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MATLAB-SIMULINK MODEL BASED SHUNT ACTIVE POWER FILTER USING FUZZY LOGIC CONTROLLER TO MINIMIZE THE HARMONICS

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ABSTRACT

Quality (PQ) maintenance has become an important concern to utility. Shunt Active Power Filters (SAPF) is considered as the best device among many harmonics compensating devices. Due to electrical energy demand, the power generation is also became an important concern. Among various renewable energy sources, solar energy is considered as best source for converting into electrical energy. The shunt compensator compensates for harmonics of load current, improves power factor, overcomes voltage sags, reduces total Harmonic Distortion (THD), etc., and thus enhances the power quality. Proportional Integral (PI), Fuzzy Logic Controller (FLC) based control algorithm is used for SAPF. A synchronous reference frame (SRF) algorithm is used for improving the SAPF performance. The proposed system is implemented in Matlab/Simulink environment and the simulation results exhibit the high value performance for micro grid applications.

KEYWORDS: *Power Quality, Harmonics, SAPF, Fuzzy Logic Controller, Synchronous Reference Frame*

Article History

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INTRODUCTION

The advancement of semiconductor technology increases the penetration of power electronics loads, such as switching mode power supplies (SMPS), adjustable speed drives, computer power supplies, etc. Though these loads possess good efficiency, they grab nonlinear currents, because of which voltage distortion is caused at PCC-Point of Common Coupling. Therefore emphasis on generation of clean energy is increasing by installing rooftop photovoltaic systems in apartments, commercial buildings, etc., [1][2]. But, the intermittent behaviour of PV sources, an increased penetration of these kind of systems, especially in weak distribution systems cause voltage related problems such as voltage sags and voltage swells, eventually making the grid unstable [3]-[7]. These problems result in frequent false tripping, false triggering, malfunctioning of electronic systems and capacitor banks heating, etc. [8]-[10].The problems of power quality at both grid and load sides are considered as major issues in modern distributed systems. The concept of multifunctional systems arises for generation of clean energy apart from improving power quality. Literature [11], [12] proposes a three-phase multifunctional system for converting solar energy, compensates for issues of power quality at load side. A single phase PV inverter with the capability of active power filtering was proposed in [13], [14]. The series active filters were used in apartments and marketable buildings for maintaining voltage quality of electronic loads [15], [16]. A solar PV system with

Dynamic Voltage Restorer (DVR) was proposed in [17]. In recent times researchers are showing more interest on connecting PV array via Shunt Active Power Filter to distribution system. In this scheme the power developed in PV array provides the real reactive energy. This paper presents the study of operation of SAPF system for concurrent harmonic compensation. PI Controller and Fuzzy Logic controller -Based predictive Algorithm is used as control methodology for SAPF. Simulations are performed using MATLAB/SIMULINK software.

THE PROPOSED SYSTEM

Active power filters are being widely applied in modern distribution systems for suppressing harmonics connected with it. They are in parallel connection with the nonlinear load and are used to eliminate current harmonics on the ac side making the mains current sinusoidal. SAPF provides dynamic and robust performance with a control algorithm that works accurately. The control techniques generate reference currents used in triggering voltage source inverters. With the use of SAPF the following are the advantages;

- Current harmonics elimination,
- Balancing and regulation of terminal load/line voltage,
- Reduction of negative sequence voltage,
- Voltage harmonics compensation.

The proposed system is depicted in Fig.1. The nonlinear load here is the diode rectifier with a RL load and is connected to the source via load inductance L_L. The shunt active power filter is connected in parallel to the system. The controller generates the pulses to trigger the switches of the VSI. The VSI is used as active power filter that compensates the harmonics of reactive power and nonlinear load.

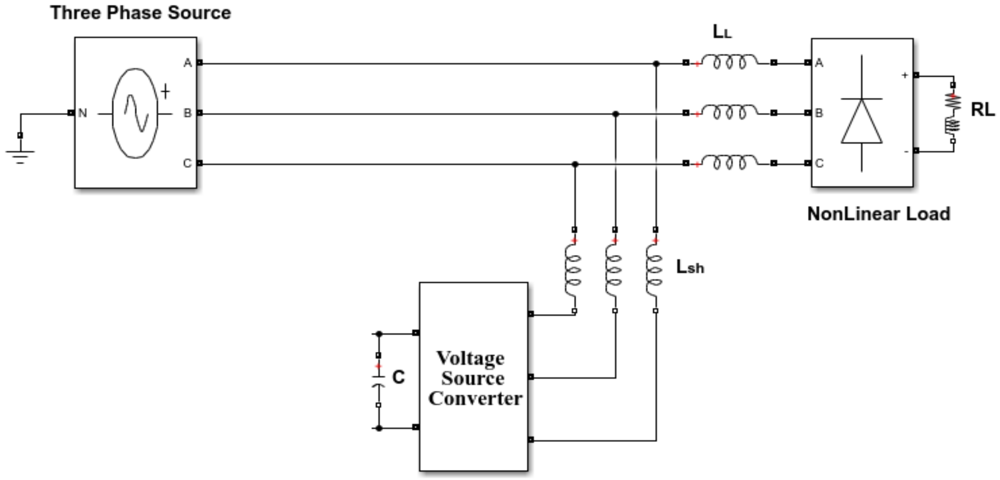

Figure 1: Schematic Diagram of the Proposed System.

The presentation parameters are smoothing and decoupling element, L_c, energy storage element C_{dc}, the techniques used for extracting compensation reference currents, i_{sa}*, i_{sb}*, i_{sc}* and control system used to control the compensation currents, i_{ca}, i_{cb}, i_{cc} and the DC voltage, V_{dc}. The desired compensation current is injected by the SAPF into the distribution system at PCC, ensuring sinusoidal source current. The source current, i_s and source voltage, v_s of thesystem are represented in Eq. (1) and Eq. (2).

$$v_s(t) = v_m \sin \omega t \tag{1}$$

$$i_s(t) = i_l(t) - i_c(t) \tag{2}$$

As the load is Nonlinear, Load current has fundamental component and harmonic component. Mathematically represented as in Eq. (3)

$$i_l(t) = I_1 \sin(\omega t + \varphi_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \varphi_n) \tag{3}$$

Load power can be represented as

$$p_l(t) = v_s(t) * i_l(t) \tag{4}$$

Substitute Eq. (1) and Eq. (3) in Eq. (4), then

$$+v_m \sin \omega t * \sum_{n=2}^{\infty} I_n \sin(n\omega t + \varphi_n) \tag{5}$$

From Eq. (5) it is clear that load current has three components. They are Active Power ($P_f(t)$), Reactive Power ($P_r(t)$), and Harmonic Power($P_h(t)$)

$$p_l(t) = p_f(t) + p_r(t) + p_h(t) \tag{6}$$

The active power drawn by the load is

$$p_f(t) = v_m I_1 \sin^2 \omega t * \cos \varphi_1 \tag{7}$$

But$p_f(t) = v_s(t) * i_s(t)$

$$i_s(t) = \frac{p_f(t)}{v_s(t)} = I_1 \cos \varphi_1 \sin \omega t = I_{sm} \sin \omega t \tag{8}$$

The compensating current is calculated by using Eq. (9)

$$i_c(t) = i_l(t) - i_s(t) \tag{9}$$

Where $i_s(t)$ is the fundamental component of the load current $i_L(t)$.

The source currents, after compensation, can be given a

$$i_{sa}^* = I_{sm} \sin \omega t$$

$$i_{sb}^* = I_{sm} \sin(\omega t - 120)$$

$$i_{sc}^* = I_{sm} \sin(\omega t + 120) \tag{10}$$

Where I_{sm} is the amplitude of the desired source current, while the phase angle is obtained from the source voltages. I_{sm} Can be calculated by controlling the dc-side capacitor voltage.

THE SYNCHRONOUS REFERENCE FRAME THEORY

Synchronous Reference Frame (SRF) theory is control algorithm for generating triggering pulse. The three-phase load currents, i_{La}, i_{Lb}, i_{Lc}, Voltages, V_{sa}, V_{sb}, V_{sc} and DC voltage across capacitor are considered as feedback signals. With Park's transformation, the load currents are into dq0 frame as in (13).

$$\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad (13)$$

The synchronization of current signal with voltage at PCC is done by using PLL. The low pass filter is used for extracting the DC component ofiLdandiLq from components of d-q current

$$i_{ld} = I_{ld} + \overline{I_{ld}} \quad (14)$$

$$i_{lq} = I_{lq} + \overline{I_{lq}} \quad (15)$$

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & -\sin\theta \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} \quad (16)$$

The inverse Clark's transformation converts the harmonic components into three phase quantities. The reference quantities are then to hysteresis controller, which generates VSI gate pulses. Figure 2 shows the controller's block diagram.

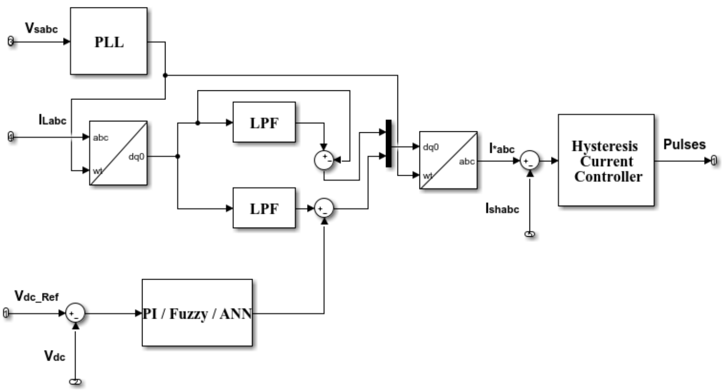

Figure 2: d-q Theory for Reference Current Generation.

PI, FUZZY AND ANN CONTROLLERS

PI Controller

A PI controller in general controls the dc-link voltage for the elimination of steady state error and for the reduction of ripple voltage. The proportional constant (K_p) and the integration constant (K_i) determine the dc-link voltage's dynamic response and its settling time respectively. The K_p and K_i values are to be properly selected to ensure the aforementioned control performances. The principle of energy-balance is used to calculate K_p, then the K_i value can be observationally determined. The dc-link voltage regulation is done by the adjustment of little amount of power flow into dc-link capacitor, therefore compensating switching and conduction losses

$$H(S) = K_p + K_i \quad (17)$$

The proper setting of K_p and K_i equals the actual V_{vsc} and reference V_{vsc_ref} across the capacitor. The dc voltage regulator, apart from determining P_{loss}, also corrects errors in the power compensation. Finally the PWM controlled VSC's ripple voltage is mitigated by PI controller. The values of K_p and K_i used in this system are 2 and 20 respectively.

Fuzzy Logic Controller

For the implementation of control technique of SAPF, the capacitor voltage (V_{dc}) is compared with the reference value ($V_{dc\text{-}ref}$). The error e= $V_{dc\text{-}ref}$ -V_{dc} is passed through low pass filter (LPF) with a frequency of 50 Hz. The error e(n) and change in error ce(n) are the inputs to the fuzzy processing. The fuzzy output restricts the magnitude of reference current (I_{max}). This current handles the non-linear load's demand of active power and also handles losses in distribution system. The pulses are generated by the comparison of actual source currents with reference currents using Hysteresis Current Control (HCC) method.

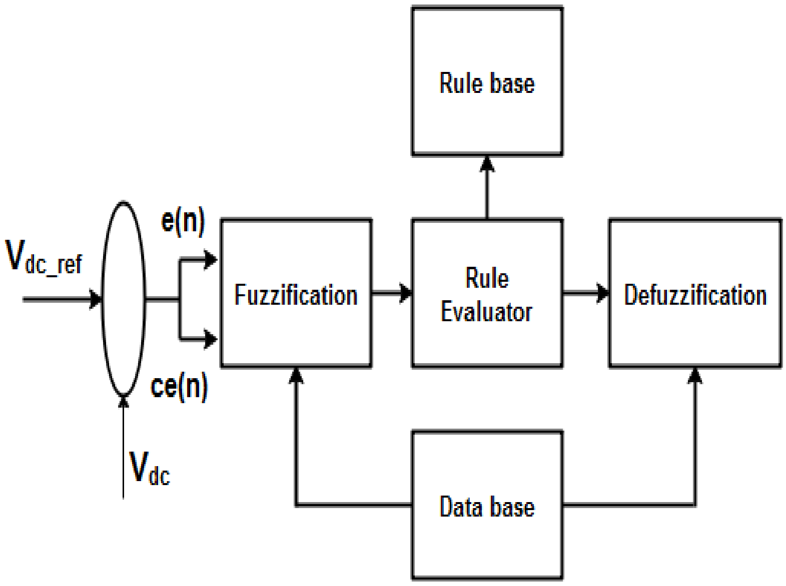

Figure 3: Fuzzy Logic Controller.

The different components of a fuzzy control system are fuzzification, rule base, defuzzification, data base and rule evaluator as shown in Figure 3. In the fuzzification process the numerical values are converted into fuzzy values or linguistic variables such as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive small (PS), Positive Medium (PM), Positive Big (PB). In the defuzzification process fuzzy values are converted into crisp values. Rule base consists of different linguistic control rules which are required by rule evaluator to solve a problem. The rules used in fuzzy controller are shown in table 1.

SIMULATION RESULTS

The simulation of the proposed system is done using Matlab/Simulink software. Thetable 3 lists the proposed system's parameter values. The simulation results compare the system with two controllers named as PI and Fuzzy Logic control. The scenarios of reactive power compensation, DC link voltage and total harmonic distortion (THD) of the proposed system were examined and are depicted in the following figures.

Table 1: Fuzzy Control Rule

e(n)/ ce(n)	NB	NNM	NNS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	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

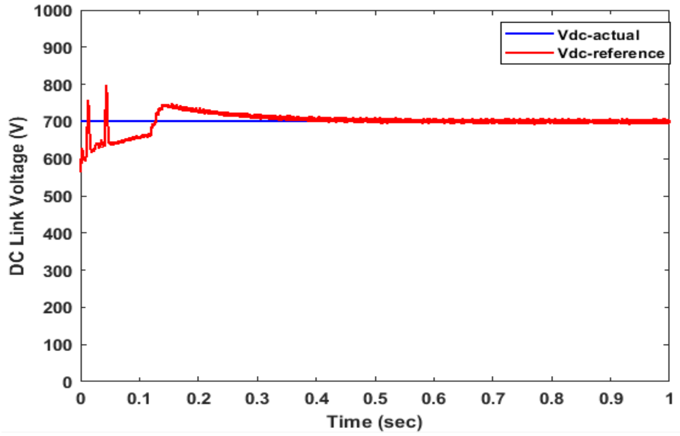

Figure 4: DC Link Voltage using PI Controller.

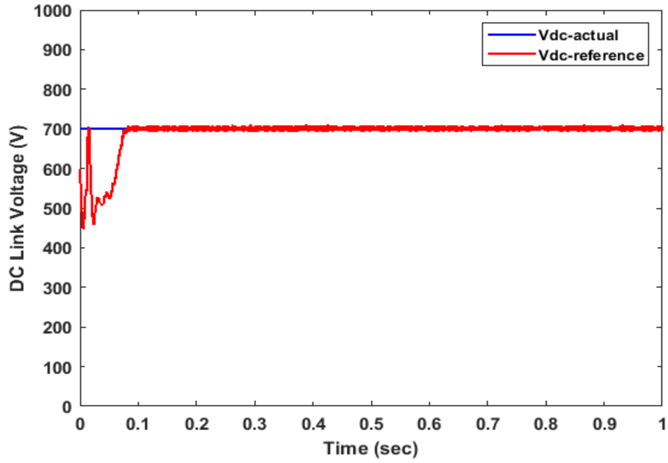

Figure 5: DC Link Voltage using Fuzzy Controller.

The control scheme of PI controller for dc link voltage is compared with the fuzzy logic control scheme .Figs. 4, 5 show the dc link voltage response at different time instants for two control schemes. The settling time of dc link voltage using PI controller is 0.15sec, with Fuzzy logic controller, it is 0.08sec .

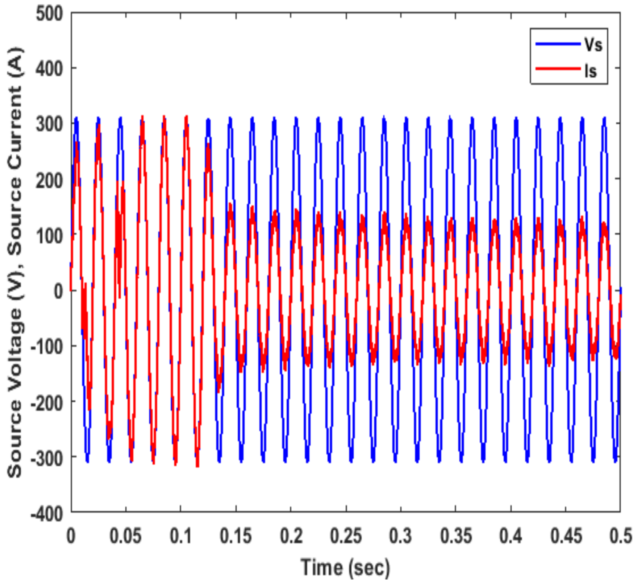

Figure 6: Reactive Power Compensation using PI Controller.

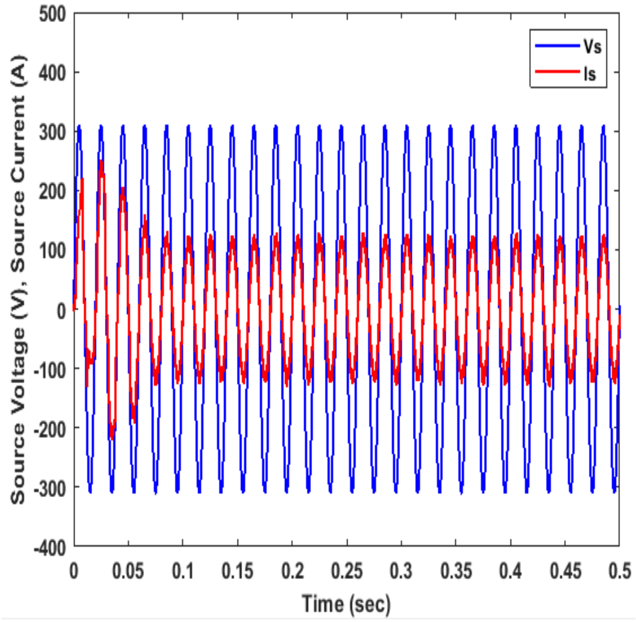

Figure 7: Reactive Power Compensation using Fuzzy Controller.

From the figures it is clear that dc link voltage control of SAPF using FLC exhibits better result compared to PI. Particularly the oscillation of dc link voltage with FLC application is lesser than with the PI applications.

Also the time interval until the dc link voltage comes back to condition of steady state is smaller when compared to PI controller.

Figs. 6, 7 depict the reactive power compensation with application of PI, Fuzzy controllers. Among the two controllers, the FLC gives better results for compensation of reactive power.

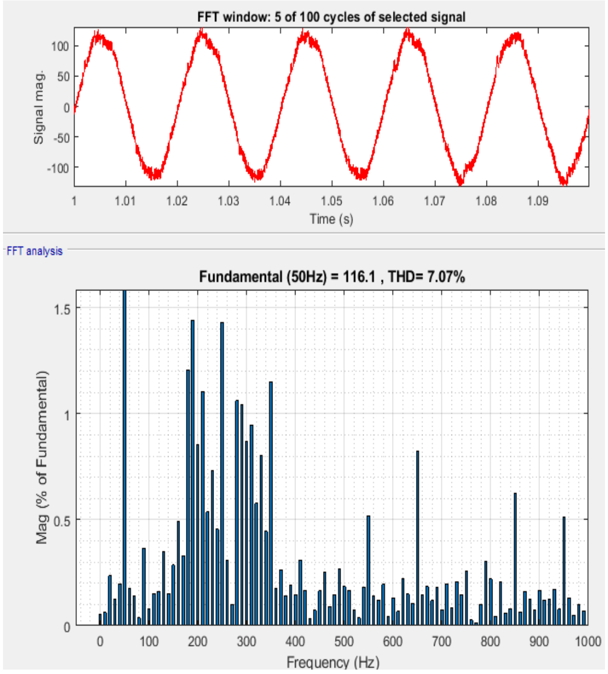

Figure 8: THD% of Source Current using PI Controller.

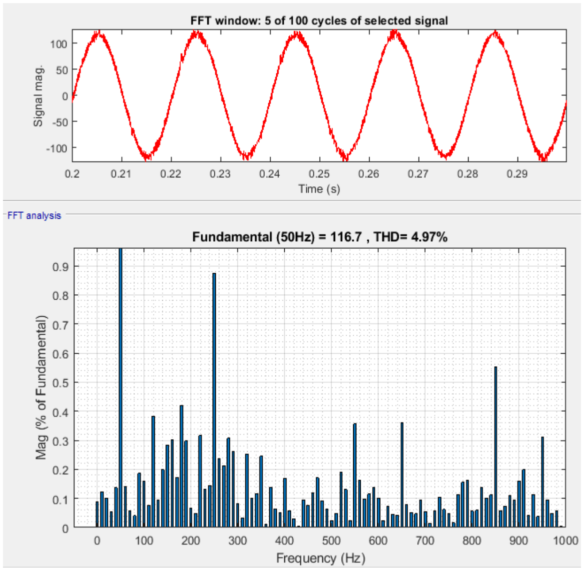

Figure 9: THD% of Source Current using Fuzzy Controller.

Table 2 Parameters List

PARAMETER	VALUE
Source Voltage (V_a, V_b, V_c)	220 V
System Frequency (f)	50 Hz
Rectifier Load	5 ohm, 8 mH
Load Inductance (L_L)	0.1 mH
Filter Inductance (L_{sh})	1 mH
DC Voltage (V_{dc_ref})	700 V
Capacitor Voltage (C_{dc})	2580 µF

The total harmonic distortion (THD) of the system for two control schemes of PI and Fuzzy logic are depicted in Figure 8 and Figure 9 respectively. The proposed system using FLC controller gives better THD of the source current compared to the other control scheme, i.e., the THD% of source current is reduced from 7.07% to 4.97% using Fuzzy controller .

CONCLUSIONS

This paper has presented operation of SAPF that simultaneously achieved the reactive power and harmonic compensation. The proposed system was simulated using Matlab/simulink software and the results demonstrate the harmonic free source current. Also the PI and Fuzzy controllers are compared for reactive power compensation, dc link voltage and THD of the source current. The THD has been reduced much better using FLC controller ensuring good operation of shunt active power filter thus resulting in improved power quality.

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