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Implementation of Shunt Active Filter for Harmonic Compensation in a 3 Phase 3 Wire Distribution Network

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Abstract

This paper explores the modeling of a Proportional Integral (PI) and fuzzy logic controller (FLC) based, shunt active power filter (SAPF) for a three wire network to compensate current harmonics fed to a nonlinear load. In the fuzzy logic controlled SAPF mathematical model of the system is not required since it is based on an inference system incorporating intelligence derived through human expertise. The PI controlled and fuzzy logic based (SAPF) have been developed using the Simulink tool box of MATLAB. Simulation results illustrate that the fuzzy logic based active filter outperforms the PI based shunt active filter. To validate the simulation results a hardware setup is developed making using of the instantaneous Id-Iq theory using for a three phase three wire system. The hardware results were found to match closely with simulation outputs.

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Keywords: Shunt active filter; PQ Theory; dq Theory; Field Programmable Gate array; Total harmonic distortion(THD)

1. Introduction

In the modern decade, the sudden growth in power electronic switching loads (such as, Variable Frequency Drives (VFDs), and switched mode power supplies (SMPS), etc.) to enhance the controllability and efficiency of the system are the main sources for harmonic distortion on power system network. These loads draw harmonic non-

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sinusoidal currents because of switching. Therefore, generation of harmonics that causes power quality disturbances has become a significant problem for the distributors and consumers of electric power as well. In order to eradicate such issues and enhance the quality of power supply, active power filters (APFs) have been proposed. The most commonly used power circuit for power disturbances nullification and compensating reactive power is the shunt power filter.

The shunt active filter has numerous control algorithms, topologies, and reference generation techniques. The instantaneous PQ theory and reference SRF theory involving Park transform had attracted the attention of researchers due to their simple principle and high efficiency. The direct control strategy of APF has been the mostly used in literary. Numerous regulations that are concerning the emission of harmonics have been suggested by various international electrical committees such as IEEE Std. 519-92 and IEC-61000 [1, 2]. In domestic as well as industries, the utilization of excessive reactive power also leads to considerable disturbances in power quality for the electrical grid. For designing and analyzing the SAPF with the reference used for generating the reference current using the current component of i_d-i_q method is presented in [3] that compensate harmonic unbalance. Reactive power elimination technique involving power electronic devices is proposed in [4], which may not be need of additional storage components.

APF that uses voltage-source with quad series pulse-width-modulated (PWM) converters for eliminating the line harmonics through injecting the equivalent compensating currents into the electrical grid system is presented in [5]. Experimental investigations with different types of control strategies for active filters are investigated in [6-10]. [11-12] presents a review of different modeling strategies for active power filters. [13] presents the implementation of a hybrid filter using neural network for varying load conditions. In industrial power system, for shunt active filters, the bus voltage and branch current estimation are projected in [14]. Shunt active power filters with hysteresis control techniques with SVM are discussed in [15]. This paper presents the hardware and software realizing a PI and FLC controlled SAPF design in a three wired distribution system.

2.Modelling of SAPF

The basic building block diagram for the compensation techniques in a SAPF is illustrated in Fig 1. The SAPF is controlled for generating compensating currents i_c such that it not only cancels the current harmonics that are predominant in the AC mains, but also adjusts the supply current to be in-phase and sinusoidal in nature.

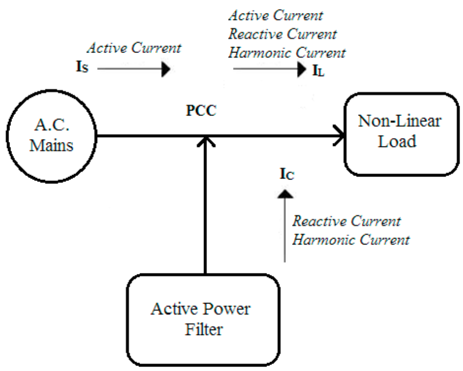

Fig. 1. Conventional working principle of SAF

In proposed compensation technique the harmonics are nullified using the SAPF by infusing the generated current at the PCC using fuzzy logic controller. The operation of 3 phase SAPF designed for AC/DC rectifier as shown in the Fig. 2.

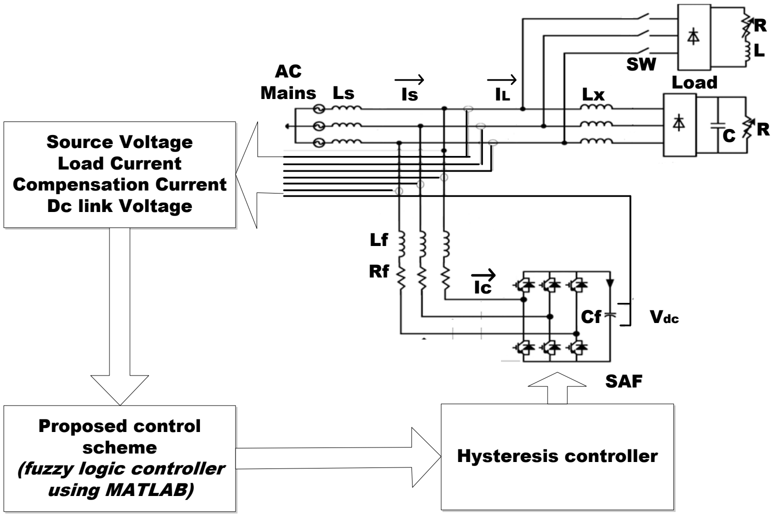

Fig. 2. System configuration with practical realization of SAF.

By relating Clarke's transformation, Load currents are obtained in stationary (αβ) frame as given by Eq. (1)

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 0 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \tag{1}$$

From the transformation equations, the dq current components are shown in Eq. (2).

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \frac{1}{\sqrt{V^2_{\alpha F} + V^2_{\beta F}}} \begin{bmatrix} V_{\alpha F} & V_{\beta F} \\ -V_{\beta F} & V_{\alpha F} \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} \tag{2}$$

The average and oscillatory quantities found in i_{ld} and i_{lq} from Eq. (2) are disintegrated as

$$i_{ld} = \overline{i_{ld}} + \tilde{} \tag{3}$$

$$i_{lq} = \overline{i_{lq}} + \tilde{} \tag{4}$$

After the elimination of the average components found in equations (3) & (4) expressions for the compensation currents are

$$i^*_{cd} = -\tilde{} \tag{5}$$

$$i^*_{cq} = -\tilde{} \tag{6}$$

By using inverse park transformation, Eq. (7) provides the computation of $i^*_{c\alpha}$ and $i^*_{c\beta}$.

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{\sqrt{V^2_{\alpha F} + V^2_{\beta F}}} \begin{bmatrix} V_{\alpha F} & -V_{\beta F} \\ V_{\beta F} & V_{\alpha F} \end{bmatrix} \begin{bmatrix} i^*_{cd} \\ i^*_{cq} \end{bmatrix} \tag{7}$$

Eq. (8) provides the inverse of the Clarke's transformation equation to obtain reference current values for the SAPF from Eq. (7).

$$\begin{bmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} \quad (8)$$

2.1 Simulation results and analysis

The system studied has been modelled using Simulink as shown in Fig. 3 and performance of PI and FLC is analysed in this section. Fig. 8-15 presents Matlab simulation responses for the proposed system with the above mentioned control techniques.

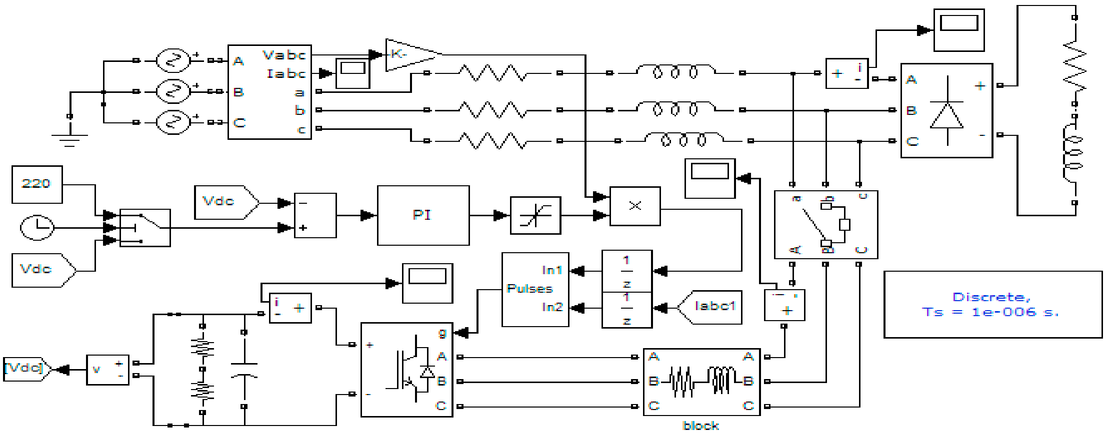

Fig. 3 Matlab circuit for Shunt Active Power Filter

The voltages is considered as a sinusoidal and balanced in the Matlab simulation. The load current THD is found to be 27.88% when a switching power electronic load is considered. The parameters for voltage sources, transmission lines, filters and the load details are provided in the Table 1.

Table. 1.System parameters used in Simulink.

Simulation Parameters	Values	Simulation Parameters	Values
Supply Voltage (Vs)	100 V (Peak value)	Optimal values (K_p and K_i)	0.2 and 9.32
System Frequency (Fs)	50 Hz	Hysteresis Band	±0.2 A
Source Impedence(Rs ; Ls)	0.1 Ω ; 0.15 mH	Load	Diode Rectifier
Filter Impedence(Rc ; Lc)	0.1 Ω ; 0.15 Mh	Snubber Resistance (R_{sn})	500 Ω
Dc Link Voltage (V_{dc})	170 V	Snubber Capacitance (R_{sn})	250 e-9 F
Dc Link Capacitance (C_{dc})	2000 µF	Load Impedence(R_l ; L_l)	30 Ω ; 20 mH

Estimation of harmonic reduction

The source current for one of the three phases without compensator is shown in Fig. 4.

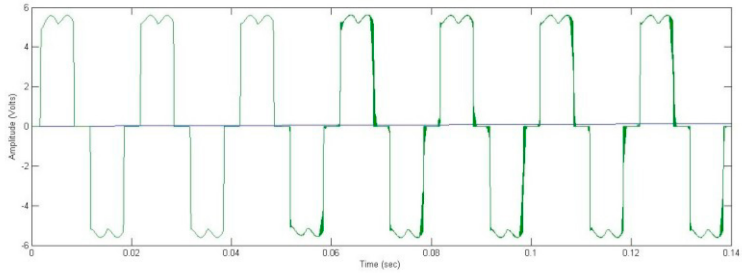

Fig. 4. Source current without compensator.

During, t=0.05seconds, compensator is set to active mode (i.e., pulse applied for the inverter section). The source current, compensation current, and DC capacitor voltage for proportional-integral and Fuzzy controlled SAPF have been illustrated from Fig. 5 to 10.

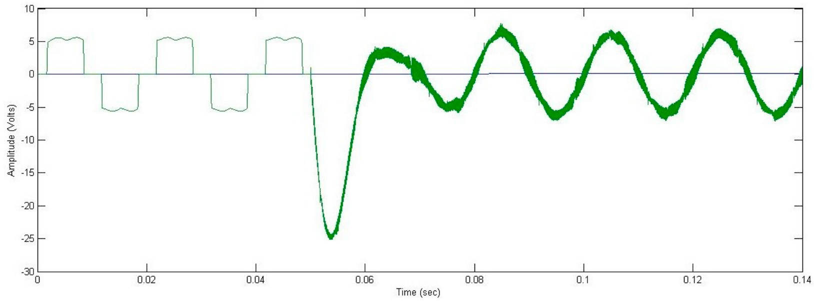

Fig. 5. Source current with PI controlled SAPF

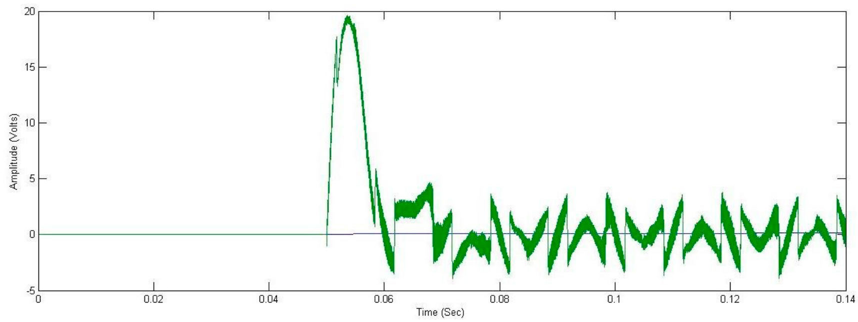

Fig. 6 Compensating current with PI controlled SAPF

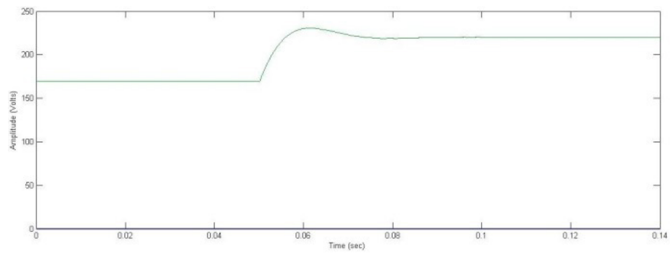

Fig. 7 DC Capacitor Voltage with PI controlled SAPF

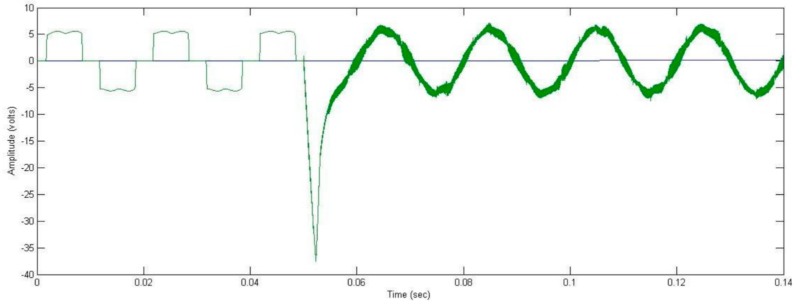

Fig.8.Source current with Fuzzy Controlled SAPF

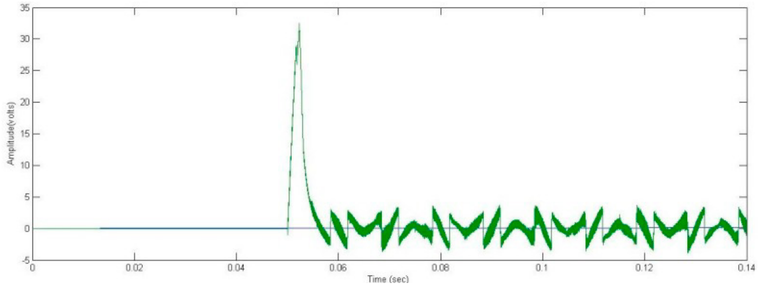

Fig.9 . Compensation current with Fuzzy Controlled SAPF

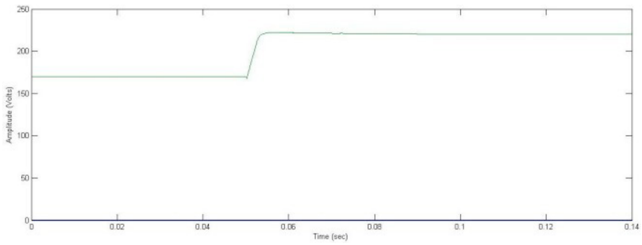

Fig.10 DC Capacitor voltage with Fuzzy Controlled SAPF

3.0 Hardware Implementation

Computer simulation of the Shunt active filter with instantaneous d-q reference current extraction and current control strategies were presented in the previous sections. This section describes in detail about the hardware implementation of active filter (SAPF) with adaptive control strategy, to suppress reactive elements and harmonic contents. The compensation currents have been derived using instantaneous d-q theory. The proposed algorithm is implemented using the Field Programmable Gate Array (FPGA). The implemented hardware is tested for ideal source voltage condition and the test results are presented. The basic building block for a SAPF incorporating major elements is observed from Fig. 11.

The Spartan-3A DSP Trainer Kit has an architecture designed specifically for real-time signal processing. In this work, the Spartan-3A DSP FPGA is used for the implementation of the proposed control strategy. Fig. 12 shows the Spartan-3A DSP trainer kit, which includes several peripherals on its core.

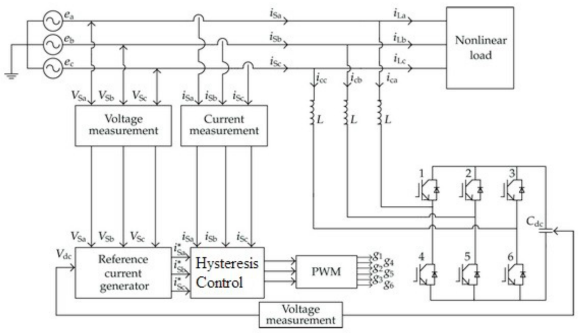

Fig. 11 Block Diagram of Hardware Implementation

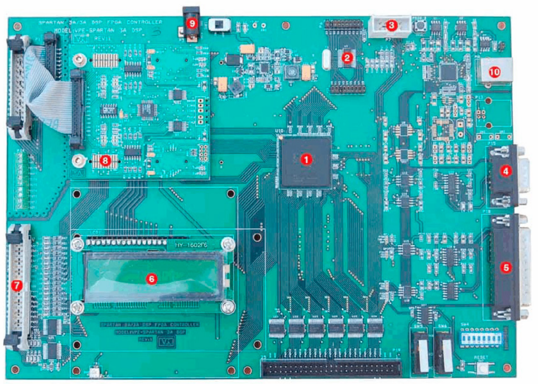

Fig. 12 Spartan-3A DSP trainer kit pictorial view

The proposed control technique is realized by VHDL (Very High Speed Integrated Circuit Hardware Description Language) coding algorithm in the FPGA (SPARTAN 3A DSP). The Modelsim software is used to verify the control logic in the FPGA module. Three phase AC supply with line voltage (230V) has been considered for the practical implementation. A rectifier load with RL components (R=100Ω and L=100mH) is taken as load. The power circuit is constructed using MOSFETS. First the system performance is studied without filter. When the load is operated without filter, Fig. 13 shows the waveform of the source current. The source current after filtering is depicted in Fig.14.The THD value in supply current is found to be 45.6% and the frequency spectrum for the same without filter is illustrated in Fig. 15.

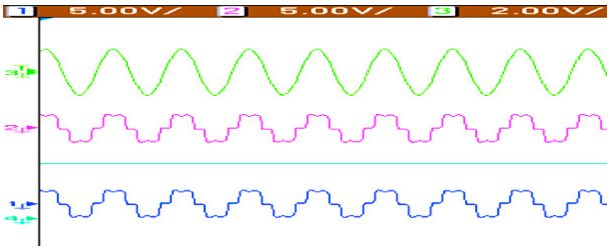

Fig. 13. Phase A Source Current of Hardware Implementation

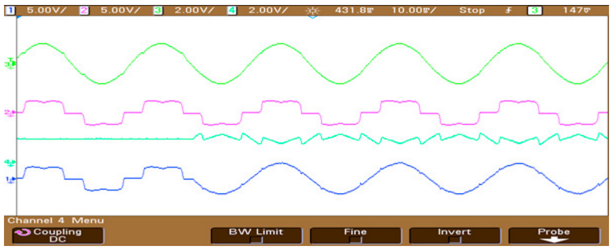

Fig.14. Source Current after Filtering

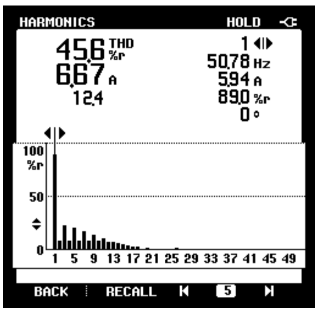

Fig. 15. Frequency Spectrum of source current.

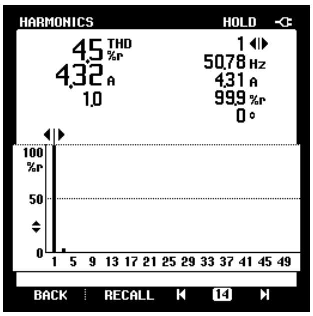

Fig. 16. Frequency Spectrum of Source Current after Filtering

The total harmonic distortion with filter turned on has reduced to 4.5%. as illustrated in Fig. 16. Hence, the proposed algorithm is implemented for reducing harmonic current within the IEEE 519-1992 harmonic standard [1].

3.1 Inferences

An experimental prototype is developed with hysteresis current control technique in Spartan-3A DSP platform. The SAPF performance in the process of suppressing maximum harmonics is studied in a three phase three wire test set up. The experimental result is found to match with the simulation results and the filter is able to compensate current harmonics within the limit of IEEE standard.

4.0 Conclusion

This paper presented an appropriate reference control technique with SAPF for a three phase distribution network connected to switching loads to enhance the power quality. A PI controller and fuzzy based matlab-simulink model has been simulated for SAPF in order to eliminate the harmonic elements due to non linear load. An FPGA model has been developed for the proposed current component (Id - Iq) control method and the performance of the same is verified with the compensation of current harmonics and to overcome dynamic load changes. As per the limitation of harmonics imposed by IEEE, the source current THD is below 5%.

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