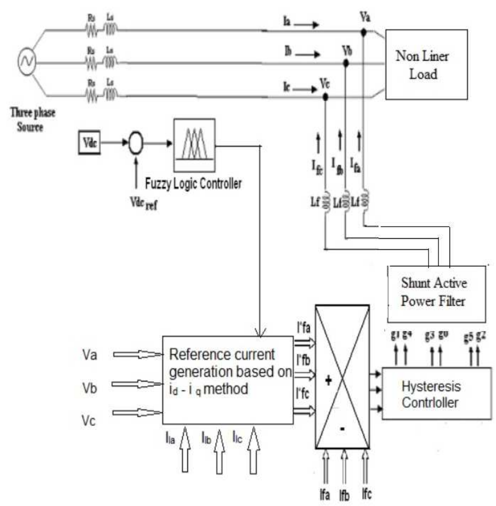

Figure 3: Proposed Shunt Active Power Filter with Fuzzy and Hysteresis Control

There are several methods to extract the harmonic components from the detected three-phase waveforms. In this work instantaneous active and reactive current method ($I_d - I_q$ method) on time domain approach has been applied to the harmonic extraction circuit of SAPF. In this method reference currents are obtained through instantaneous active and reactive currents I_d and I_q of the non linear load. Calculations follow similar to the instantaneous power theory however *dq* load currents can be obtained from Equation 3.

Transformation of the phase voltages *Va*, *Vb*, and *Vc* and the load currents I_{La}, I_{Lb}, *and* I_{Lc} into the α - β orthogonal coordinates are given in Equations (1-2).

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \quad (2)$$

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$$\begin{bmatrix} I_{Ld} \\ I_{Lq} \end{bmatrix} = \frac{1}{\sqrt{V_\alpha^2 + V_\beta^2}} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (3)$$

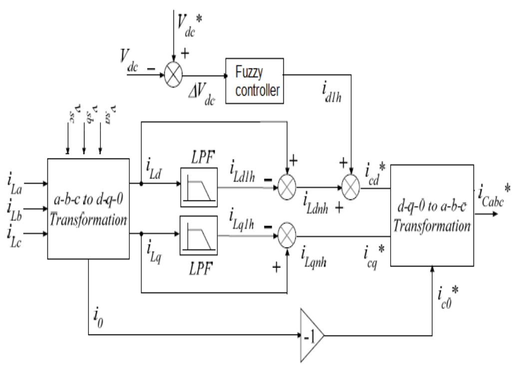


Figure 4: Circuit for reference compensating current Generation

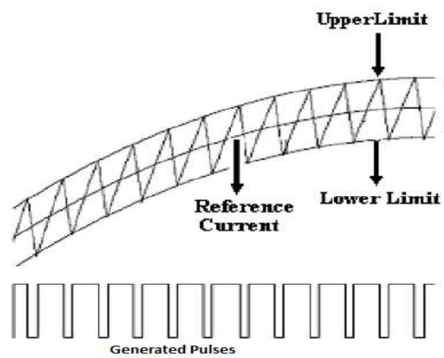
According to id-iq control strategy, only the average value of d-axis component of load current should be drawn from supply. I_{Ld1h} and I_{Lq1h} indicate the fundamental frequency component of I_{Ld} and I_{Lq}. The oscillating components of I_{Ld} and I_{Lq}, i.e., I_{Ldnh} and I_{Lqnh} are filtered out using low-pass filter. The currents I_{Ldnh} and I_{Lqnh} along with I_{d1h} are utilized to generate reference filter currents icd* and icq* in d-q coordinates, followed by inverse Park transformation giving away the reference compensation currents are ica*, icb*, icc* is shown in Figure 4.

The compensation objectives of active power filters are the harmonics present in the input currents. The three phase reference filter current is compared with the active filter compensating currents Ica, Icb, and Icc obtained from the system. The current error is given to a HCPWM scheme, which is used to generate controlled gate signal for SAPF.

4. HYSTERESIS CONTROLLER

The current controller decides the switching patterns of the devices in the SAPF. In this work, hysteresis current controller is used in Figure 5. Among different Pulse Width Modulation (PWM) techniques, hysteresis current control technique is most suitable for generating switching pulses for the switching devices of VSI based active filter because of its simplicity and robustness. This strategy provides satisfactory control of current without requiring extensive knowledge of control system parameters. Hysteresis current control method is the best because it follows more accurately the current reference of the filter. The actual source currents are monitored instantaneously, and then compared to the reference source currents generated by the proposed fuzzy logic based control algorithm. The positive group device and the negative group device in one phase leg of VSI are switched in complementary manner for avoiding a dead short circuit

Figure 5: Hysteresis current control based PWM



generation

The current controllers of the three phases are designed to operate independently. Each current controller determines the switching signals to the inverter. The switching logic for phase A is formulated as below;

If $I_{ca}^{*} - I_{ca} > HB$, upper switch G_1 is OFF and lower switch G_4 is ON.

If $I_{ca}^{*} - I_{ca} < HB$, upper switch G_1 is ON and lower switch G_4 is OFF.

In the same fashion, the switching of phase B and C devices are derived.

5. FUZZY LOGIC CONTROLLER

Fuzzy logic becomes more popular due to dealing with problems that have uncertainity, vagueness, parameter variation and especially where system model is complex or not accurately defined in mathematical terms for the designed control action.

The fuzzy control rules based on membership function relate input variables to output variables. The number and type of MF determines the computational efficiency of fuzzy control technique. The shape decision of MFs affects how well a fuzzy system rules approximate a function.

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In this work, triangular membership function (TMF) has been used due to its simplicity, easy implementation and symmetry along the axis. Triangular membership functions used for the input and output variables are shown in figure.6.

Variables which can represent the dynamic performance of the plant to be controlled should be chosen as the inputs to the FLC. It is common to use the output error (e) and the rate of change of error (e') as controller inputs. On regulation of first harmonic active current of positive sequence i_{d1h} it is possible to control the active power flow in the VSI and thus the capacitor voltage $V_{dc.}$ In order to implement the control algorithm of the proposed SAPF in closed loop, the DC side capacitor voltage is sensed and then compared with a reference value. The obtained error e (=$V_{dc,\ ref} - V_{dc,\ act}$) and the change of error signal $e'(n)$= e(n)-e(n-1) at the n^th sampling instant are taken as inputs for the fuzzy processing and first harmonic active current of positive sequence i_{d1h} is taken as the output of the FLC.

Table 1 Fuzzy control rules

e e'	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

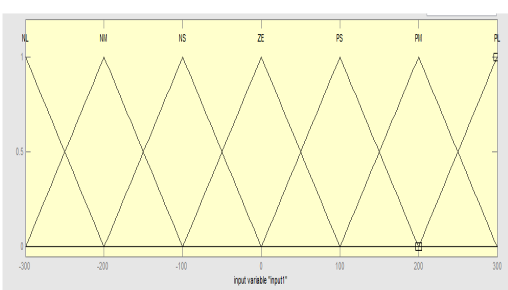
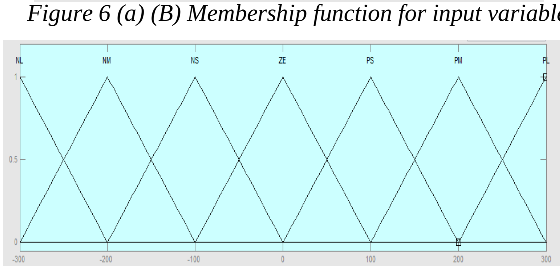


Figure 6 (a) (B) Membership function for input variable



(B) Membership function for output variable

The input and output variables are converted into linguistic variables. In this case, seven fuzzy subsets namely NL (Negative Large), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium) and PL (Positive large) have been chosen. As both inputs have seven subsets, a fuzzy rule base formulated for the present application is given in Table 1.

6. SIMULATION AND RESULTS

The simulation of the proposed shunt active filter was performed in MATLAB/SIMULINK environment. The complete system is composed mainly of three-phase source, uncontrolled rectifier with RL load as a nonlinear load, a voltage source PWM inverter, coupling and smoothing inductor, fuzzy controller and hysteresis controller.

A three phase system with a nonlinear load and without SAPF is simulated. It is observed that due to the nonlinear load, harmonics are produced and the three phase source current is distorted as shown in the Figure.7. Total Harmonic Distortion (THD) is found out by the FFT analysis as shown in figure.8.

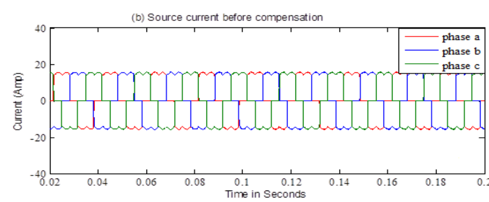


Figure.7. Source Current Without SAPF

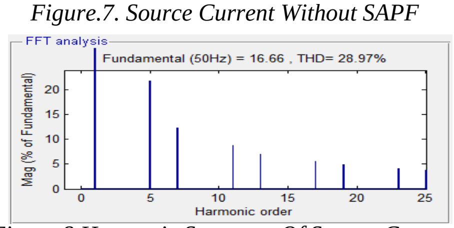


Figure.8 Harmonic Spectrum Of Source Current Without SAPF

It is observed that harmonics has severely distorted the source current. From FFT analysis the THD of the phase-a source current is found to be 28.97%.

The same test system is simulated with the proposed SAPF to show its effectiveness. Figure.9 shows the three phase system with the proposed SAPF. The values of the circuit elements used in the simulation are listed in Table 2.

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Table 2. Circuit Parameters Used For SAPF Simulation

PARAMETERS	VALUES
Source Voltage, Vs	415V, 50 Hz
D.C capacitor	2200 µF
D.C capacitor reference voltage	440 V
Diode rectifier load resistance and inductance	15 ohm, 35 mH
Filter inductance, resistance	10 mH, 5 ohm,

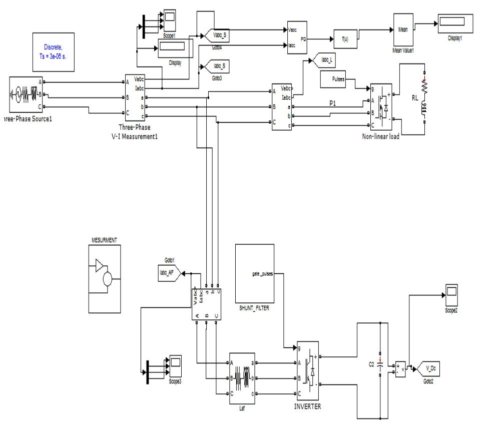

Figure 9: Simulink Model Of The Proposed SAPF

Figure 10 shows the three phase source current of the system with proposed SAPF. The waveform obtained is almost sinusoidal. Harmonic spectrum of the source current waveform in phase-a is shown in figure 11. It is seen that with the proposed SAPF the THD is reduced to 2.33% from 28.97%.

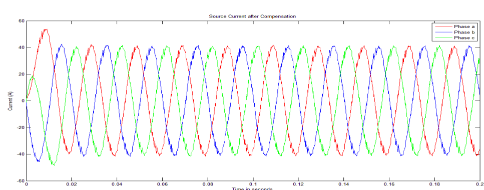

Figure 10: Three Phase Source Current Of The System With The Proposed SAPF.

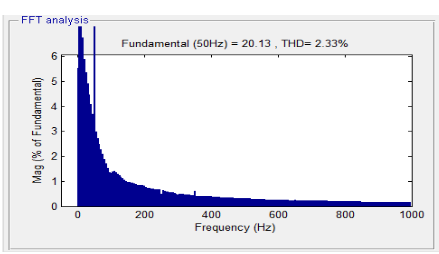

Figure 11 Harmonic Spectrum Of Source Current Of The System With The Proposed SAPF

Table 3. Total Harmonic Distortion

Methods	Unbalanced		Balanced	
	THD	PF	THD	PF
Uncompensated system	31.55	0.8962	28.97	0.901
SAPF with PI Controller	6.05	0.7103	4.85	0.715
SAPF with Fuzzy Controller	2.38	0.9141	2.33	0.946

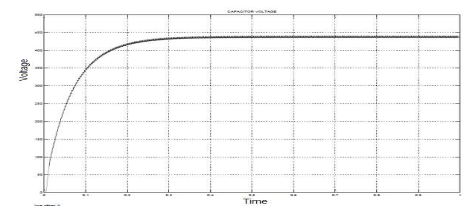

Figure.12 Capacitor Voltage of SAPF

The voltage across the capacitor is shown in Figure 12. The capacitor voltage is maintained as constant with fuzzy logic Controller. The simulation results are compared with conventional controller for balanced and unbalanced load. The THD and power factor values are given in the table 3. From the results, it is inferred that fuzzy logic controller based SAPF perform well and THD in the three phase system is much reduced.

7. CONCLUSION AND FUTURE SCOPE

Three phase shunt active power filter with fuzzy and hysteresis controller was proposed to improve the power quality of the system. The SAPF was simulated in MATLAB/SIMULINK. It is found that the proposed shunt active power filter improves the power quality of the power system by eliminating harmonics and makes the source current almost sinusoidal .It is seen that the THD of the source current 5%, which is below the harmonics limit imposed by IEEE standards.

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