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Shunt active Power Filter Performance Evaluation Using Artificial Neural Networks

Somlal Jarupula

Department of Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, 522502, India

Mail id: jarupulasomu@kluniversity.in

Abstract

Objective: This paper explores the power condition abilities of Shunt Hybrid Power Filter (SHPF) with fuzzy tuned PI based control method in a distribution system. **Method: A** fuzzy tuner is proposed in this paper for tuning the parameters of proportional plus integral (PI) controller so that to improve the performance of the SHPF. The compensation process is based on source current sensing only. Synchronous Reference Frame (SRF) theory is used for generating reference currents, whereas linear current controller has been used to track these reference currents. Space Vector Pulse Width Modulation (SVPWM) has been employed to obtain the switching signals required for Voltage Source Converter (VSC). **Findings/Improvements:** Simulation analysis has been carried out to assess the performance of proposed control scheme. The simulation analysis proved that shunt hybrid power filters to be a potent solution for compensating the harmonics and reactive power of the distribution system. From the Simulation results, total harmonic distortion (THD), steady state response and dynamic behaviour of the fuzzy tuned PI controller based SHPF is found to be better than conventional PI controller.

Keywords: Fuzzy tuned to PI, Reactive Power, SHPF, SRF, SVPWM, Total Harmonic Distortion (THD)

1. Introduction

Power Quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. The widespread increase in renewable energy generation, increased usage of power electronic equipment and nonlinear loads for the industrial and commercial applications, has increased the harmonic distortion levels in the end use facilities and on the overall power system. On the other hand, the demand for clean power supply is increasing for sensitive loads such as medical electronic equipment and automated processes [1]. This demand has led to the advancement of various harmonic mitigation techniques [2]

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The most basic method of harmonic mitigation is to use Passive LC filters. The tuned LC filters are connected in parallel to harmonic generating load/source. The tuned LC filters exhibit low impendence at tuned frequency [4]. Because of their simplicity, low cost and high efficiency passive filters have been used in the power system to absorb the harmonics [5]. But passive filters are bulky in nature. Installing passive filter for each dominant harmonic component is difficult and rigorous. Multiple passive filters connected to utility might cause series and parallel resonance in the power system. To overcome the issues, active power filters have been proposed in the literature [6]. To mitigate the harmonic components, active power injects equal and opposite components there by cancelling original harmonics. For current harmonic mitigation an active power filter (APF) connected in parallel with load is used [7]. The shunt APF is operated in closed loop, such as to force the source current to be free of harmonics and at unity power factor (UPF) [8]. But they are limited by high maintenance, high cost, low power to volume ratio and difficulty in operating under high voltage conditions.

Figure1 shows the schematic diagram and control structure of proposed SHPF. The main purpose of the SHPF is to do current harmonic mitigation and reactive power compensation of the load [9]. Figure1 also illustrates the proposed control scheme for the SHPF. D and Q axis cur- rents are regulated separately. To obtain the information of phase and amplitude of source voltage vector, Phased Locked Loop (PLL) has been used. SRF-PLL, most commonly used in the grid connected converters [11], has been used for synchronizing the converter. In the SRF- PLL, by synchronizing PLL reference frame vector to grid voltage vector, the instantaneous phase angle θ or *wt* is determined [12].

1. Shunt Hybrid Power Filter and its Proposed Control Scheme

The control strategy employs an outer voltage loop (to control DC link voltage) with inner current loop (to control source currents). The current loop is very fast compared to the voltage loop so that inner current loop can trace the references generated by outer voltage loop. The inner current loops regulate the active and reactive currents in Synchronous Reference Frame (SRF) which is aligned to source voltage vector [13]. The active and reactive currents are controlled independently. Most of the cases the loads are lagging reactive loads. While the converter is injecting reactive power to the power system the fundamental voltage at the inverter terminals (Vs1) should be more than PCC voltage (V_{pcc}), which demands high volt- age on dc side (Vdc). But the DC link voltage is limited by insulation levels and DC side capacitor specifications [14].

To achieve satisfactory operation even under lesser DC link voltages, Space Vector Pulse Width Modulation (SVPWM) has been used. For appropriate control of SHPF in closed loop, the DC link capacitor voltage (Vdc) is sensed and compared with reference value (V *). The error e (V * - V)

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obtained and change in error (ce (n) = e(n) – e(n-1)) at nth sampling instant are given to Fuzzy inference mechanism [15]. The fuzzy process generates desired adjustments to the Kpand Ki values. The fuzzy adjusted or tuned PI controller generates d-axis source current (isd*) to inner current loop. The inner current loop generates modulation signals in d_q domain. The modulation signals are further transformed back to stationary coordinates and fed to SVPWM block which drives converter switches. Cross coupling terms are added at the output of current controller to decouple d and q axis currents. As the d-axis is aligned to grid voltage vector (Vq = 0), for UPF operation Iq* = 0.

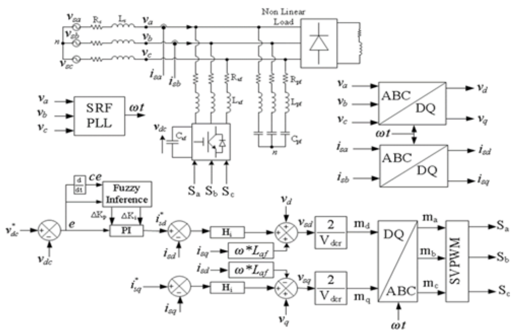

Figure 1. Proposed Control Scheme for the Shunt Hybrid Power Filter

The block diagram of fuzzy logic tuner is depicted in Figure 2. The fuzzification block converts the real word crisp inputs to fuzzy sets. To convert the crisp inputs from the real world to linguistic variables, nine linguistic values are chosen. The ranges of linguistic variables e(n), ce (n), Δ Kp and ΔKi are acquired based on SHPF parameters and heuristic experience. The membership functions, which describe the certainty of real quantity to linguistic values, will be used in fuzzification and defuzzification. Figure 3 shows the normalized membership functions for the input and output variables.

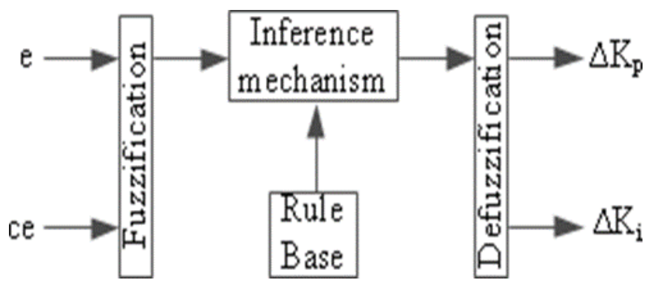

Figure 2. Block Diagram of Fuzzy Tuner

The heart of fuzzy logic control is the fuzzy linguistic rule, which is acquired mainly from the intuitive feeling and experience of the plant. Table 1 shows the fuzzy control rule table. The elements of this rule table are obtained based on the knowledge of the filter behavior in the dynamic and steady state. The fuzzy linguistic rules are saved in the rule base. The inference mechanism uses the fuzzy linguistic rules in the rule base to produce fuzzy conclusions (concluded fuzzy sets). The defuzzification block converts these concluded fuzzy sets into the crisp outputs. The Center of Gravity (COG) method has been used for defuzzification.

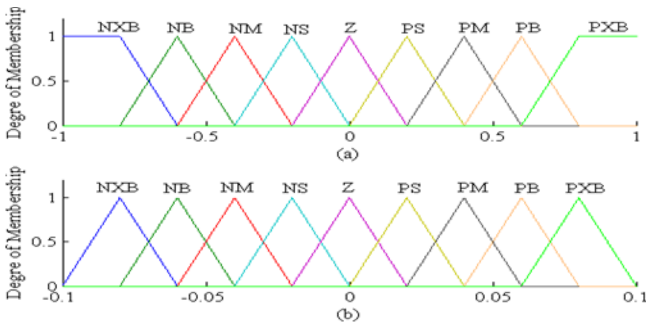

Figure 3. Membership Functions for the fuzzy variables. (a) Membership Function of e(n) and ce(n). (b) Membership function of ΔKp and ΔKi

3. SIMULATION RESULT

To verify the feasibility of the proposed control strategy, the SHPF has been simulated using MATLAB-SIMULINK environment. The main electrical parameters of the power circuit and control data are mentioned in the table. The Passive Power Filter (PPF) is tuned to offer low impedance at 5th harmonic component. An inductive load is used as a low power factor load and a three-phase diode rectifier with an RL load was used as harmonic generating load. The values of K_p and Ki for reference current generation are respectively. Simulation results with the conventional PI controller and with the Fuzzy tuned PI controller are presented in Figures 4 and 5 respectively.

Figure 4 depicts the response of SHPF with Fuzzy tuned PI controller. The hybrid filter is turned on at 0.1sec. It is seen that the DC side capacitor voltage reached its set value within 0.06sec (3 cycles). It has been also observed that soon after switching on the hybrid filter the source is in phase with source voltage. Since the Passive filter is tuned for 5th harmonic component, it is observed that the 5th harmonic in the source current is nullified. Figure 5 shows the response of SHPF with conventional PI con- troller with the SHPF switching on at 0.1sec. It is observed that the DC link voltage took 0.14sec (7 cycles) to attain its set value.

Table1. Fuzzy Control Rule Table

Error	Change in Error (ce)

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(e)	NXB	NB	NM	NS	Z	PS	PM	PB	PXB
NXB	NXB	NXB	NXB	NXB	NXB	NB	NM	NS	Z
NB	NXB	NXB	NXB	NXB	NB	NM	NS	Z	PS
NM	NXB	NXB	NXB	NB	NM	NS	Z	PS	PM
NS	NXB	NXB	NB	NM	NS	Z	PS	PM	PB
Z	NXB	NB	NM	NS	Z	PS	PM	PB	PXB
PS	NB	NM	NS	Z	PS	PM	PB	PXB	PXB
PM	NM	NS	Z	PS	PM	PB	PXB	PXB	PXB
PB	NS	Z	PS	PM	PB	PXB	PXB	PXB	PXB
PXB	Z	PS	PM	PB	PXB	PXB	PXB	PXB	PXB

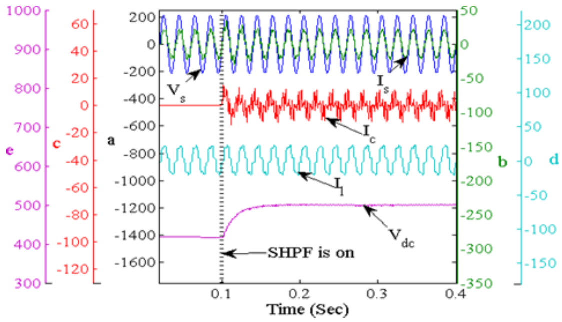

Figure 4. Switch on Response of Fuzzy Tuned PI Based SHPF a (Dark Blue):- Source Voltage (Vs) in volts, b (Green) :- Source Current (Is) in Amps, c (Red) :- Compensator

Current (Is) in Amps, d (Sky Blue) :- Load Current (Is) in Amps, e (Dark Blue):- DC Side Voltage (Vdc) in volts

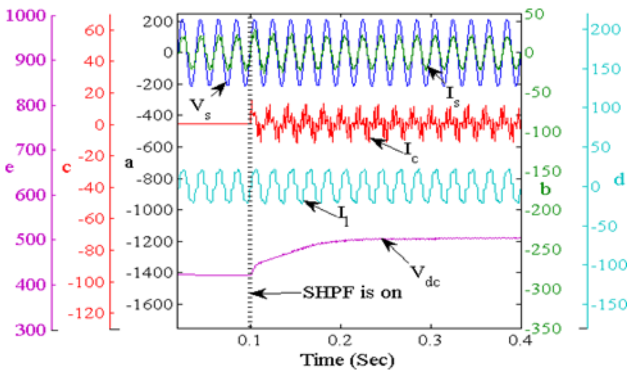

Figure 5. Switch on Response of Conventional PI Based SHPF

a (Dark Blue):- Source Voltage (V_S) in volts, b (Green) :- Source Current (I_S) in Amps, c (Red) :- Compensator Current (I_S) in Amps, d (Sky Blue) :- Load Current (I_S) inAmps, e (Dark Blue):- DC Side Voltage (V_{dc}) in volts

Table 2. Parameters of System

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Parameter		**Value**
Source Voltage (V_s)		150V
Frequency (F_s)		50Hz
Source Inductance (L_s)		1.5mH
Source Resistance (R_s)		0.1Ω
Non-Linear Load	Resistance (R_d)	20Ω
	Inductance (L_d)	6mH
Passive Filter	Capacitance (C_{pf})	12.5μF
	Inductance (L_{pf})	32.5mH
	Internal Resistance (R_{pf})	0.1Ω
Active Power Filter	Switching Frequency (F_{sw})	20kHz
	Input Inductor (L_{af})	8.5mH
	Input Inductor Resistance (R_{af})	0.1Ω
	DC Link Voltage (V_{dc})	500V
	DC Side Capacitor (C_{dc})	1300μF

Table 2 shows the parameters of the system used in simulation. On the basis of simulation results, important parameters for the conventional PI and fuzzy tuned PI controllers presented in Table 3 and Table 4. It is obliviousfrom the simulation results that dynamic performanceof the DC side capacitor voltage and source current is improved with fuzzy tuned PI controller compared to thegeneral PI controller. The steady state performance is alsoslightly improved with the fuzzy tuned PI controller com-pared to that of conventional PI controller.

Table 3. Harmonic Current of Load and Sourcecurrents at 14.9A(Fundamental) Load Current

Harmonic Order	**Load Current (I_l) in A**	**Source Currents (Is) in A**	
		With PI Controller	**With Fuzzy tuned PI Controller**
1	14.83	14.53	14.48
5	2.85	0.0565	0.02828
7	1.25	0.106	0.01414
11	0.87	0.2262	0.191
13	0.55	0.205	0.205
17	0.346	0.29	0.275
19	0.254	0.035	0.042
THD	25.26	3.82	3.56

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Table 4. Dynamic response parameters

Parameter	PI Controller	Fuzzy PI Controller
Settling Time	0.14	0.06
Vdc Peak to Peak Ripple at14.9A	2.2V	1.9V

4. Conclusion

To reduce harmonics and the reactive power demand of the nonlinear load, a fuzzy tuned PI controller-based shunt hybrid power filter has been investigated. Investigated and contrasted with traditional PI controller is the performance of the fuzzy tuned PI controlled SHPF. The simulation findings make it clear that the compensating procedure is solely reliant on source current sensing. When compared to a normal PI controller, fuzzy tuned PI controllers have been found to offer greater transient responsiveness. Additionally, it can be shown that the proposed strategy marginally enhanced the steady state responsiveness. After adjustment, the line currents' harmonic distortion (THD) is below 5%, the maximum allowed by IEEE 519 rules.

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