

A Novel Approach in Design of a Fuzzy Based Shunt Active Power Filter for the Enhancement of Power Quality

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Abstract

Active power filters most of the times are employed for elimination of the harmonics created by non-linear loads in power system and for reactive power compensation of linear and non-linear loads. Compensating current is sent by shunt active power filter (SAF) at Point of Common Coupling (PCC) to mitigate current harmonics in the line. Hence sinusoidal nature of current and voltage waveforms are reintroduced. Usually shunt active power filters are connected in parallel with non-linear and reactive loads. Fuzzy logic controller is used as it doesn't require complex mathematical model. Filter inductor current is shaped by fuzzy controller so that line current is in phase with and of input voltage shape. Simulation of the proposed filter is carried out using MATLAB/SIMULINK.

Keywords

Shunt active power filter, fuzzy logic controller, hysteresis band current controller, power quality.

1. Introduction

Nowadays there has been tremendous growth of power semiconductor technology resulting in increase of power electronics based devices like uninterruptible power supplies (UPSs), Static var compensators (SVCs) and adjustable speed drives (ASDs). There has been destruction of power quality because of increase in number of non-linear loads. As current and voltage harmonics are existing in the power distribution system, it leads to larger losses in the lines and hence diminishes power factor and ultimately results in resonance with capacitors which is in parallel with the system. Harmonics have adverse effect on power system network and hence lead to overheating of neutral conductors, bus bars, motor and switchgear, measuring instruments error, unbalanced power supply, large neutral current, reduced power factor and overall poor efficiency.

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Problems regarding power quality are mostly in commercial, industrial and utility networks. To minimize problems related to harmonics, power distribution utilities are initiating serious standards on its customers. These standards keep control on the amplitude of current harmonics and highest level of Total Harmonic Distortion of voltage waveform which is permitted by utility. It is important to mitigate harmonics less than 5% as mentioned in IEEE 519-1992 harmonics standard. Now the next question arises how to minimize the problems related with the harmonics and hence enhance the power quality.

Earlier days, passive filters (LC filters) have been used to reduce current harmonics created by non-linear loads and power electronics devices. Also capacitor banks are used for correction of power factor of AC loads. But the passive filters have the disadvantage of huge size, large weight, more losses and resonance problems [1]. To overcome these problems of passive filters active power filters were developed which are also known as active power line conditioner or active power quality conditioner. Active power filters have the advantage of small size and weight, less losses and elimination of resonance problems. But still they have demerits as they are more expensive and difficult to handle.

Most important configuration for active power filters is shunt active power filter which is connected across non-linear loads. Active power filters are classified as single phase and three phase active filters. If voltage harmonics elimination is required, active power filter is connected in series and for current harmonics compensation, it is connected in parallel [2]. Active filters use active components such as MOSFET, IGBT, transistor etc. The paper consists of single phase shunt active power filter for the purpose of harmonics and reactive power compensation of linear and non-linear loads.

2. Fundamentals of shunt active power filter

Fig.1 shows the fundamental concept of active power filter [2]. It works on the principle that a distorted sine waveform at a bus is converted into pure sinusoidal waveform by sending current of correct magnitude and waveform at PCC.

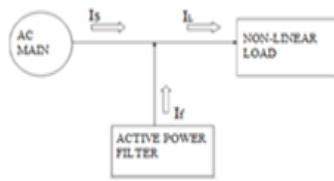


Fig.1: Basic concept of shunt Active filter

Its fundamentals are explained using simple equations given below:

$$I_L = I_S + I_F$$

(1)

The load current consists of fundamental and harmonic components and I_F is harmonic compensating current. $I_L + I_H = I_S + I_H$

(2)

Filter injects the current which is required for harmonic current compensation

$$I_L + I_H = I_S + I_H$$

(3)

$$I_L = I_S$$

(4)

Fig.2 depicts the shunt active filter with full bridge converter and non-linear load which results in mitigation of current harmonics, reactive power compensation and balancing of unbalanced currents.

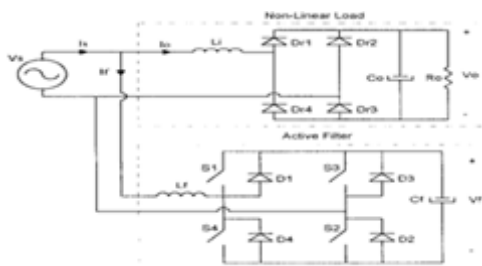


Fig.2: Shunt Active power filter

3. Configuration of active power filter

Fig.3 shows the proposed block diagram of shunt active power filter which comprises of power circuit and control circuit. Power circuit and control circuit are the two major components of shunt active power filter [1]. Single phase converter operates in two directions in two modes: conversion from Dc to Ac i.e. inverter and conversion from Ac to Dc i.e. charger, Dc side capacitor and Ac side inductor are the three main components of power circuit. Reference current generator, hysteresis current controller and fuzzy logic controller [6] are the three main components of control circuit. As the power switches require gate pulses to turn on them, output of control circuit which are gating signals are fed to power

switches. Finally, to depict the circuits' performance, simulation results are shown.

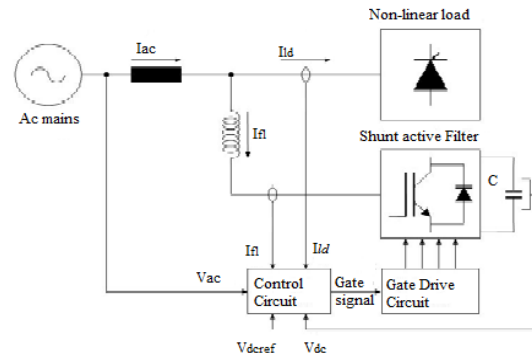


Fig.3: Block diagram of shunt active power filter

The block diagram of proposed filter consists of single phase voltage source, full bridge converter consisting of IGBT switches with Dc side having condenser and it is in parallel with linear and non-linear loads and Ac side consisting of filter inductor. Various types of linear and non-linear loads [1] are shown in Fig.4.

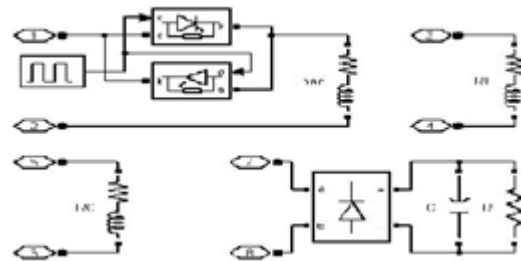


Fig.4: various types of linear and non-linear loads

Loads in which current and voltage waveforms are sinusoidal are known as linear loads i.e. current is in proportion with voltage at any instant of time. Ex: Capacitor, incandescent lamp, heater, resistive, inductive loads. Loads in which current and voltage waveforms are not proportional to each other are non-linear loads. Ex: computer, laser printer, rectifier, PLC, refrigerator, T.V etc.

4. Control methodology

4.1. Fundamental reference source current estimation

Reference source current generation is required to estimate harmonic current and reactive content of load current. It is required to follow proper methods and procedures to generate reference source current [3]. The converters need current reference signals which are found by reactive power theory at each instant. As per the reference signals, active power filter is able to compensate

for displacement power factor of the system. Here we are using product of sine function method for getting reference source current as depicted in Fig.5. The advantage of using this method is that it requires less computation time.

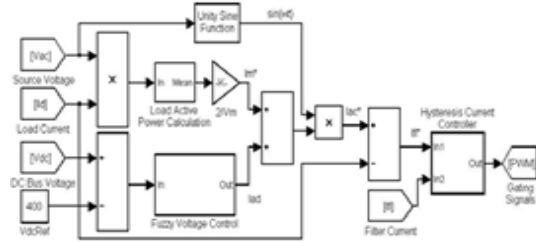


Fig.5: Block Diagram of proposed control scheme

From the block diagram it can be clearly explained that source voltage and load current are fed to product block. Dc bus voltage and Dc reference voltage are fed to add block with negative sign. These two blocks are available in Simulink library Browser. The output of product block is fed to load active power calculation block. The output of add block is fed to fuzzy voltage controller. Finally providing gain as circuit design parameter, hysteresis controller [4] is fed with output of load active power calculation and filter current. The following equations clearly explain how the harmonics are compensated and later how the source current will be in phase with the voltage.

$$V_a(t) = V_{max} \sin(\omega t) \quad (5)$$

$$I_a(t) = I_{max} \sin(\omega t) \quad (6)$$

$$P_{load}(t) = V_a(t) I_a(t) = V_{max} I_{max} \sin^2(\omega t) \quad (7)$$

Load takes the active power which is given by equations (8) and (9)

$$P_{load} = \frac{1}{2\pi} \int_0^{2\pi} V_{max} I_{max} \sin^2(\omega t) d\omega t \quad (8)$$

$$P_{load} = \frac{V_{max} I_{max}}{2} \quad (9)$$

If we equate load active power before and after compensation, maximum value of reference source current is calculated as

$$I_{max}^* = \frac{2P_{load}}{V_{max}} \quad (10)$$

Reference source current is given by :

$$I_a^*(t) = I_{max}^* \sin(\omega t) = \frac{2P_{load}}{V_{max}} \sin(\omega t) \quad (11)$$

Reference filter current is given by :

$$I_{filter}(t) = I_a^*(t) - I_{load}(t) \quad (12)$$

4.2. Description of shunt active filter using Fuzzy logic controller

4.2.1. Basics of Fuzzy concept

Fuzzy logic variables have truth values which are in the range of degree between 0 and 1. Fuzzy logic is related to reasoning which is approximate but not fixed and exact. Fuzzy logic term was inferred in 1965 by Lotfi A. Zadeh. Whenever it becomes complex to form mathematical equations, fuzzy logic method [6] is best solution. Fig.6 shows basic concept of fuzzy logic. Dc capacitor voltage V_{dc} is sensed and compared with reference voltage V_{dref} . The error generated e is given by $e = V_{dref} - V_{dc}$. The error signal is sent to Butterworth low pass filter [5] having 50Hz threshold frequency. The two inputs for fuzzification are error $e(n)$ and error integration $ce(n)$.



Fig.6: Fuzzy Logic Controller

4.2.2. Fuzzification

Here, crisp quantity is made to fuzzy [7]. Membership functions are used to depict fuzzy values. Triangular membership function is used for fuzzification. Difference between reference and output signal is denoted as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), Positive Big (PB).

4.2.3. Fuzzy Rules

Linguistic variables are used here to form fuzzy rules rather than numerical values. Fundamental fuzzy rules are:

Intersection: $\mu [AND] \quad A \cap B = \min [\mu A(X), \mu B(X)]$

Union : $\mu [OR] \quad A \cup B = \max [\mu A(X), \mu B(X)]$

Complement: $\mu [NOT] \quad A = 1 - \mu A(X)$

4.2.4. Defuzzification

It involves conversion from fuzzy to crisp. As it is not possible to use fuzzy output as it is, it is required to get crisp quantity from fuzzy quantity for next step to be carried out [6].

4.2.5. Design of Fuzzy logic controller

- FLC input signals are to be recognized.
- Membership functions are to be identified.

- Decision making about type of membership function to be used.

4.2.6. Data Base

Data base keeps record of triangular membership function which is needed by fuzzier and defuzzier.

4.2.7. Membership function

It denotes degree of truth and graphically depicts a fuzzy set. The universe of discourse is shown by X-axis. Membership degree [10] in interval [0, 1] is shown by Y-axis. Quality of control is estimated by number of membership functions and it can be attained by Fuzzy logic controller. Control quality can be improved by increasing number of membership function but it results in more time for calculations and computer memory requirement is also more. For every input and output seven membership functions are taken into consideration. For the proposed filter, dc bus voltage controller which is fuzzy based is implemented to control dc bus voltage of shunt active power filter. Linguistic words like IF-THEN rules are used to understand dynamics of non-linear system. As shown in Fig.3 capacitor voltage is compared with reference voltage (V_{dcref}). Error of capacitor voltage (e) and voltage error variation (Δe) are input variables to fuzzy controller and at n th sampling time they are depicted by equations given below:

$$e(n) = \alpha(V_{dc}(n) - V_{dcref}) \quad (13)$$

$$\Delta e(n) = \beta(e(n) - e(n-1)) \quad (14)$$

here α and β are input scaling factors

Variation in adjustment current (ΔI_{ad}) is fuzzy controller output and given as:

$$I_{ad}(n) = I_{ad}(n-1) + \gamma \Delta I_{ad}(n) \quad (15)$$

γ is output scaling factor

If equation (11) is re-written newly developed reference source current is given by current. The disadvantage of using this method is that commutation frequency cannot be fixed. But this demerit is not important and current controllers using this technique

$$I_{ac}^*(t) = (I_{max}^* + I_{ad}) \sin(\omega t) = \frac{2P_{load}}{V_{max}} \sin(\omega t) \quad (16)$$

Fig.7 demonstrates input membership function. Totally four rules are applied using any combination of capacitor voltage error (e) and change in voltage error (Δe) and is assured by triangular membership functions.

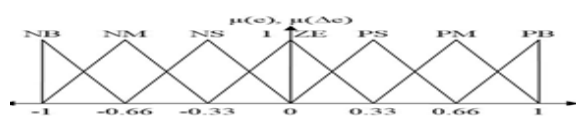


Fig.7: Membership function for (e) and (Δe)

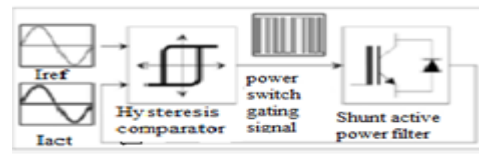


Fig.8: Block Diagram of Hysteresis current controller

If $e(n)$ is X_i AND $\Delta e(n)$ is Y_i THEN $\Delta I_{ad}(n)$ is Z_i . Here X_i and Y_i are input membership functions. Fuzzy controller output function is calculated by :

$$Z_i = W_i(a_i \cdot e(n) + b_i \cdot \Delta e(n) + c_i) \quad (17)$$

$$W_i = \text{Andmethod}(X_i(e(n)), Y_i(\Delta e(n))) \quad (18)$$

a_i, b_i, c_i are coefficients of output function and w_i is firing strength of the rule.

$$\text{FinalOutput} = \frac{\sum_{j=1}^N Z_j}{\sum_{j=1}^N w_j} \quad (19)$$

Table I demonstrates 49 rules derivation to assure stabilization of output voltage of converter in proximity to set point.

Table-I Rule Table of the Fuzzy Controller

	NB	NS	ZE	PS	PB
NB	PM	PS	ZE	NS	NB
NS	PS	ZE	NS	NB	PM
ZE	ZE	NS	ZE	PS	PM
PS	NS	NB	PM	PS	ZE
PB	NB	PM	PS	ZE	NS

4.3. Hysteresis current controller

Hysteresis current controller method [8] is not costly and it gives best dynamic answer. It permits for quick control of are standard. Principle of operation of hysteresis current controller is depicted in Fig.8.

Here measured output current of APF is compared with its reference using hysteresis comparator. Gating signals are output of the comparator. If reference current is less than actual filter current (half of band value), it is required to make the respective switches to reduce output current and hence it reaches to reference. If reference current is greater than actual current (half of band value), switches are made to increase output current and it reaches reference. Hence band of output current around reference current [9] is as shown in Fig.9.

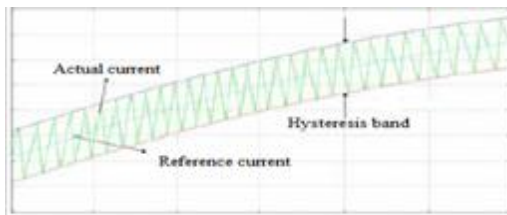


Fig.9: Reference and actual filter currents for hysteresis controller

Table –II : Circuit Parameters of Active Power Filter

Source voltage (peak value)	311 V
Source frequency	50 Hz
Coupling inductor	2 mH
DC bus capacitor	470 μ F
DC bus reference voltage	400 V
Resistance of all types of loads	50 Ω
Inductance of inductive load	2 mH
Capacitance of capacitive load	470 μ F
Inductance of ac regulator	2 mH
Capacitance of uncontrolled rectifier	470 μ F

5. Simulation results

The simulation results are shown by using Matlab-Simulink model and Simpower system Blockset are depicted. Table II shows circuit parameters of shunt APF and different types of load.

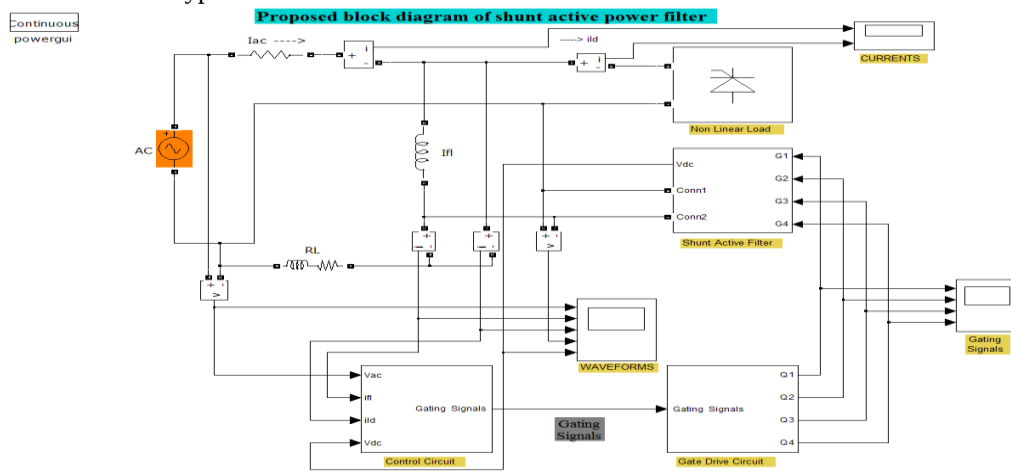


Fig.10: Proposed block diagram of shunt active power filter

Fig .11 depicts the design for Hysteresis Current Controller. It is designed using MATLAB-SIMULINK.

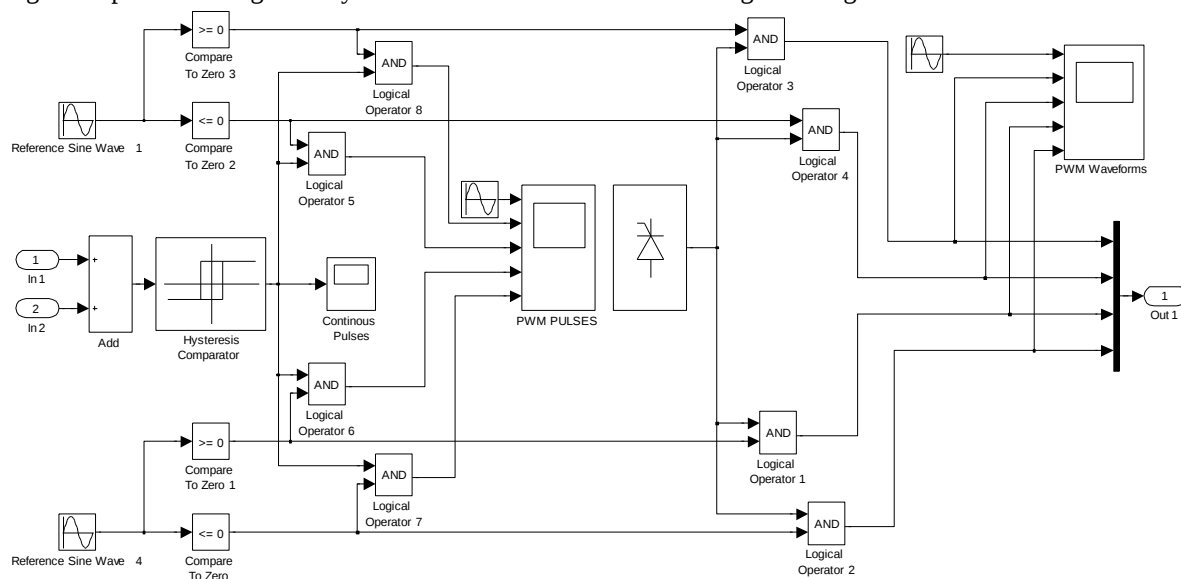


Fig.11: Simulink model for hysteresis current controller

Fig.12 shows the simulation results for source voltage, filter current, load current, Shunt active filter voltage and Dc bus voltage.

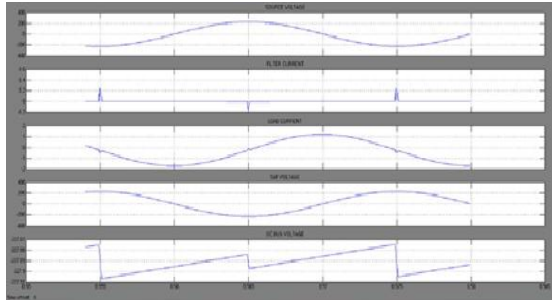


Fig.12: simulated waveform for source voltage, filter and load current, filter and DC bus voltage

Fig.13. shows the gate pulses Q1, Q2, Q3, Q4 generated to turn on/off the switches of filter according to the requirement of elimination of current harmonics and compensation of reactive power. Fig.14 shows the simulation results for source voltage, load current, Dc bus voltage and DC reference voltage. Fig.15 shows the Fuzzy waveforms.

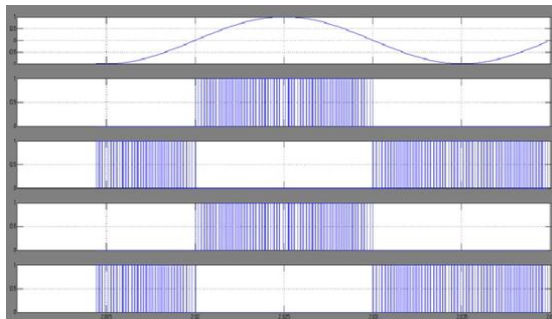


Fig.13: Gate pulses Q1, Q2,Q3 and Q4 to turn on switches of filter

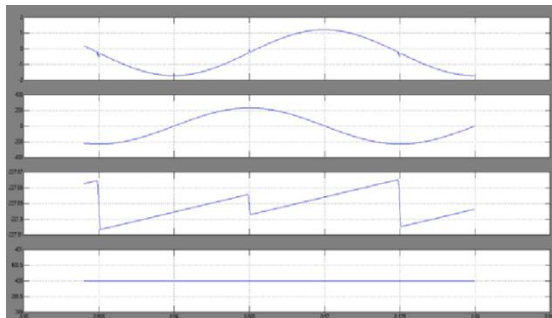


Fig.14: Waveforms for source voltage, load current, Dc bus voltage , Dc reference voltage

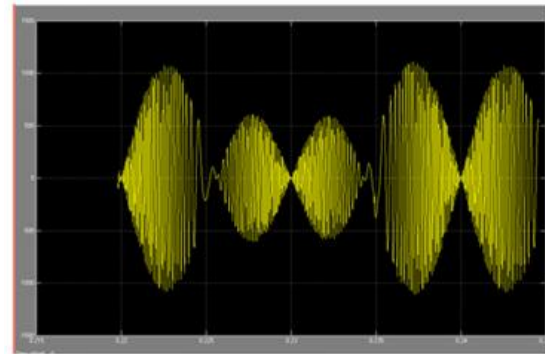


Fig.15.: Fuzzy waveforms

6. Conclusion

A shunt active power filter is presented in this paper which is reliable, efficient and cost effective solution to problems of power quality. It eliminates current harmonics and reactive power of linear and non-linear loads and also improves power factor. Here fuzzy logic controller is used which is efficient than other controllers. Hysteresis current controller is used to get the gating signals. As fuzzy logic controller doesn't require complex mathematical model, it is more suitable and flexible compared to other controllers. Overall performance of shunt active power filter is shown by simulation results which are carried out using MATLAB-SIMULINK tool.

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