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# Improvement of Power Quality by SAPF devices using Fuzzy Logic Controller

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## Abstract:

The simulation study of a fuzzy logic controlled, single-phase shunt active power filter to improve power quality by compensating harmonics and reactive power required by a nonlinear load is presented. The advantage of fuzzy control is that it is based on a Linguistic description and does not require a mathematical model of the system. 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.

## Key words:

Power Quality, Shunt Active Power Filter, Non-linear load, Fuzzy-logic controller.

## I.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 [1], 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.In recent years, the applications of power electronics have grown tremendously. Thesepower electronic system offer highly nonlinear characteristics. An increase in such nonlinearity causes various undesirable features such as increased harmonics and reactive power components of current from AC mains, low system efficiency and a poor power factor. They also Cause disturbance to other consumers and interference in nearby communication networks.

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 [3]. However, the conventional PI controller was used for the generation of a reference current template. The PI controller requires precise linear mathematical models, which are difficult to obtain and fails to perform satisfactorily under parameter variations, nonlinearity, load disturbance, etc.

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Kecently, I'uxzy logic controllers (FLCs) have generated a good deal of interest in certain applications [3-5]. The advantages or FLCs over conventional controllers are that they do not need an accurate mathematical model, they can work with imprecise inputs, can handle lion-linearity, and they are more robust than conventional nonlinear controllers.

## II.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 ic from / to the utility, so that current harmonics gets cancelled on the AC side and makes the source current almost sinusoidal.

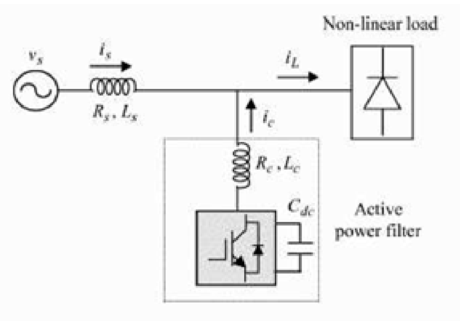


**Fig 1: Shunt Active Power Filter- Basic Compensation Principle.**

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° [6]. 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.

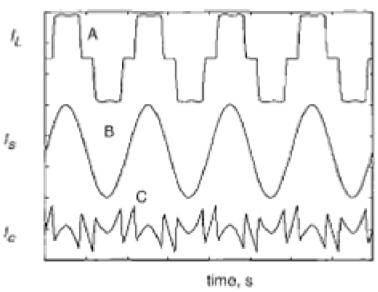


**Figure 2: Shunt active power filter waveforms of load, source and desired filter current.**

From Fig. la, the instantaneous currents can be written as

$$iS(t) = iL(t) - ic(t)$$

Source voltage is given by

$$Vs(t) = Vm \sin(wt)$$

If a nonlinear load is applied, then the load current will have a fundamental component and harmonic components,The source current supplied by the source, after compensation is

$$iS(t)= pf(t)/vs(L=)\ i1\cos\phi1 * \sin wt = Ism \sin(wt)$$

Where $Ism= i1\cos\phi1$

There are also some switching losses in the PWM converter, and hence the utility must supply a small overhead for the capacitor leakage and converter switching losses in addition to the real power of the load.If the active filter provides the total reactive and harmonic power, then is(t) will be in phase with the utility voltage and purely sinusoidalHence, for accurate and instantaneous compensation of reactive and harmonic power it is necessary to estimate is(t), i.e. the fundamental component of the load current as the reference currentThe 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 [7].

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.

## III.POWER CIRCUIT OF SHUNT ACTIVE POWER FILTER:

The design of the power circuit includes three main parameters:

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(i) Selection of filter inductor
(ii) Selection of DC side capacitor
(iii) Selection of reference value of DC side capacitor voltage

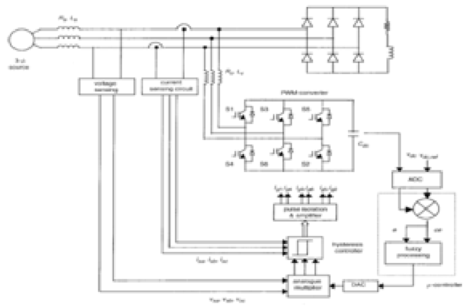

**Fig 3: Schematic diagram of closed loop controlled shunt active power filter**

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.

There are several methods to extract the harmonic components from the detected three-phase waveforms. In this work instantaneous active and reactive current method (Id–Iq 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 Id and Iq of the nonlinear load.Transformation of the phase voltages Va, Vb, and Vc and the load currents ILa, ILb, and ILc into the α - β orthogonal coordinates are given

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

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

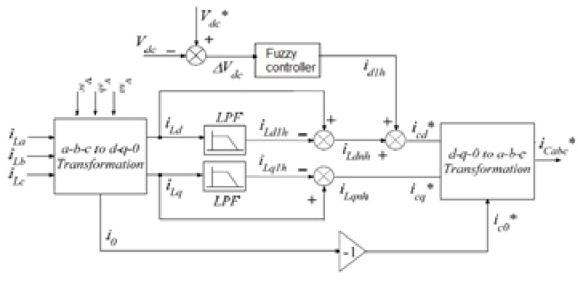

**Figure 4: Circuit for reference compensating current Generation.**

According to id-iq control strategy, only the average value of d-axis component of load current should be drawn from supply. ILd1h and ILq1h indicate the fundamental frequency component of ILd and ILq. The oscillating components of ILd and ILq, i.e., ILdnh and ILqnh are filtered out using lowpass filter. The currents ILdnh and ILqnh along with Id1h 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.

## IV.CONTROL METHOD:

The current controller decides the switching patterns of the devices in the SAPF. 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.

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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 Ica*- Ica > HB, upper switch G1 is OFF and lower switch G4 is ON.
If Ica*- Ica < HB, upper switch G1 is ON and lower switch G4 is OFF.
In the same fashion, the switching of phase B and C devices are derived.

## FUZZY LOGIC CONTROLLER:

Fuzzy logic becomes more popular due to dealing with problems that have uncertainty, 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.Triangular membership function(TMF) has been used due to its simplicity, easy-implementation and symmetry along the axis.

Triangular membership functions used for the inputand output variables are shown in figure.6.Variables which can represent the dynamicperformance of the plant to be controlled should bechosen as the inputs to the FLC. It is common touse the output error (e) and the rate of change oferror (e') as controller inputs. On regulation of firstharmonic active current of positive sequence id1h itis possible to control the active power flow in theVSI and thus the capacitor voltage Vdc. In order toimplement the control algorithm of the proposedSAPF in closed loop, the DC side capacitor voltageis sensed and then compared with a reference value.The obtained error e (=Vdc, ref – Vdc, act) and thechange of error signal e'(n)= e(n)-e(n-1) at the nthsampling instant are taken as inputs for the fuzzy-processing and first harmonic active current ofpositive sequence id1h is taken as the output of theFLC.

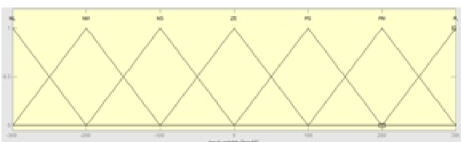

Fig 5: Membership function for input variable

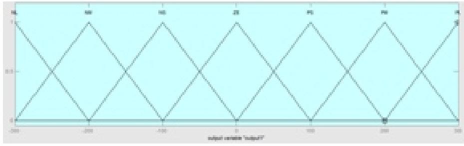

Fig 6: Membership function for output variable

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.

## V.MATLAB/SIMULATION RESULTS:

Here simulation is carried out in several cases, in that 1) A High Performance of Single Phase Source Fed Non-Linear Load without APF, 2) A High Performance of Single Phase Source Fed Non-Linear Load with APF by using PI controller. 3). A High Performance of Single Phase Source Fed Non-Linear Load with APF by using fuzzy controller.

### Case 1: A High Performance of Single Phase Source Fed Non-Linear Load without APF

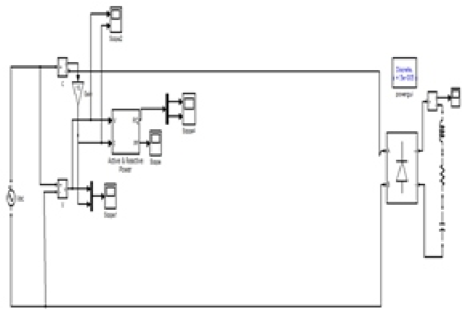

Fig 7.Proposed Single Phase Source Fed Non-Linear Load without APF Topology

Fig 7 shows the Matlab/Simulink Model of Proposed Single Phase Source Fed Non-Linear Load without APF Topology using Matlab/Simulink Platform.

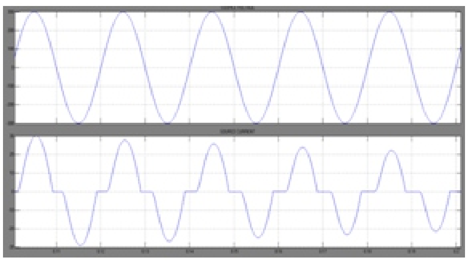

Fig 8: Source Voltage & Current

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Fig.5 shows the Source Voltage & Current of Proposed Single Phase Source Fed Non-Linear Load without APF Topology.

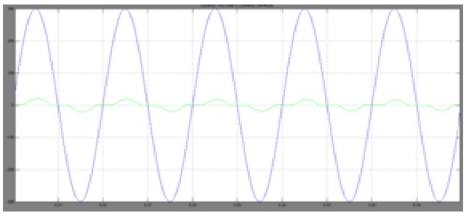

**Fig 9: Source Voltage & Current in In-Phase Condition**

### Case 2: A High Performance of Single Phase Source Fed Non-Linear Load with APF by using fuzzy controller

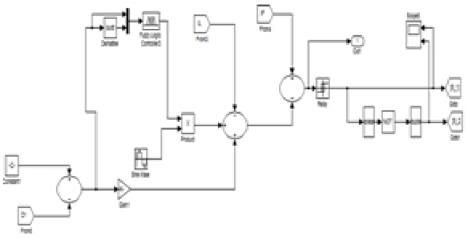

**Fig 10: Matlab/Simulink Model of controller by using fuzzy controller**

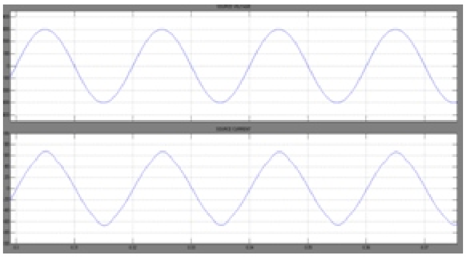

**Fig 11: Source Voltage & Current**

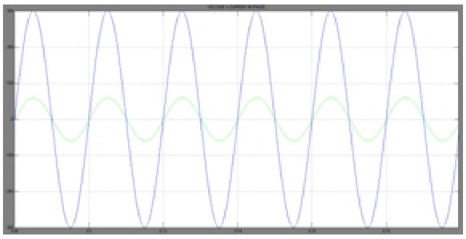

**Fig 12: Source Voltage & Current in In-Phase Condition**

## VI.CONCLUSION:

Single-phase shunt active powers filter with fuzzyand hysteresis controller was proposed to improvethe power quality of the system. The SAPF wassimulated in MATLAB/SIMULINK. It is foundthat the proposed shunt active power filterimproves the power quality of the power system byeliminating harmonics and makes the sourcecurrent almost sinusoidal. APF in the form of a 3-leg VSI bridge with HCC strategy with half bridge topology has been modeled and controlled for harmonic reduction. Fuzzy controller has a better transient response comparedto a conventional PI controller, and the steady stateperformance of the fuzzy controller is comparable to the PIcontroller.

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