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# Performance Measure of Shunt Active Power Filter Applied with Intelligent Control Technique

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**Abstract**

This paper describes a shunt active power filter for compensating harmonic currents and reactive power. The shunt active power filter(SAPF) was implemented with a phase pulse modulated current control voltage source inverter. The proposed system is based on PLL synchronization with reduced fuzzy logic controller (RD-FLC). These control techniques for SAPF prove that source current is sinusoidal even when load is non linear. The CC-VSI inverter switching is done according to gating pulse obtained from the hysteresis controller using RD-FLC controller. The proposed system is investigated using simulation results. The effectiveness of the controller is observed in the form of total harmonic distortion, reactive power compensation and settling time of dc link voltage under non linear load condition. This technology reduced the rules of fuzzy logic controller from 49 to 37.

**Keywords**: Reduced Fuzzy Logic Controller, Shunt Active Power Filter (SAPF), DC Link Inverter, Unit Template Generation.

## 1 Introduction

The use of non linear solid state devices in utility loads at the consumer end shows highly non linear characteristics and injects non linearity into the system, affecting and distorting voltage and current waveforms of the system in a phenomenon termed 'harmonics' [1]. Some major problems in the distortion of voltage and currents are: sag, swell, dip, harmonics etc. and they particularly affect consumer devices and equipment. The distorted waveforms of current and voltage not only effect the consumer's individual devices, but also affect other devices connected to the point of common coupling to that by injecting non linearity through the system [2].

To remove these non linearities or harmonics to improve power quality throughout the system some Passive (L, C) and Active power filters are introduced. Passive filters were the first measures developed to mitigate harmonics, but they have several disadvantages: resonance, bulky, tuned for a particular frequency, not used for frequency variations, ageing etc. To respond to these disadvantages, the design was modified and optimal solutions found to improve power quality - Active Power Filters. Active power filters are used to mitigate both voltage and current harmonics with reactive power compensation required by load. Active power filters are of two types (i) Series active power filters are used for voltage harmonics mitigation, and (ii) shunt active power filters are used for current harmonics mitigation. This research paper is based on current harmonics mitigation of source current and reactive power compensation demand by non linear load so that shunt active power filters are used. Generation of gating signals for the voltage source inverter is central to designing shunt APF. Various control techniques are used to generate reference current signals in shunt APF. In this paper we use current reference theory to generate and simulate these signals. Reference current signals are generated by sensing the source voltage and currents, load current and DC link voltage. Hence, the control technique should be such that it has to eliminate [3]; [4]; [5] the harmonics under steady state and transient conditions with less sensor count. In this paper source voltage sensing is for unit template generation and source current sensing is for generating the getting signals.

The controller is the heart of any system and a conventional PI controller is used to implement and design shunt APF. This PI controller can be replaced by many mathematical modeled controllers: sliding mode controller, self-tuned controller, model reference adaptive controller etc. The design and performance of these controllers is based on accurate implementation of the mathematical model and that is not easy to design. These models also do not give satisfactory results on varying load conditions with increasing reactive power compensation by load. Hence, mathematical models are complex and lack the desired robustness under transient conditions [6] .

Artificial intelligence is a new area of research, working on linguistic inputs and outputs in contrast to mathematical models, so as to reduce complexity and

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increase the robustness of the system. Fuzzy logic control AI techniques were proposed by Zadeh [7]; [8]; [9]. The fuzzy logic controller was redesigned and redeveloped as a reduced fuzzy logic controller by reducing the rule base [10]; [11]. The advantage of using reduced FLC instead of FLC is that it reduces the number of rules, reduces memory storage, reduces simulation time and increases the speed of the controller to respond in transient conditions.

This paper presents the reduced fuzzy logic controlled shunt APF for eliminating current harmonics and reactive power compensation of non linear load. This control scheme is based on indirect currents control. In this scheme only source current is sensed to reduce spikes [12]; [13]; [14].

## 2 Generation of compensating current

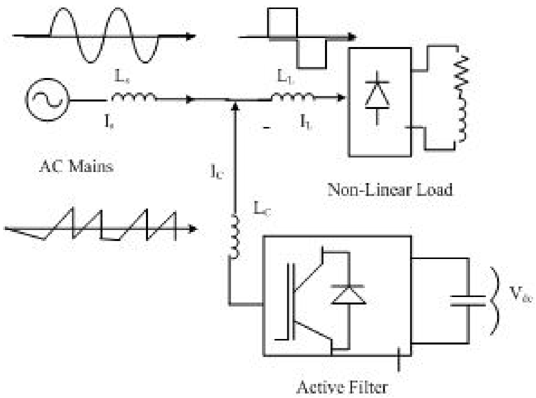



Figure 1: Basic shunt active power filter

The structure of the conventional shunt active power filter is shown in figure 1. In addition, the basic generating principle of the compensating current is set out below. Compensating current is generated by the VSI convertor. VSI convertors consist of six SCRs. For perfect operation of these SCRs, we have generated gating pulses, which is done by use of the DC link voltage and the controller. In this paper, we use the reduced fuzzy logic controller and basic compensation principle is shown in the equations below:

$$I_S\left(t\right) = I_L\left(t\right) - I_C\left(t\right) \tag{1}$$

Source voltage is given by

$$V_s\left(t\right) = V_m \sin\left(\omega t\right) \tag{2}$$

Here the load is non-linear; In this case, the load current is not sinusoidal and contains harmonics. This waveform contains fundamental components as well as harmonics components. The equation of load current can be represented as follows:

$$I_L(t) = \sum_{n=0}^{\infty} I_n \sin\left(n\omega t + \phi_n\right) \tag{3}$$

$$I_L\left(t\right) = I_1 \sin\left(\omega t + \phi_1\right) + \sum_{n=0}^{\infty} I_n \sin\left(n\omega t + \phi_n\right) \tag{4}$$

The load power can be given as follows:

$$P_L\left(t\right) = V_s\left(t\right)\ I_s\left(t\right) \tag{5}$$

$$P_f(t) = V_m I_1 \sin^2\left(\omega t\right) \cos\left(\phi_1\right) \tag{6}$$

$$P_r(t) = V_m I_1 \sin\left(\omega t\right) \cos\left(\omega t\right) \sin\left(\phi_1\right) \tag{7}$$

$$P_h(t) = \sum_{n=0}^{\infty} I_n \sin\left(n\omega t + \phi_{(n)}\right) \tag{8}$$

$$P_L\left(t\right) = P_f\left(t\right) + P_r\left(t\right) + P_h\left(t\right) \tag{9}$$

From the the above equation the fundamental component of power drawn by the load side is as follows:

$$P_f\left(t\right) = P_L\left(t\right) \tag{10}$$

So from this equation source current after compensation is given by:

$$I_s\left(t\right) = \frac{P_f\left(t\right)}{I_s\left(t\right)} \tag{11}$$

$$I_s(t) = I_1 \cos(\phi_1) \sin(\omega t) \tag{12}$$

$$I_s(t) = I_{SM} \sin(\omega t) \tag{13}$$

and

$$I_{SM} = I_1 \cos(\phi_1) \tag{14}$$

If the active filter provides the total reactive and harmonic power, then source current will be in phase with the utility voltage and purely sinusoidal. At this time the filter injects compensating current into the electrical system and this is given by:

$$I_C(t) = I_L(t) - I_S(t) \tag{15}$$

For dynamic compensation for reactive and harmonic power, it is necessary to evaluate the fundamental component of load current as of the reference current.

## 3 The proposed reduced fuzzy logic controller

The fuzzy logic controller is used due to its capability to handle a highly non-linear system. The basic principle of the FLC comprises 3 processes (1) fuzzification (2) inference engine (3) defuzzification.

At the first controller, inputs are error and change in errors. These inputs are in crisp sets, which we convert into fuzzy sets by the fuzzification process. In the inference engine, they are processed and controlled to get the desired output, and then the fuzzy output is obtained. This fuzzy output is then subjected to defuzzification and given to the system to control the parameters. The design of the controller is based on the volume of inputs and outputs in the system. The inference engine contains decision rules and tables. These fuzzy rules control the controller's work. The design of these rules depends on expert knowledge, intuition knowledge, and experience. If the controller input is denoted by n and each input is partitioned into m membership functions, then the dimension of the decision table is n with nm; and rules and design parameters are n(m+1) + nm. If any system has higher input and output parameters then it leads to incrementing the rules. The Design and tuning of the controller are very complex and the dimension of the system is very large, so the response time of the controller is increased due to the processing of rules inside controller inference engine. Hence, a novel design is proposed to reduce the rules and facilitate the tuning and organizing of fuzzy logic controller.

Table 1: Reduced rule base for SAPF

| E/CE | NB | NM | NS | ZE | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| **NB** | * | * | * | NB | NM | NS | ZE |
| **NM** | * | * | NB | NM | NS | ZE | PS |
| **NS** | * | NB | NM | NS | ZE | PS | PM |
| **ZE** | NB | NM | NS | ZE | PS | PM | PB |
| **PS** | NM | NS | ZE | PS | PM | PB | * |
| **PM** | NS | ZE | PS | PM | PB | * | * |
| **PB** | ZE | PS | PM | PB | * | * | * |

In this paper an SAPF with reduced fuzzy logic controller is presented. The inputs for the controller are error (e) and change in error (ê). The control surface has the nonlinear property, and the non linear function is given as:

$$U = f(e, \hat{e}) \tag{16}$$

This surface reveals that if the control surface is rotated so that its intersection with the horizontal plane becomes one coordinate axis and the control surface is the sole function of the other input. To apply this approach to SAPF reduced fuzzy logic controller, the rules are reduced from 49 to 37. Here θ is the angle between the axis ê and intersection of the control surface. This approach is shown in Table 1 and the decision rules changes along the new axis is depcted in figure 2.

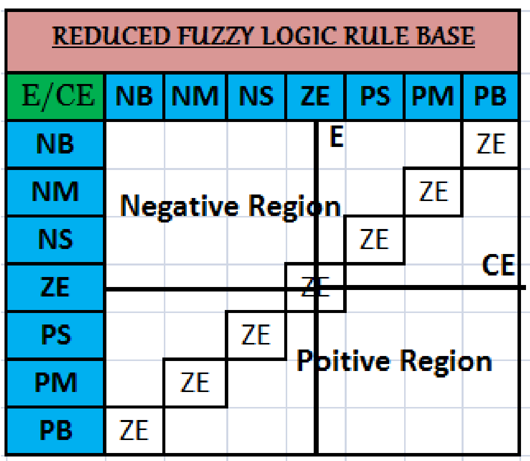



Figure 2: Decision rules changes along the new axis

# 4 The proposed application of reduced fuzzy in SAPF

In this paper, SAPF is used with a reduced fuzzy logic controller. When designing the SAPF the basic parameters of design are: compensating inductor ($L_C$), DC link capacitor ($C_{DC}$) which is to be constant after turning on the VSI and reference value of the voltage ($V_{DC\ ref.}$).

(i) Compensating inductor ($L_C$):- The output of the VSI is PWM voltage and this has to be filtered by the $L_C$ to limit current ripple. Ripples are generated by the switching operations of SCR used by VSI, hence the design of $L_C$ depends on the harmonic current reduction techniques.

(ii) DC-link voltage ripple is reduced by the use of the DC link capacitor value. its value is so high because when the system is connected to the load it will give higher ripple; hence large values keep it safe, give a better dynamic response and reduce 2nd order harmonic.

Therefore, the value of the $L_C$ and $C_{DC}$ are as follows:

$$L_C = \frac{maV_{dcref}}{\left(2\sqrt{(2)}\right) I_{SWp-p}K_L\ f_{SW\ \ max}} \quad (17)$$

and

$$C_{DC} = \frac{\pi\ I_{Crated}}{\sqrt{3}\omega V_{derfp-p}} \quad (18)$$

The proposed MATLAB model of reduced fuzzy logic controller based shunt active power filter is depicted in figure 3.

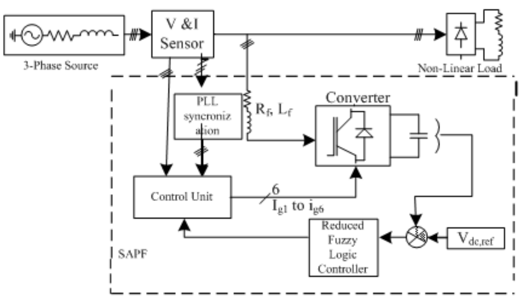



Figure 3: Realization of RD-FLC SAPF

System parameters of this model are as shown in Table 2 below:

Table 2: System Data Specification for Simulink Modelling

| | |
|---|---|
| Source | Supply-voltage: 400V (RMS line voltage) |
| | Source frequency = 50Hz, |
| | Switching frequency=10kHz |
| APF | DC link capacitor, $C_{DC} = 2000\mu F$ |
| | Reference DC link Voltage : $V_{DC}$=680V |
| | Filter inductor, $L_C$ = 3.35 mH, $R_C$ = 0.4 $\Omega$ |
| Loads | Three-phase diode rectifier with $L_L$ = 100 mH, |
| | and load $R_L$ = 100 $\Omega$ |

# 5 Simulation Results

The MATLAB/SIMULINK model was developed for the shunt active power filter with reduced fuzzy logic. The proposed system is shown in figure 3. The system is simulated with non linear loads. The simulation time is 0 sec to .35 sec. The VSI triggers with step signal application after 0.1 sec, previously there is no compensation. The three phase source voltage is illustrated in figure 4.

The non linear RL load consists of a six-pulse diode rectifier. Source current after compensation is represented in figure 5(a). The non linear load currents or source currents before compensation are examined in figure 5(b). The proposed SAPF that supplies the compensating current is depicted in figure 5(c). These current waveforms are for all three phases.

Power factor correction is achieved, as is shown in figure 5(d). The voltage and current for a phase are in phase, as shown in figure 5(e).

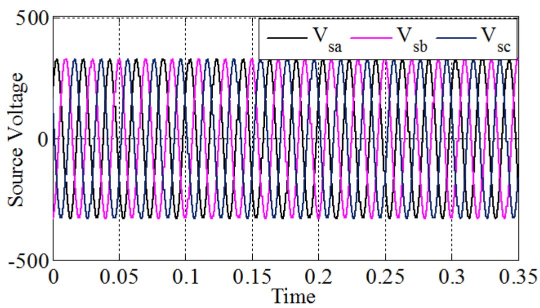



Figure 4: Source voltages

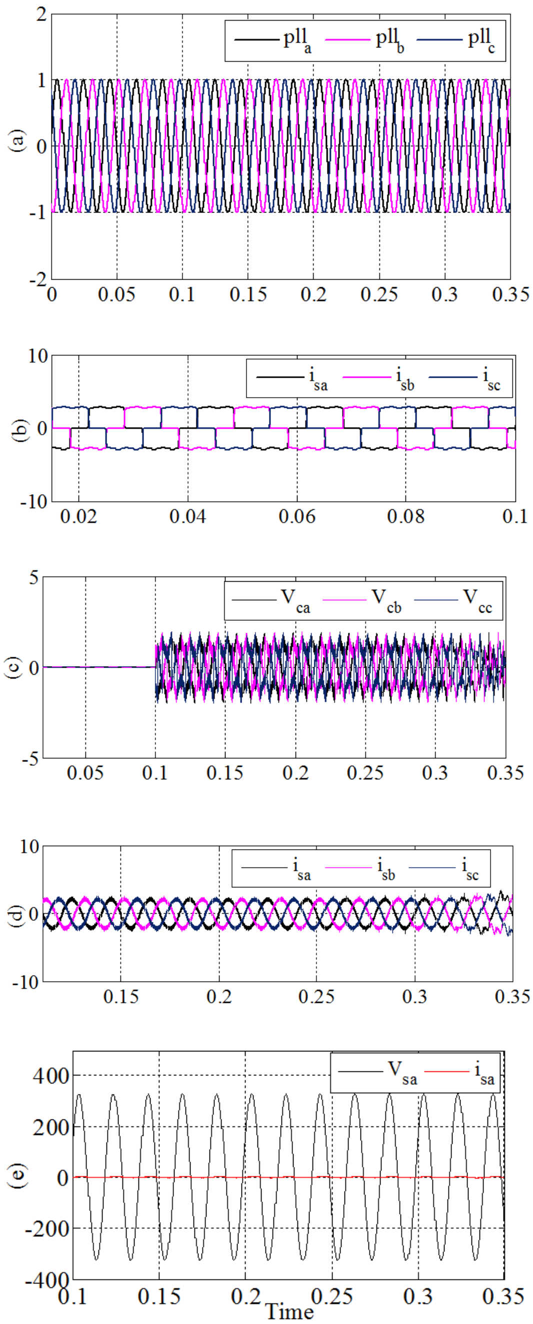



Figure 5: Simulation results for SAPF under nonlinear load condition (a) load current before compensation (b) PLL synchronization output current (c) source current after SAPF (d) compensation current by SAPF (e) phase relation between source voltage and source current.

## 5.1 DC side capacitor voltage:

The reduced fuzzy logic controller controls DC side capacitive voltage and settling time. It is illustrated in figure 6.

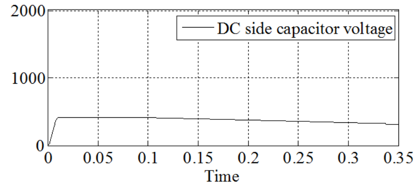



Figure 6: DC link voltage

Table 3: Active reactive power and power factor

| Element | Active and Reactive Power | Power Factor |
|---|---|---|
| Non-linear load | P=1359W, Q=-738.9VAR | 0.8785 |

## 5.2 Real and reactive power:

PLL synchronization with reduced fuzzy logic controller based compensation delivers better power quality. Active and reactive powers are shown in figure 7 and figure 8, respectively. The improvement in power factor is obtained, as shown in figure 9.

The reduced fuzzy logic controller based SAPF system compensates harmonics, improves power factor and reduces reactive power. Active power and reactive power are measured under non-linear load condition, as given in Table 3.

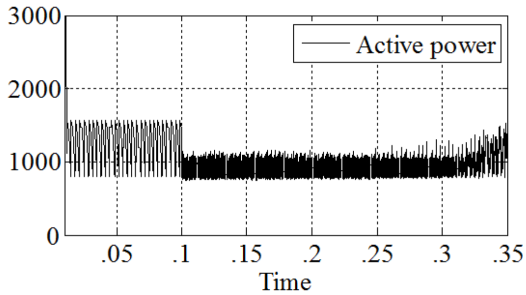



Figure 7: Active power

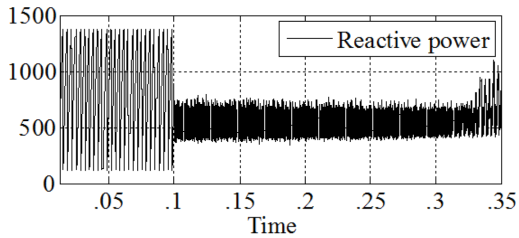



Figure 8: Reactive power

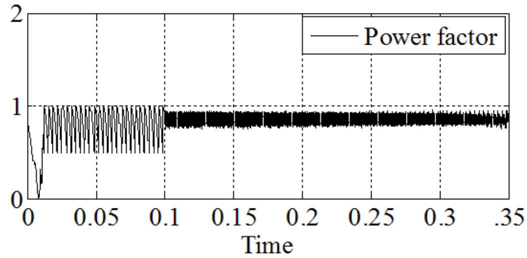



Figure 9: Power factor

## 5.3 Order of harmonics:

The Fourier analysis of the source current is performed to find the magnitude of different harmonic frequencies. The proposed system findings of uncompensated and compensated source current waveforms FFT are plotted in figure 10 and figure 11, respectively.

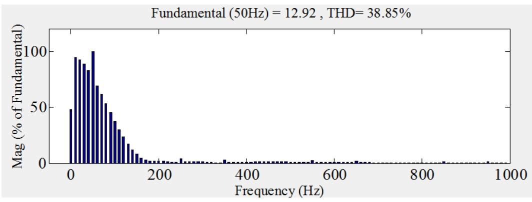
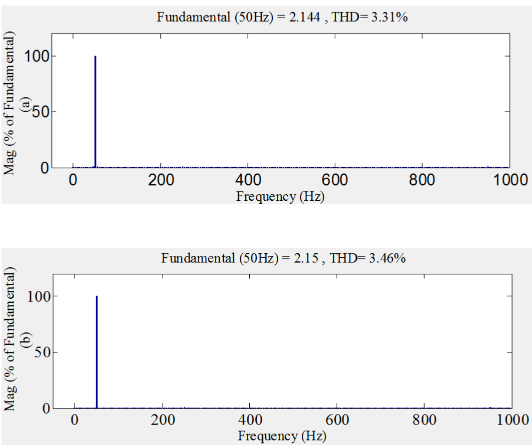



Figure 10: Frequency spectrum of source current before compensation for three phase SAPF with non linear load




## 5.4 Total harmonic distortion (THD):

Reduced fuzzy logic controller based SAPF makes source current in supply sinusoidal. THD is measured using source current waveforms. Total harmonic distortion is calculated as Table 4 with and without SAPF.

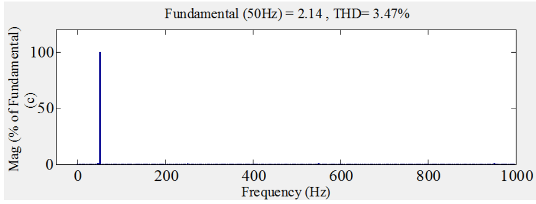



Figure 11: Frequency spectrum of source currents (phase a, phase b phase c respectively) after compensation for RD-FLC based APF with non linear

Table 4: FFT Analysis of THD

| Elements | *p.f.* | THD |
|---|---|---|
| Non linear load (with SAPF) | 0.8785 | 3.31% |
| Non linear load (without SAPF) | 0.5887 | 38.85% |

The simulation is done for nonlinear load condition. Spectral analysis proves that the SAPF based on RD-FLC brings the total harmonic distortion of source current to less than 5%, which meets IEEE-519 standards for harmonics under balance and unbalance conditions.

# 6 Conclusion

In this investigation, SAPF uses a PLL synchronization circuit with reduced fuzzy logic controller(RD-FLC). It is demonstrated that SAPF with the proposed controller keeps DC link voltage nearly constant and settles under non-linear loads condition. The shunt active power filter is connected to AC mains in parallel with the load. It compensates three-phase current harmonics and reactive power under non-linear load conditions. The reference currents are generated using RD-FLC with a PLL synchronization control algorithm. The proposed SAPF is validated through MATLAB simulation. The performance parameters are represented graphically and THD is found to be 3.31 % under non linear load condition, which complies with IEEE standards. The performance of the proposed approach is found to be satisfactory under non-linear loads condition.

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