Performance Analysis Of Shunt Active Filter Using Different Controllers

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***Abstract*— In this paper, Performance of Shunt active power filter (SAPF) is analyzed for various types of non linear loads. Among the various control schemes available for SAPF, indirect current control scheme is used here. PI controller and fuzzy logic controller are used to analyze its performance for various types of nonlinear loads (R, DC motor, Induction motor). The output parameters are Total Harmonic Distortion (THD) and power factor. The results are obtained with the conventional PI controller and fuzzy controller. The proposed method offer an efficient control method under the various load conditions results in power factor improvement and THD reduction. Simulation of the proposed controller(PI and fuzzy logic controller) of a shunt active power filter has been carried out in MATLAB/SIMULINK and the aim is to reduce the THD and improve the power factor.**

***Keywords* - Active power filter(APF), Harmonics,Power quality, Selective harmonic compensation**

I. INTRODUCTION

The main objective of the power system is generation of electrical energy to transmit and distribute to the end-user. Many power system are internally connected into a network. If a fault exists in any one of the network, it should affect the whole power system. Transients, sagging, variations in voltage, harmonics are the some of disturbances affecting power system. The aim of this paper is to reduce the current harmonics. Basically, AC electrical power system mainly uses non-linear loads. For these types of loads, the load current and voltages are non-sinusoidal. So it is necessary to compensate the voltage and current harmonics. Non-linear loads are mainly used in adjustable-speed drives, switch mode power supply(SMPS), and unintertable power supply(UPS). These types of loads will cause harmonic voltage drop across the network impedance, resulting in distorted voltage. Harmonics are one of the major concern in a power system. Harmonics are the non-integer multiples of the fundamental frequency. It is generated in a power system by means of non-linear loads. In order to reduce the harmonic distortion two types of filters can be used. 1) active filter 2) passive filter. A passive filter is composed of only passive elements such as inductor, capacitor and resistor. The passive filters are inexpensive. But they are ineffective due to the inability to adapt to network characteristic variations, which leads the use of active filters. an active filter is implemented when orders of harmonic currents are varying. It use active components such as MOSFET, IGBT-transistors etc. Its structure may be either of the series or shunt type. Shunt active power filters are widely used for mitigating current harmonics. Series active filters are widely used for mitigating voltage harmonics. The drawbacks of series active filter is, they have to handle high load currents, which increase their current rating and increasing I^2R losses. It is mainly used at the load because non-linear loads inject current harmonics. It injects equal compensating currents, opposite in phase,to cancel harmonics and/or reactive currents of the non-linear load current at the point connection.

More recently, voltage source inverter or current source inverter based active power filter is used. They have many advantages as compared to the previously used methods, which include potential size, weight and cost reduction ,small size and light weight, low power losses, tracking of the power system frequency change, fast dynamic response to load changes and reduction of resonant problems. In addition, APF can provide other conditioning functions such as reactive power control, load balancing and flicker mitigation. selective harmonic compensation can be used in to reduce the harmonics chosen by the designer.

Many types of control schemes and controllers are available. The control algorithms are stationary reference frame theory, indirect current control method, Hysteresis current control, Band-rejectfilter method, and Synchronous-detection algorithm. Along with these, different soft computing techniques are used such as Artificial Neural Network (ANN), Genetic Algorithm (GA). Here linear current control scheme with PI and fuzzy logic controllers are discussed. This paper presents an alternate and effective method for controlling shunt active power filter. A fuzzy logic control based (FLCB) shunt active filter (SAF) capable of reducing harmonic distortion in power system proposed. The proposed method has advantage that the control block becomes simpler. The dc link fuzzy control has better dynamic behavior than conventional PI controller. The factors should be analyzed are total harmonic distortion(THD) and power factor(PF) improvement. The shunt active filter control seems to be an attractive solution for harmonic current pollution problem. Here, harmonics reduction in the source current and power factor improvement are considered.

II. SHUNT ACTIVE POWER FILTER WITH NON-LINEAR LOAD

Shunt active filter is used in the load side of the system. Because non-linear loads is to generate harmonics in the current waveform.

A. Basic concept of active power filter

Fig.1shows the configuration of active power filter with non-linear load. The basic operating principle of active power filter is that a non sinusoidal waveform at a bus can be corrected to sinusoidal by injecting current of proper magnitude and waveform.

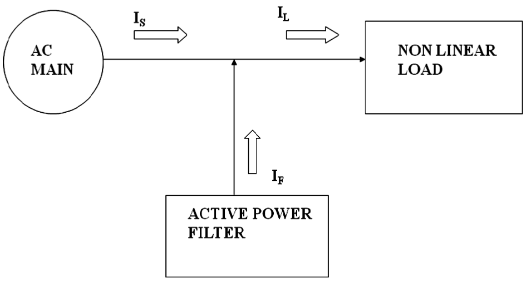

Fig.1 Basic concept shunt active filter

The basic concept of APF is explained in fig

$$I_L = I_S + I_F \qquad (1)$$

The load current having fundamental and harmonic content, and I_F is the harmonic compensating current.

$$I_L + I_H = I_S + I_H \qquad (2)$$

Filter provide harmonic requirement of the load

$$I_L + I_H = I_S + I_H \qquad (3)$$

$$I_L = I_S \qquad (4)$$

Thus the supply current represents the fundamental waveform input output harmonics. Fig.2. shows the configuration of active shunt filter with non-linear load and the full bridge converter. which is almost widely used to eliminate current harmonics, reactive power compensation and balancing the unbalanced currents.

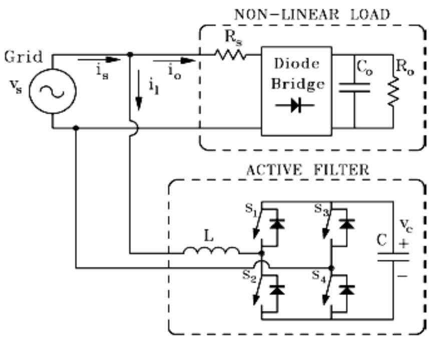

Fig.2 Shunt APF with non-linear load and the full-bridge converter

B. Non-linear loads

Non-linear loads are considered as the second category of loads. The application of sinusoidal voltage does not result in a sinusoidal flow applied sinusoidal voltage for a non-linear devices. In this system the nonlinear load consists of a diode bridge, a series resistance (R_s), a load resistance (R_o) and a load capacitance (C_o), Induction motor load, and DC motor load.

III. CONTROL LOOPS

This section reviews the, Indirect current control method, based on the outer voltage loop and inner current loop.

A. Design of the outer voltage loop

For an indirect current control method, outer voltage loop is mainly used for capacitor voltage regulation. The capacitor is mainly used at the load side. For the design of outer voltage loop cut off frequency and phase margin is essential. Its value should be 2.5Hz and 56^0 based on the small signal model analysis.

B. Inner current loop

For this linear current control scheme inne current loop is used for reference current tracking.Based on that reference is subtracted from the actual current, error current is produced. And then error current is compensated by PI controller.

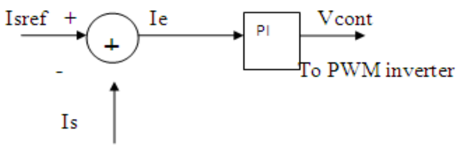

Fig.3 Inner current loop

The control signal Vcont is the input of a pulse width-modulation. It will drives the power switches.

C. Reference generator

A reference generator is used to produce reference current signal by using the controller $H_1(s)$ and $H_2(s)$. Source current and reference current are subtracted. This operation is based on the closed loop Loop operation of notch filters.

The generalized integrators can be expressed as

$$H_1(s) = \frac{2\xi\omega_1\kappa_1 s}{s^2 + 2\xi\omega_1 s + \omega^2_1} \qquad (5)$$

$$H_2(s) = \sum_{n=3}^{h} \frac{2\xi n\omega_1\kappa_n s}{s^2 + 2\xi n\omega_1 s + (n\omega_1)^2} \qquad (6)$$

The filter current is used in the inner current loop in order to track the load current harmonics. As an alternative, the indirect method generates a sinusoidal reference signal by means of grid-voltage sensing.

IV. SAPF WITH PI CONTROLLER

The main drawback of using repetitive current control is, there is no control action, to avoid the distortion From the grid voltage. In-order to overcome this drawback, it needs some additional algoritham.

A. Conventional method

The PI controller operation with shunt active filter is shown in figure.6.source voltage and source current values are given to the reference generator. It will produce I_{ref} and given to PI controller. Using PI controller error should be compensated.

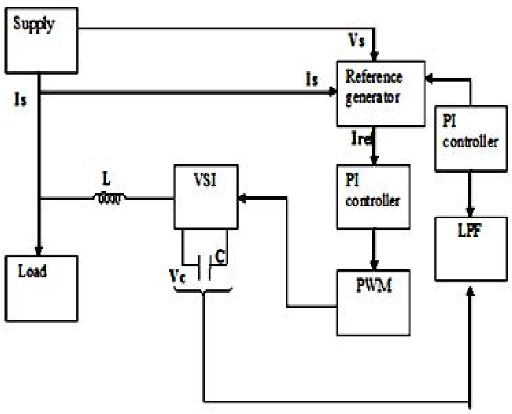

Fig.4 Structure of PI controller

A low-pass filter is used to attenuates the frequencies higher than the cutoff frequency. It is sometimes called a high-cut filter, or treble cut filter when used in audio applications.A filter with low pass crossover frequency 10Hz is used. Based on the PWM signal the switches will be operated. And the signal is given to the Inverter bridge.

B. Power Supply

A single phase 110V, 50Hz, 500VA AC supply has been used for designing the whole circuit in simulation by Mat lab 7. 9 simulink. The switching frequency is selected as 15 kHz.

C. PWM Inverter

PWM or Pulse width Modulation is used to keep the output voltage of the inverter at the rated voltage (110V AC / 220V AC) irrespective of the output load.

V. SAPF WITH FUZZY LOGIC CONTROLLER

The Fuzzy Logic tool is a mathematical tool for dealing with uncertainty. It is important to observe that there is an intimate connection between Fuzziness and Complexity.

A. Fuzzy Logic Controller

fuzzy logic controller (FLC) are suitable for systems that are structurally difficult to model due to naturally existing non linear ties and other model complexities. This is because ,unlike a conventional controller such as PI controller, rigorous mathematical model is not required to design a good fuzzy controller. The database, consisting of membership functions. Basically membership value should lies between 0 to 1. The operations performed are fuzzification , interference mechanism and defuzzification. The interference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally defuzzification is used to convert the fuzzy outputs into required crisp signals.

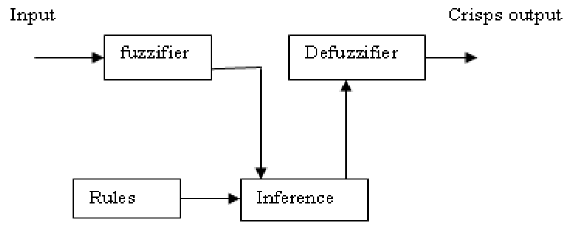

Fig.5 Fuzzy controller block diagram

B. Fuzzification

Fuzzification is an important concept in the fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy (crisp to fuzzy).By identifying some of the uncertainties present in the crisp values, we form the fuzzy values. The conversion of fuzzy values is represented by the membership functions .

C. Defuzzification

Defuzzification means the fuzzy to crisp conversions .The fuzzy results generated cannot be used as such to the applications, hence it is necessary to convert the fuzzy quantities into crisp quantities for further processing.

D. FLC Design Methodology

Design of fuzzy logic controller comprises the following steps.

1.Identifying the input signals to FLC.
2.Determining the number of membership function, and
3.Decide upon the type of membership function.

E. Membership function

The number of membership function determines the quality The number of membership function determines the quality of control which can be achieved using fuzzy logic controller(FLC). As the number of membership function increase, the quality of control improves at the cost of increased computational time and computer memory. Investigations are carried out considering seven membership function for each input and output signal.

Table 1. Fuzzy rule Base

e / de	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	NL	NM	NS	ZE	PS	PM	PL

F. Fuzzy control scheme for APF

In the fuzzy logic control algorithm for APF two inputs are required. The inputs are error and chancge in error. The two inputs were related by member functions. Basically forty nine rules are there. Based on the operation it will be used. The membership functions are expressed in negative large (NL), negative middle (NM), negative small(NS), zero(ZE), positive small(PS), positive middle(PM) and positive large(PL). Actual voltage is compared with the reference voltage, based on that error will be produced. It can be compensated by using fuzzy logic controller. Actual current is compared with the reference current, and error is compensated by fuzzy controller. Fuzzy sets support a flexible sense of membership functions.

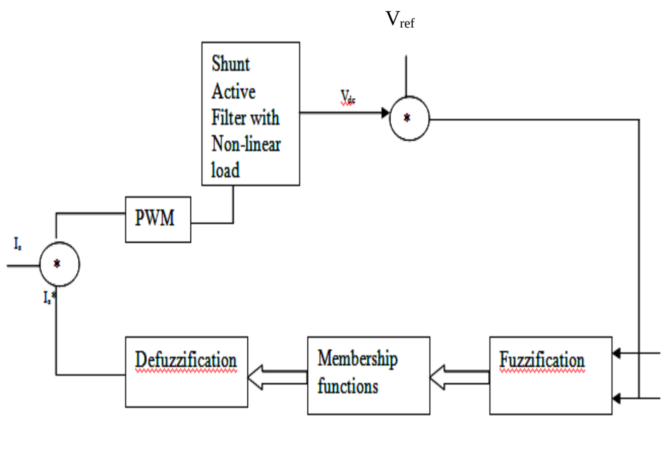

Fig.6. Structure of the fuzzy for APF controller

A triangular membership function has the advantage of simplicity and easy implementation and is adopted in the application. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The centroid method of defuzzification is generally used, but the disadvantage of this method is, it is computationally difficult for complex membership functions. Here bisector method of defuzzification is used.The advantages of bisector method are ,it is fast and generally produces good results.

Table 2. System Parameters

Symbol	Quantity	value
V_s	Grid voltage	110V
F_1	Grid frequency	60Hz
R_s	Non-linear load series resistance	4Ω
R_o	Non linear load resistor	90Ω
C_o	Non linear load capacitor	500uF
L	Active filter inductance	3.14mH
C	Active filter capacitance	1.5mF
K_{pv}	Propotional voltage control gain	1e-6
K_{iv}	Integral current control gain	5e-6
K_{pi}	Propotional current control gain	2
K_{ii}	Integral currentcontrol gain	2.10^{4}

VI. SIMULATION RESULTS

Simulations were performed to show the effectiveness of the APF, by means of PI controller and fuzzy logic controller with multiple non-linear loads. which can control the THD and Power factor improvement. The simulation model of the shunt active power filter with PI controller(R-load) is shown in Fig.7.

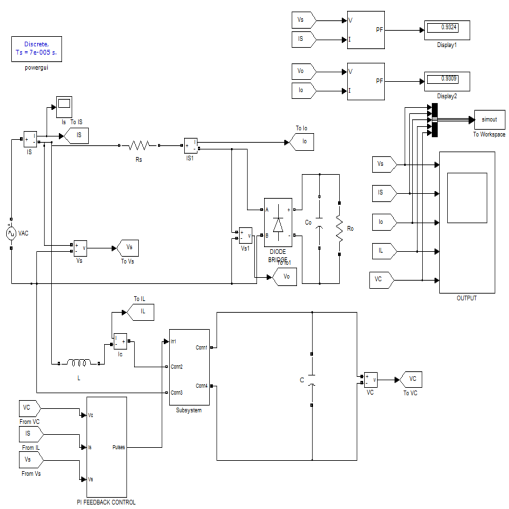

Fig.7 SAPF with PI controllers

Simulation results with PI controller

Waveform for source voltage, source current, load current with PI controller fig.8. fig.8.a,b,c,d shows that the source voltage, source current ,and load current, filter current. The harmonic profile of the source current is shown in fig.9.

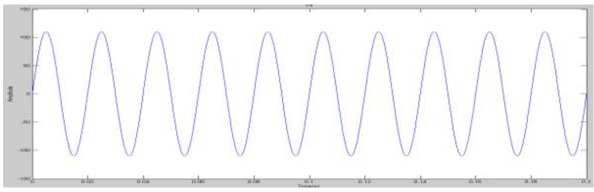

Fig.8a Source voltage with PI Controller

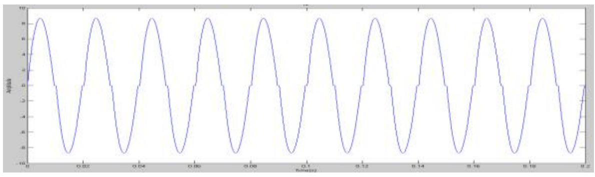

Fig.8b Source Current with PI Controller

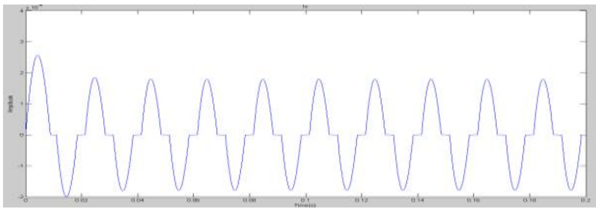

Fig.8c Load Current with PI Controller

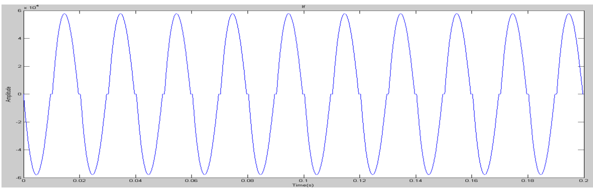

Fig.8d Filter Current with PI Controller

FFT analysis with PI

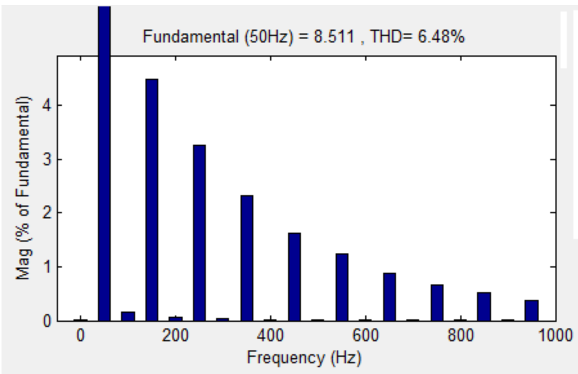

Fig.9 FFT analysis of source current with PI controller

The simulation model of the shunt active power filter with fuzzy controller is shown in Fig.10

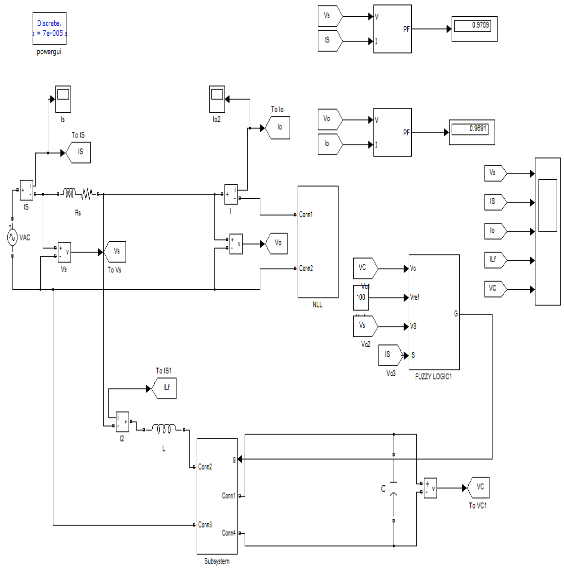

Fig.10 SAPF with fuzzy logic controller

Simulation results with fuzzy logic controller

Waveform for source voltage ,source current, load current with fuzzy logic controller fig.10.. fig.10a,b,c,d. shows that the source voltage, source current, and load current, filter current. The harmonic profile of the source current is shown in fig.11.

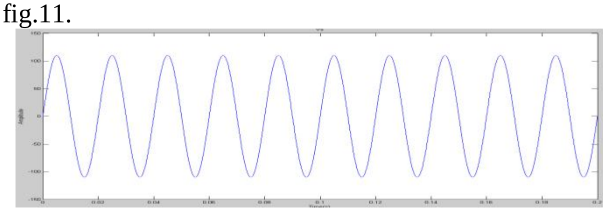

Fig.10a. Source Voltage with Fuzzy Logic Controller

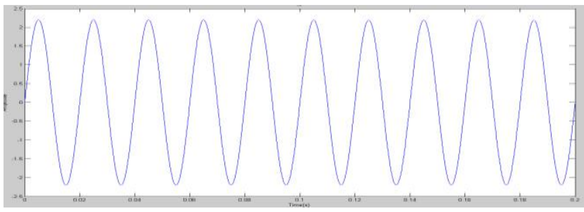

Fig.10b. Source Current with Fuzzy Logic Controller

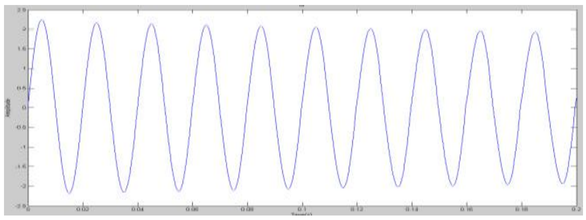

Fig.10c. Load current with Fuzzy Logic Controller

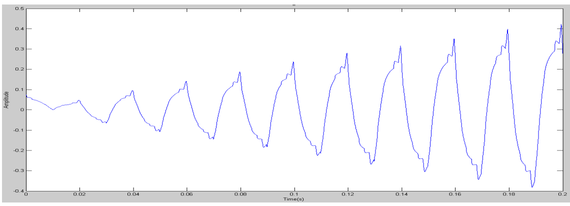

Fig.10d Filter Current with FLC

FFT analysis with FLC

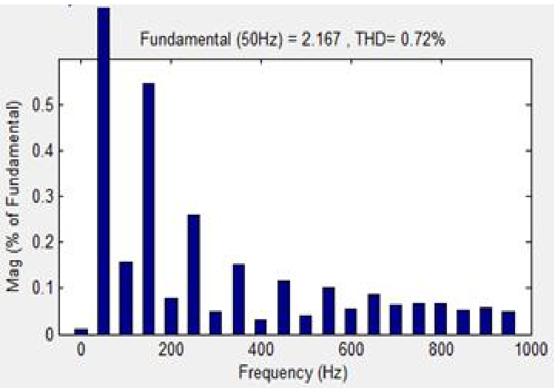

Fig.11 FFT analysis of source current with FLC

Performance comparision

From the simulated circuits, We found that the total harmonic distortion is reduced from 31.57% to low value with fuzzy logic controller which is well within the permissible limit of 5% as recommended by IEEE-519 standard.

LOADS	APF with PI controller		APF with FUZZY logic controller	
	THD%	PF	THD%	PF
R	6.48	0.9324	0.72	0.9708
DC-motor	7.32	0.8265	0.08	0.9346
Induction motor	15.55	0.8314	10.6	0.8826

Table3. Performance comparision

VII. CONCLUSIONS

The proposed method provides an efficient method of achieving better THD and control of active power filter dealing with harmonic and reactive current compensation. The control of an active power filter using fuzzy logic controller is simulated in MATLAB 7.9/Simulink and the simulation results are compared with the conventional PI controller. From the comparison, it was found that the shunt active filter with fuzzy logic controller attained more power factor than that of with PI controller. The total harmonic distortions were observed to be more for shunt active power with PI controller than with fuzzy logic controller. The simulation results shows that the shunt active filter with fuzzy logic controller gives better result for all type of loads. Using fuzzy logic controller THD is considerably reduced, and the power factor gets improved.

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