Design of Shunt Active Power Filter with Fuzzy Logic Control for Mitigating Harmonics

Dr.K. Sebasthirani and G. Mahalingam

Abstract--- *In this paper Shunt Active Power Filter (SAPF) with Fuzzy Logic Controller (FLC) is modeled and tested. The instantaneous reactive power theory is used for extracting the reference compensating current. A fuzzy logic controller is used to regulate the DC link voltage of Voltage Source Inverter (VSI) in order to improve the dynamic performance, to ensure sinusoidal source currents and to produce a high power quality. In this work single phase shun active power filter is implemented to compensate harmonics and reactive power using Fast Fourier Transform (FFT) analysis. The main goal of the proposed active filtering system is to maintain the Total Harmonics Distortion (THD) well within IEEE-519 on harmonics levels. The simulation results were taken from Matlab simulink tool box.The proposed system was implemented by using hard ware setup. Sinusoidal Pulse Width Modulation (SPWM) pattern is used to generate switching signal to the Voltage source inverter.*

Keywords--- *Shunt Active Power Filter (SAPF), Fuzzy Logic Controller (FLC), Voltage Source Inverter (VSI), Fast Fourier Transform (FFT), Total Harmonics Distortion (THD), Sinusoidal Pulse Width Modulation (SPWM)*

I. Introduction

DUE to increase in use of static converters in domestic, commercial and industrial applications. The use solid state semiconductors are responsible for harmonics and reactive power disturbances. The harmonic and reactive power disturbances cause various problems such as low power factor, overheating of transformer, excessive neutral currents, feeder voltage problems and mal function of sensitive equiments. This causes various power quality problems in power systems applications .Active Power Filter (APF)is a feasible solution to mitigate harmonics and compensate reactive power. This class of filter configurations is the most important and most widely used type in active filtering applications. The purpose is to cancel the load current harmonics fed to the supply. . It can also contribute to reactive-power compensation and balancing of single phase currents as mentioned above. Parallel filters have compensation current plus a small amount of active fundamental current supplied to compensate for system losses. It is also possible to connect several filters in parallel for higher currents, which makes this type of circuit suitable for a wide range of power ratings. The advantages are: FACTS Devices, Smart grid system, HVDC converters. The purpose of Shunt Active Power Filter (SAPF) is to detect load harmonics current and reactive current and to inject equal and opposite current to cancel out the load harmonics and reactive currents, thus only fundamental currents supplied by the source. Figure 1.1 represents basic principle of Shunt Active Power filter. It consists of three parts such as Source, Non-linear load and Shunt active power Filter**.**

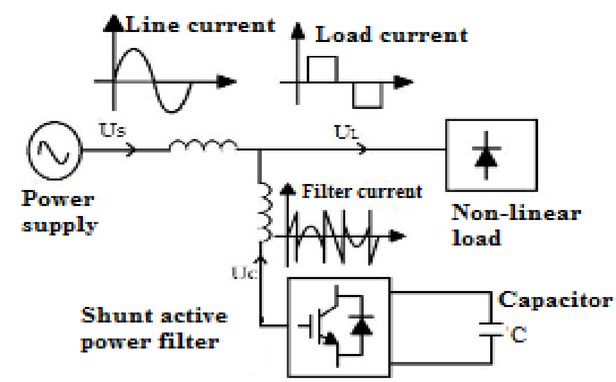

Figure 1.1: Basic Principle of Shunt Active Power Filter

II. Total Harmonic Distortion

The presence of harmonics in the power lines results in greater power losses in distribution, and cause problem by interfering in communication systems and, sometime cause operation failures of electronic equipment, which are more and more critical because it consists of microelectronic control systems, which work under very low energy levels. Because of these problems, the power quality issues delivered to the end consumers are of great concern. IEEE Std 519 was first introduced in 1981 to provide direction on dealing with harmonics introduced by static power converters and other nonlinear loads so that power quality problems could be averted.

A. Voltage THD

It represents the Total Harmonic Distortion of the voltage waveform. It is the ratio of the root-sum-square value of the harmonic content of the voltage to the root-mean-square value of the fundamental voltage.

$$V_{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots}}{V_1} \times 100 \quad (1)$$

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B. Current THD

It represents the Total Harmonic Distortion of the current waveform. It is the ratio of the root-sum square value of the harmonic content of the current to the root-mean-square value of the fundamental current .The design of the active filter is made keeping in mind that it minimizes the Total Harmonic Distortion to keep it within the limits specified in IEEE Std 519.

$$I_{THD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots}}{I_1} \times 100 \quad (2)$$

III. Fuzzy Logic Controller

A fuzzy logic controller is based on a collection of control rules governed by the compositional rule of inference applied to maintain the constant voltage across the capacitor by minimizing the error between the capacitor voltage and it reference voltage the block diagram of an illustrated by the Figure.3.0

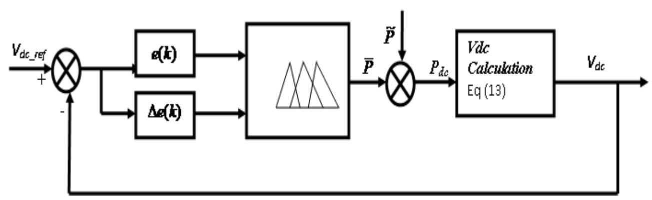

Fig. 3.0: Control of DC Voltage Source of SAPF

A fuzzy logic controller (FLC) converts is advanced control strategy the based fuzzy rules are constructed by expert experience or knowledge database.

In the input of (FLC), the error e (k) and the Change of error Δe (k) have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of (FLC) the fuzzy logic controller is presented by the control voltage μ (k), the type of fuzzy inference engine used is Mamdani. The seven linguistic input variables are defined as (NB,NM,NS,Z,PS,PM,PB) which, Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium, Positive Big respectively. In The output the linguistic variables are defined as (NB,NM,NS,Z,PS,PM,PB) which, Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium, Positive Big. Since there are seven input and seven output variables we have framed 49 rules. Fuzzy logic technique is an alternative technique that gives an improved performance of the switching pulse for the VSI. Fuzzy logic control is established on a logical system that involves the evaluation of the set of simple lingusitis rule called fuzzy logic for the determination of control action .it has four main components; fuzzifier, rules, inference engine, and defuzzifier, knowledge base, process. These components are represented on the general architecture fuzzy logic controller as shown in Figure 3.0.1

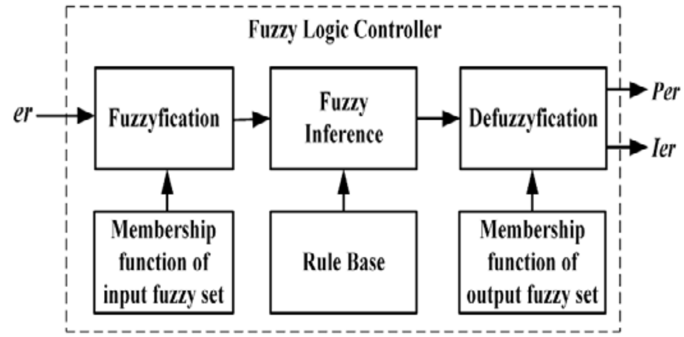

Fig. 3.0.1: Block Diagram of Fuzzy Logic Controller

The fuzzy logic controller consist of two inputs namely Error and change in error (Ce) and one output named lm is placed in rule base. The error signal is the difference between reference current I_{Ref} and actual current I_{Inv} of voltage source inverter for each phase.

$$\text{Error} = I_{Inv} - I_{Ref}$$

- For each of the two inputs, three fuzzy sets with bell and gaussian membership functions of NB, NM, NS, Z, PS, PM and PB are configured.
- The fuzzy sets with triangular membership functions NB NM, NS, Z, PS, PM and PB are configured for output.

Defuzzification using centroid method.

1. If (CHANGE OF ERROR is NB) and (ERROR is NB) then (lm is NB) (1)
2. If (CHANGE OF ERROR is NB) and (ERROR is NM) then (lm is NB) (1)
3. If (CHANGE OF ERROR is NB) and (ERROR is NS) then (lm is NM) (1)
4. If (CHANGE OF ERROR is NB) and (ERROR is ZE) then (lm is NS) (1)
5. If (CHANGE OF ERROR is NB) and (ERROR is PS) then (lm is ZE) (1)
6. If (CHANGE OF ERROR is NB) and (ERROR is PM) then (lm is PS) (1)
7. If (CHANGE OF ERROR is NB) and (ERROR is NB) then (lm is PM) (1)
8. If (CHANGE OF ERROR is NM) and (ERROR is NB) then (lm is NB) (0.92)
9. If (CHANGE OF ERROR is NM) and (ERROR is NB) then (lm is NB) (0.89)
10. If (CHANGE OF ERROR is NM) and (ERROR is NM) then (lm is NM) (0.83)

The above mentioned ruled base systems are used to control DC link voltage source.

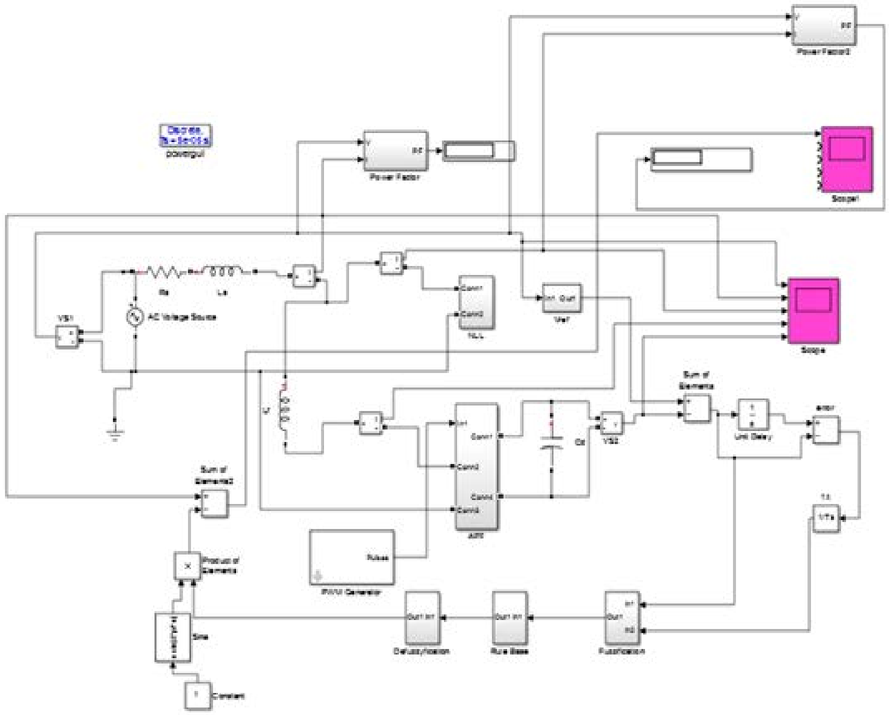

Fig. 3.0.2: Simulation Diagram of Fuzzy Logic Control Technique

Generating Gating Pulses to the Shunt Active Power Filter

The control of Active filter is to generate switching signals Voltage source inverter based on derived compensating commands in terms of voltage and currents.

A variety of approaches hysteresis based current control, PWM control, dead beat control ,fuzzy base current control neural network based current control are implemented through software or hardware models to get gating signals for Shunt active power filter.PWM is the most popular method for producing controlled output of the inverter. In this proposed system Sinusoidal PWM technique is used to produce gating pulses of the inverter.

Generation of Reference Compensating Techniques

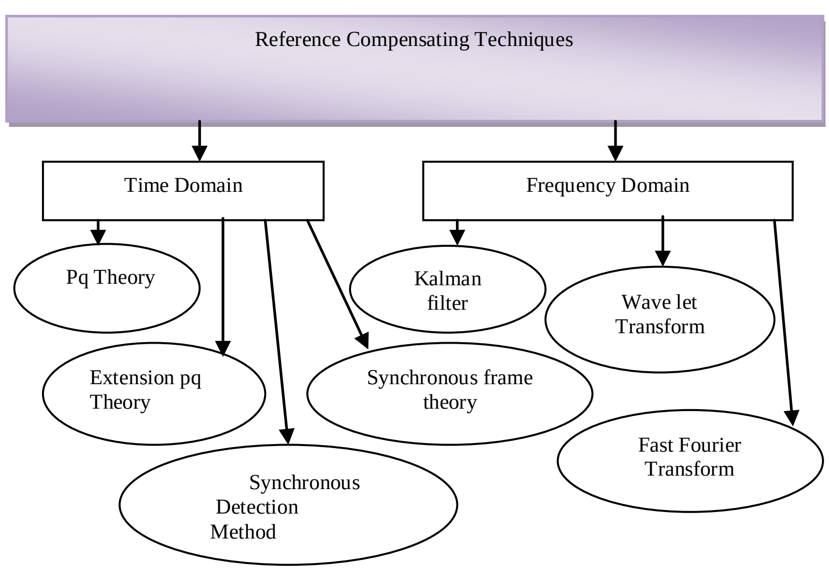

Fig. 3.1: Generation of Reference Compensating Techniques

IV. SIMULATION RESULTS

Figure 3.0 shows the Shunt Active power filter with nonlinear load including the structure of proposed controller. The controller has two current sensors for measuring the load current and filter currents and voltage sensors for.

A simulation based on Matlab/Simulink was performed to verify the proposed Shunt Active Power Filter. Table 1 shows the design parameters used for this simulation work. The test system consists of an uncontrolled rectifier with RLC load and is supply by a Single phase voltage source. To compensate harmonics, shunt active filter is connected to the test system through a filter inductor L. Figures 4.1 to 4.8 below shows the signal waveforms of simulation result. The harmonic spectrum of the distorted waveform is shown on figure 4.3. The Total Harmonic Distortion (THD) of the distorted line current due to non-linear load is 24.17% as depicted in figure 4.4 from FFT analysis of load current before compensation. From this harmonic spectrum, it is clear that, the supply current is distorted without APF. Next, application of APF reduces the THD of load current from 24.17% to 1.27%. Figure 4.1 Waveform of source current. Figure 4.2 waveform of the source voltage. Figure 4.3 waveform of the source current before compensation. Figure 4.4 waveform of the load current. Figure 4.5 waveform of the filter current. Performance of PI controller in regulating DC bus voltage is shown in figure 4.6. It is observed that the DC bus voltage is exactly maintained at the reference value (400V) by the PI controller. Figure 4.7 FFT analysis for the Source current after compensation. Figure.4.8 FFT analysis for the load current after compensation.

Table 1: Designed Parameters

System Parameters	Values
Supply frequency	50 Hz
Supply voltage	220V
Source impedance (Rs, Ls)	1KΩ, 0.72mH
Line impedance(Rr, Lr)	1Ω, 1mH
Load impedance (RL,LL)	2x20Ω, 2x1mH
Filter inductance	2.25mH
DC Voltage,	400V
Capacitance(Cdc)	1000µF

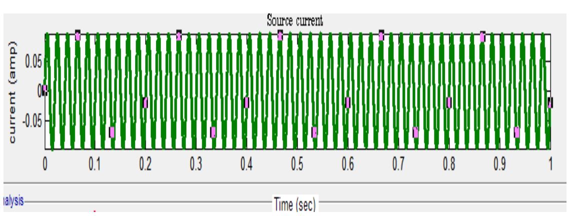

Fig. 4.1: Waveform of the Source Current

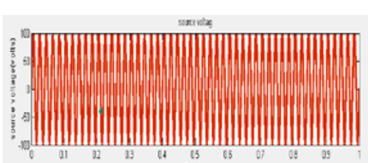

Fig. 4.2: Waveform of the Source Voltage

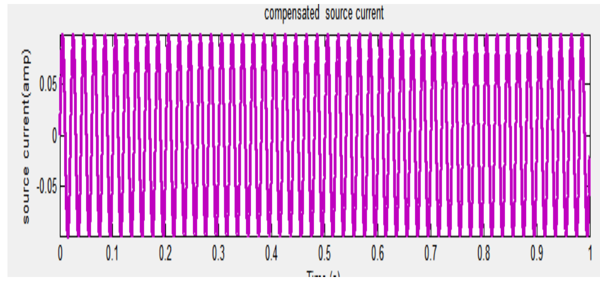

Fig. 4.3: Waveform of the Source Current Before Compensation

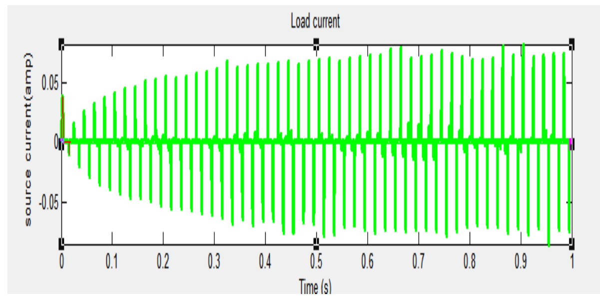

Fig. 4.4: Waveform of the Load Current

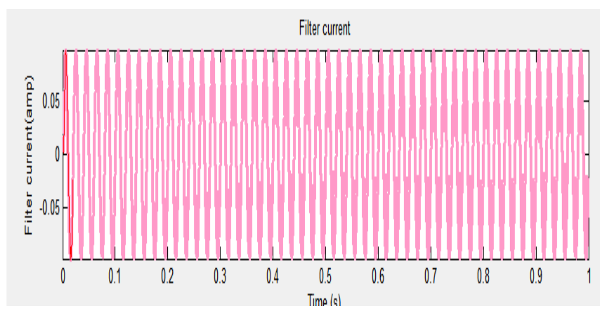

Fig. 4.5: Waveform of the Filter Current

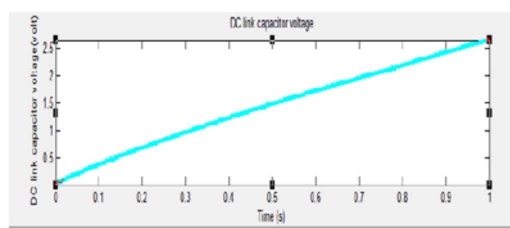

Fig. 4.6: Waveform of Voltage Across Capacitor

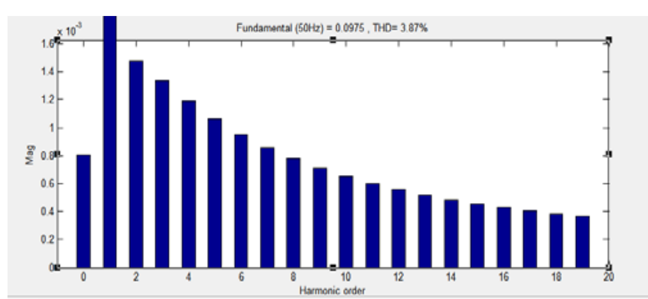

Fig. 4.7: FFT Analysis for the Source Current After Compensation

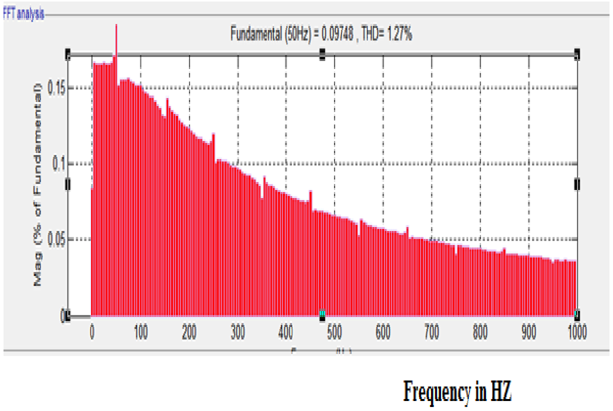

Fig. 4.8: FFT Analysis for the Load Current After Compensation

V. Conclusion

A fuzzy logic current control shunt active power filter is designed using MATLAB toolbox. It is aimed at achieving adequate compensation to mitigate load current harmonics, so as to improve the power quality by compensating harmonics and reactive power requirement of the nonlinear load. Simulation was carried out with fuzzy logic controller. The THD is reduced from 24.17% to 1.27% by the fuzzy controller and is found to be in agreement with the IEEE standard. Fuzzy logic controller is used to regulate DC link capacitor voltage. The fuzzy controller has a better transient response compared to a conventional PI controller.

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