Performance Analysis of A PI Controller and A Fuzzy Controller for Single Phase Shunt Active Power Filter

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ABSTRACT: Recent wide spread applications of power electronic equipments have caused an increase of the harmonic disturbances in the power systems. The nonlinear loads draw harmonic and reactive power components from AC mains. Here a PI controlled shunt active power filter and fuzzy controlled shunt active power filter are presented to eliminate harmonics and to compensate the reactive power of single phase rectifier. The performances of both controllers are analyzed from the simulation results obtained.

KEYWORDS: Active power filter, PI controller, Fuzzy Controller, Hysteresis Current Controller

I. INTRODUCTION

Power quality has become a research topic in power distribution systems due to a significant increase of harmonic pollution caused by proliferation of nonlinear loads, rectifiers, switching power supplies, and other line connected power converters. Harmonic pollution in electrical networks cause voltage distortion, additional losses and heating in electrical equipments, perturbing torque, vibrations and noise in motors, malfunction and failures of sensitive equipment, resonances and interference with electronic equipment and premature ageing[8] .

Traditionally passive inductance-capacitance (LC) filters have been used to eliminate the current harmonics and to improve the power factor. However, passive LC filters are bulky, load dependent and inflexible. They can also cause resonance to the system [9]. For instance, shunt active filters are known to be an appropriate means of eliminating harmonic contamination created by nonlinear loads [5].

Active power filters can be divided into single phase and three phase active filters. Single phase APFs have attracted less attention than three phase APFs because they are limited to low power applications. However, installing low power single phase APF near each single phase non-linear load may be sometimes a better solution than installing one medium power three phase APF at the point of common coupling due to simplicity of control without complex heavy mathematical equations and decreasing cost of APF from medium to low power.

In this paper, a simple control scheme of single-phase shunt active power filter for harmonic and reactive power compensation of linear and non-linear loads is proposed. Proposed APF consists of two major parts; power circuit and control circuit. Power circuit comprises a voltage source single phase converter that works bi-directionally in two modes; inverter and charger, an energy storage capacitor at the dc side and a filter inductor at the ac side. Control circuit comprises a reference current generator, a hysteresis current controller and a fuzzy logic based or PI based dc bus voltage controller.

Outputs of control circuit are the gating signals for the power switches. To indicate the steady state and transient performance, some simulation results are presented.

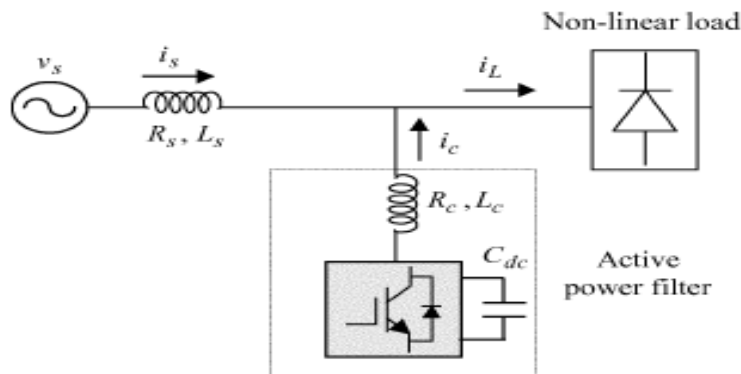## II. SINGLE PHASE SHUNT ACTIVE POWER FILTER

Fig 1. The Shunt Active Power Filter

Shunt active power filters can be classified depending on inverter types as a current source inverter (CSI) or a voltage source inverter (VSI). In this study a single phase shunt active power filter which is also known as a VSI has been used. The shunt active power filter comprises a DC capacitor, semiconductor switches and a line inductor. Figure 1 illustrates the structure of a shunt active power filter. Shunt active power filters compensate load 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°.Thus the source current is forced by the current components to be in sinusoidal waveform. The relationship between these currents is given in Equation 1.

$$I_C = I_L - I_S \tag{1}$$

III. CONTROL OPERATION OF INVERTER

A. Reference Current Generation

In order to determine harmonic and reactive component of load current, reference source current generation is needed. Thus, reference filter current can be obtained when it is subtracted from total load current. For better filter performance, generation of reference source current should be done properly. For this purpose several methods such as pq-theory, dq-transformation, multiplication with sine function and Fourier transform can be used. Here Fourier transform is used for extraction of reference source current. This method requires very less computation time compared to the other methods.
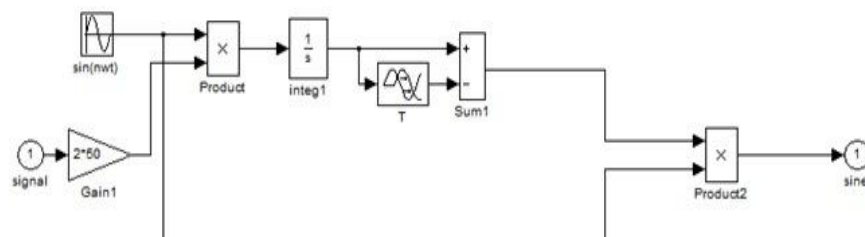

Fig 2. Reference Current Generation Block

When a signal is expanded using Fourier series, we have fundamental component and harmonics. As we need to supply harmonics only, the filter has to supply load current minus fundamental. So by Fourier series, we calculate the fundamental first and then it is subtracted from load current to give reference current for active filter.

B. DC Bus Voltage Control

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 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.

However, when the load condition changes the real power balance between the mains and the load will be disturbed. This real power difference is to be compensated by the DC capacitor. This changes the DC capacitor voltage away from the reference voltage. In order to keep satisfactory operation or the active filter, the peak value of the reference current must be adjusted to proportionally change the real power drawn from the source. This real power charged/discharged by the capacitor compensates the real power consumed by the load. If the DC capacitor voltage is recovered and attains the reference voltage, the real power supplied by the source is supposed to be equal to that consumed by the load again.

1. PI Controller

The PI controller consists of a proportional term and an integral term. Proportional value determines the reaction to the current error; the Integral determines the reaction based on the sum of recent errors. Kp and Ki are the proportional and the integral gains of the dc bus voltage PI controller.
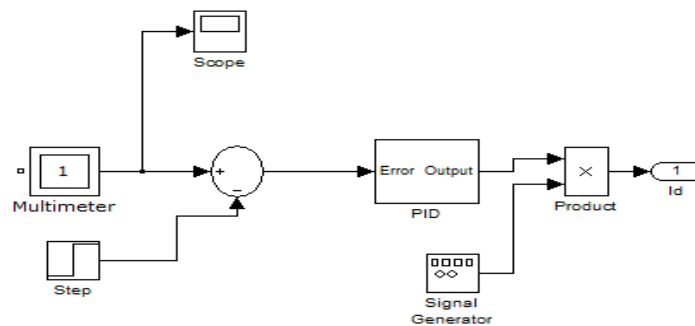

Fig 3.PI Controller For DC Voltage Control

Here the values of proportional and integral gain taken as Kp=10, Ki=0.1. PI controller has been widely used for DC bus voltage regulation in shunt active power filters. This operation has been performed by comparing the real DC bus voltage of the active power filter with a reference DC bus voltage. Difference between two values is error signal applied to PI controller input. The PI controller output is active component added to the active component of load current. Thus the filter losses have been supplied from the grid in steady state and power balance between the grid and the load has been protected in transient state.

PI controller need a precise mathematical model of the system otherwise the control operation of PI controller is not efficient and accurate. If there are any changes occurring in the system, the existing PI controller in the system is not able to provide sufficient control of dc capacitor voltage and as a result the THD value is not reduced.

2. Fuzzy Controller

The fuzzy controller has two inputs, one is error voltage of dc capacitor voltage and other is change of voltage (previous error – current error). These two inputs have seven Gaussian membership functions in linguistic terms, by using these

function the 49 'IF THEN' rules were generated. Output of fuzzy controller is active component added to the active component of load current which a crisp number and it is obtained by using Centroid method. The rule base of the fuzzy controller is given in Table I.

$e(n)$ \ $ce(n)$	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	MN	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table 1. Rule Base For Fuzzy Controller
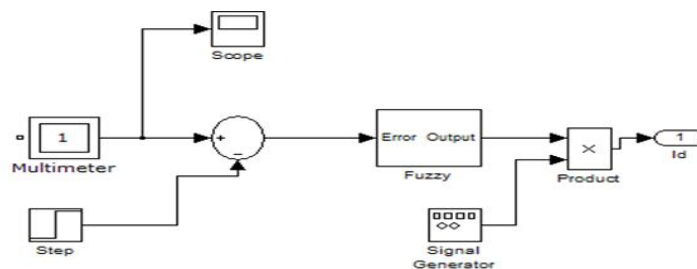
Fig 4. Fuzzy Logic Based DC Voltage Controller
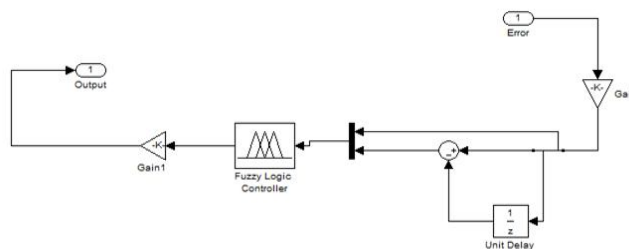
Fig 5. Fuzzy Controller

Mamdani Fuzzy system has been used in the fuzzy controller. The input and output variables of the fuzzy logic controller have seven membership functions named as negative big (NB), negative medium (NM), negative small (NS), zero (Z),

positive big (PB), positive medium (PM) and positive small (PS). Figure 6 depicts the membership functions of inputs, while the membership functions of output variable are shown in Figure 7.
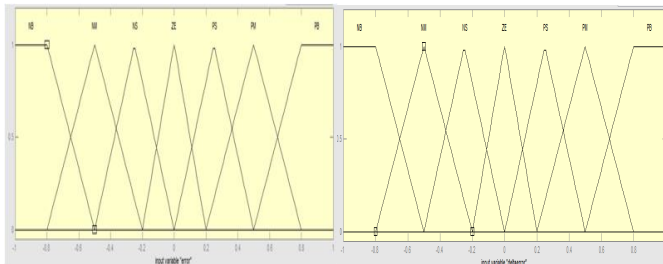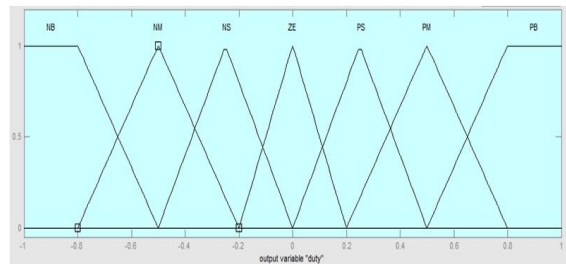

Fig 6. Membership Functions of Inputs   Fig 7.Membership Functions of Output

The advantages of fuzzy controllers are that they do not require an accurate mathematical model; it can work with imprecise inputs, can handle non-linearity, and are more robust than conventional controllers.

C. Hysteresis Current Controller

   The third stage of the shunt APF control circuit is generating appropriate gating signals for the power switches that forces the filter current follow derived reference current. The goal is to reduce the current error. In this paper, hysteresis band current control method is used because implementation of this control is not expensive and the dynamic answer is excellent. It allows a fast current control. Unfortunately, in this control it is not possible to fix the commutation frequency. However, this disadvantage is not ever critical and current controllers based on this method are now standard in most APF control schemes.
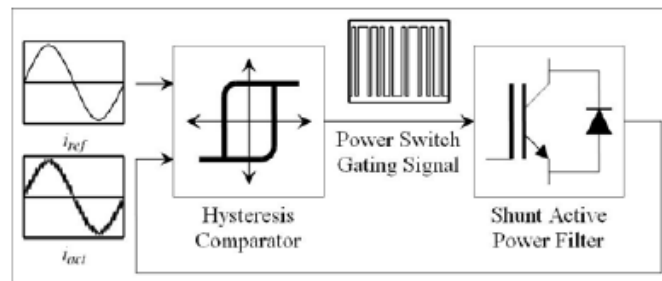

Fig 8.Block diagram of hysteresis Current Controller

   The operating principle of the hysteresis band current controller which is shown in Fig. 8, depends on comparing of measured APF output current with its reference by the hysteresis comparator. The outputs of the comparator are the power switch gating signals.

   If the measured filter current is bigger (half of the band value) than the reference one, it is necessary to commute the corresponding power switches to decrease the output current, and it goes to the reference. On the other hand, if the measured current is less (half of the band value) than the reference one, the switches commute to increase output current and it goes to the reference. As a result, the output current will be in a band around the reference current.

IV. SIMULATION STUDY

The simulation circuit has been developed in a Matlab/Simulink/simpower tool to prove the validation of the proposed technique. The system parameters used for simulation are given in Table 2 and the simulation diagram is shown in figure 9.

SOURCE VOLTAGE	230V
SOURCE INDUCTANCE	1mH
FILTER INDUCTOR	0.8mH
DC CAPACITOR	500mF
LOAD RESISTOR	10Ω
LOAD INDUCTOR	100mH
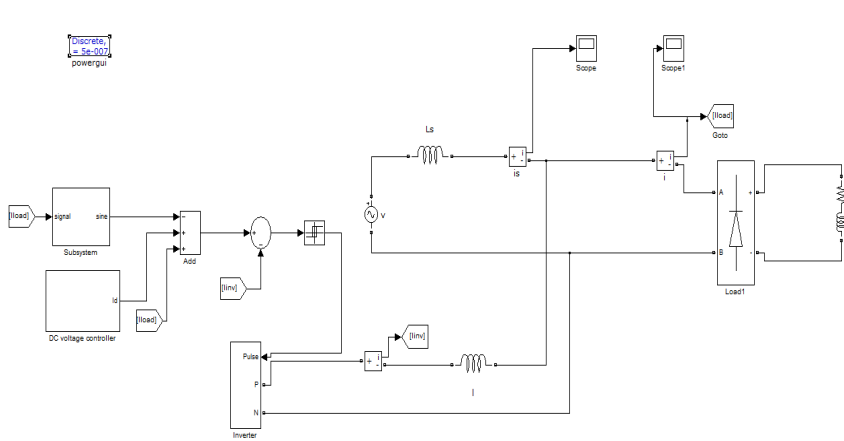
Table 2.Simulation Parameters   Fig 9.Simulation Diagram of the System

V. PERFORMANCE ANALYSIS

In this study, waveform of the grid voltage has been assumed as a pure sinusoidal. Figure 10 illustrates the waveform of the load current and the THD analysis of the load current is given in Figure 11 before connection of shunt active power filter. The load current is equal to the mains current before the connection of the active power filter and the THD ratio of a nonlinear load current has been measured as 42.33%
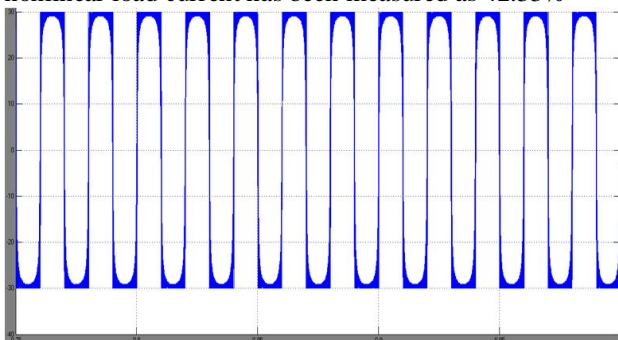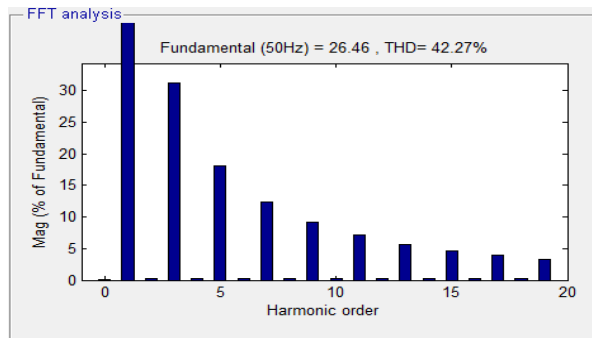

Fig 10. The Load Current   Fig 11. THD Analysis of Load Current

A. PI Controller

After connecting PI controller based SAF, the THD of the source current is reduced from 42.27% to 1.64%. Fig 12 shows the filter current supplied by filter. The waveform of the source current is shown in Figure 13, while Figure 14 illustrates the THD analysis of the source current.
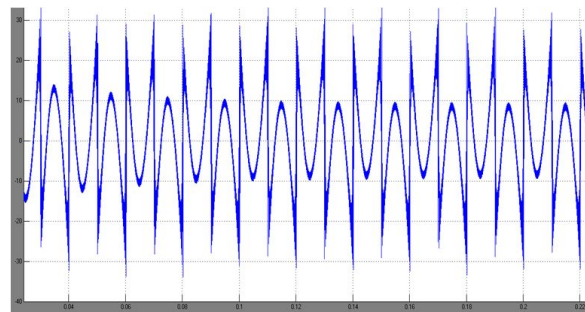

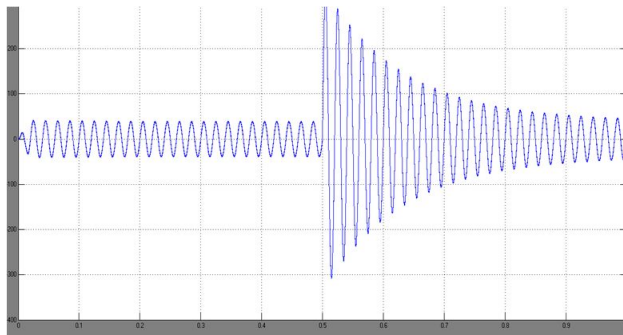Fig 12. Filter Current Supplied by Filter
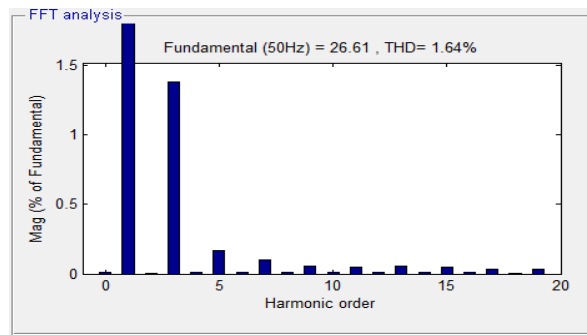

Fig 13. Source Current with SAF

Fig 14.THD Analysis of Source Current

B. Fuzzy Controller

Fuzzy logic based SAF reduces the THD of the source current from 42.27% to 0.86%.Filter current supplied by SAF is shown in figure 15. The waveform of the source current is shown in Figure 16 while Figure 17 illustrates the THD analysis of the source current.
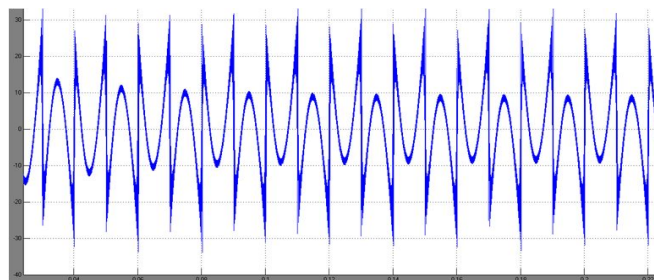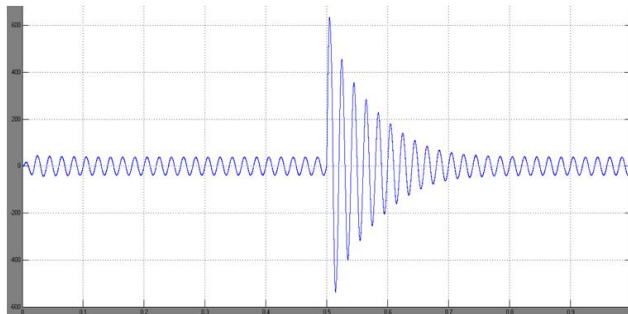

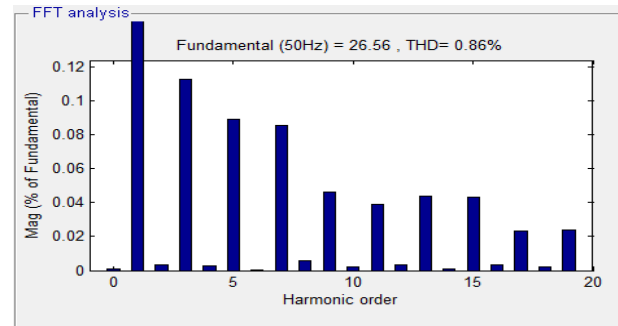Fig 15.Filter current supplied by SAF

Fig 16.Source Current with SAF

Fig 17.THD Analysis of Source Current

The above result shows that THD gets reduced significantly on using a fuzzy controller than with the conventional PI controller.

When sudden changes occur in the system, the PI controller alone is not sufficient for controlling the dc capacitor voltage. But in the case of fuzzy controller, the THD level reduces below the IEEE standard.

VI CONCLUSION

The harmonics caused by nonlinear loads result in low power factor and losses in power systems. To minimize this problem, shunt active power filters have been used. A PI controlled shunt active filter and fuzzy controlled shunt active filter are presented in the paper. From the simulation results it is clear that THD has been reduced from 42.27% to 1.64% in case of PI controller and to 0.86% in case of fuzzy controller .So fuzzy controller is able to provide much better performance than PI controller under varying load condition.

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