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Shunt Active Power Filter for Power Quality Enhancement of Distribution Power System Using Fuzzy Logic Controller

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Abstract. Renewable Energy Sources are being connected in distribution systems utilizing power electronic converters. This paper uses Fuzzy Logic controller (FLC)-based Shunt Active Power Filter (APF) is a solution to the total harmonic distortion (THD) caused by nonlinear loads in distribution generation integrated systems like Solar energy conversion. Shunt Active Power Filter using Proportional Integral (PI) controllers are easy to implement and fewer complex but having several drawbacks. They can't reduce nonlinearity problems. These drawbacks can be overcome by using FLC(fuzzy logic controller). A single-stage solar PV integrated shunt active power filter is used to improve the power Quality in a system. The current reference generator that was chosen to be used in the active power filter is also described.

Keywords: Shunt APF · Power Quality · THD · Distribution Power system · PV system

1 Introduction

Problems with electrical power can be broken down into two categories: those related to voltage and current [1]. Since non-linear loads cause current quality issues, shunt compensation is necessary to alleviate the problem; in shunt APF, an active power filter is used to eliminate harmonics. Several control strategies have been proposed in the literature; a simplified d-q control is implemented. Distributed generation refers to the integration of RES at the distribution level (DG). Utility companies worry that instability and power quality (PQ) difficulties may arise due to the widespread use of intermittent RES in distribution networks [2]. Recent developments in power electronics and digital control have made it possible to actively regulate DG systems for better system performance and higher power quality (PQ) at the power conversion centre (PCC). However, harmonic currents are generated at PCC due to the heavy reliance on power electronics-based equipment and non-linear loads, which could reduce the reliability of the power supply [3]. In a distributed energy system, intermittent RES are typically interfaced using current-controlled voltage-source inverters.

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A limited control schemes for grid-integrated inverters utilizing PQ solution was projected recently. A d-q control technique is used to solve this problem is the main contribution in this paper. Pre-tuned controllers have often been used for active power filter operation [4]. Fuzzy controller will receive input on the circuit's voltage change and use that to make judgements about the steady-state signal. For this purpose, the fuzzy logic controller acts as a smart controller [5–8]. If there are issues with the electricity, active power filters are typically used to rectify this. In this work, a PV generation system is grid-connected while the power quality (PQ) is preserved without the use of an APF (Active Power filter) [9]. While PI, PD, and PID controllers have traditionally dominated the market, numerous researchers have reported finding success with Fuzzy Logic Controller (FLC) as a viable alternative. In order to improve efficiency, reliability, and quality, two separate fuzzy controllers were developed for the DG interface [10]. These controllers will act as active power filters (by removing harmonics).

This work discusses a single-phase inverter with a fuzzy logic controller for grid-connected DG systems that need power quality features like harmonic and reactive power adjustment [11]. The current reference generator that was chosen to be used in the active power filter is also described in detail. Figure 1 depicts the block diagram of the PV-Shunt APF system.

2 PV-Shunt APF System

There are a number of different configurations and classifications of Shunt APFs based on their supply, connections (right shunt, left shunt), and operating principle. The shunt active power filter corrects for current harmonics, power factor, and other current-related power quality issues. The PV-Shunt APF is made up of two voltage-sourced pulse width modulated inverters connected by a dc connection. The PWM inverter is shunt connected to the system [12]. Nonlinear load is wired into the system using all three phases and all three wires. The ripples are caused by the high switching frequency operation, and the RC filter is attached to the circuit to reduce the ripples to an acceptable level. Block diagram of the PV- Shunt APF System is depicted in Fig. 1.

3 Control Algorithm for Shunt APF

Harmonics in the load current can be filtered out using a shunt-APF, which has the arrangement depicted in Fig. 2 and filters a current that is same in magnitude but opposite in direction.A shunt active power filter (APF) serves the same purpose as a current source filtering the harmonic of the load with a 180^0 phase shift. The APF is frequently used as a current controller and harmonic alienator between the consumer side source and the nonlinear load.The mathematical formulae obtained with respect to the respective phases are provided below, based on p-q theory. In – coordinates, for phases a, b, and c can be represented by Π/2 lead as

$$\begin{bmatrix} v_{Lr\_\alpha} \\ v_{Lr\_\beta} \end{bmatrix} = \begin{bmatrix} v_{Lr}^{ref}(\omega t) \\ v_{Lr}^{ref}(\omega t + \pi/2) \end{bmatrix} = \begin{bmatrix} v_{Lm}\sin(\omega t - 120^\circ) \\ v_{Lm}\cos(\omega t - 120^\circ) \end{bmatrix} \tag{1}$$

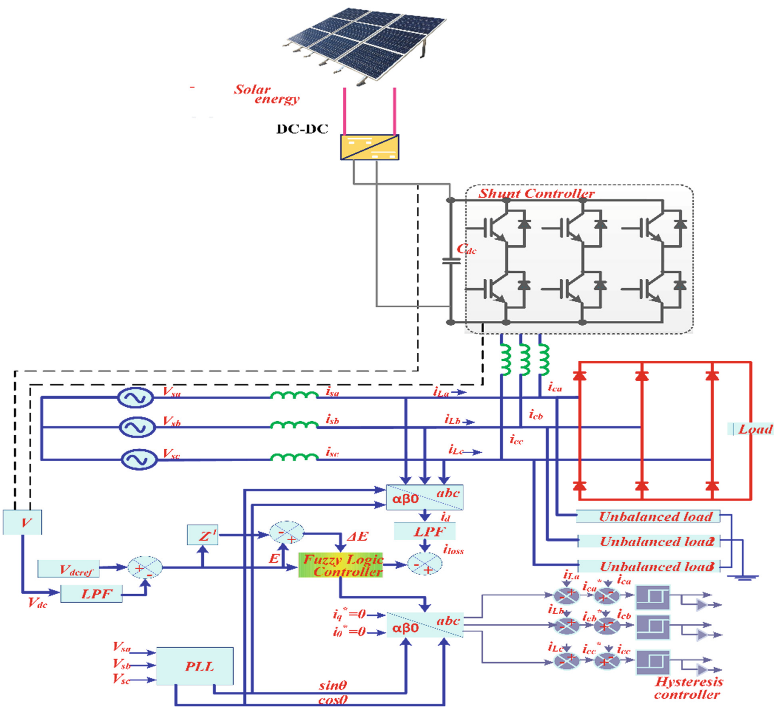

Fig. 1. Block diagram of PV-Shunt APF System

$$\begin{bmatrix} i_{Lr\_\alpha} \\ i_{Lr\_\beta} \end{bmatrix} = \begin{bmatrix} i_{Lr}(\omega t + \varphi L) \\ i_{Lr}[(\omega t + \varphi L)] + \pi/2 \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} v_{Ly\_\alpha} \\ v_{Ly\_\beta} \end{bmatrix} = \begin{bmatrix} v_{Ly}^{ref}(\omega t) \\ v_{Ly}^{ref}(\omega t + \pi/2) \end{bmatrix} = \begin{bmatrix} v_{Lm}\sin(\omega t - 120^\circ) \\ v_{Lm}\cos(\omega t - 120^\circ) \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} i_{Ly\_\alpha} \\ i_{Ly\_\beta} \end{bmatrix} = \begin{bmatrix} i_{Lr}(\omega t + \varphi L) \\ i_{Ly}[(\omega t + \varphi L)] + \pi/2 \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} v_{Lb\_\alpha} \\ v_{Lb\_\beta} \end{bmatrix} = \begin{bmatrix} v_{Lb}^{ref}(\omega t) \\ v_{Lb}^{ref}(\omega t + \pi/2) \end{bmatrix} = \begin{bmatrix} v_{Lm}\sin(\omega t - 120^\circ) \\ v_{Lm}\cos(\omega t - 120^\circ) \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} i_{Lb\_\alpha} \\ i_{Lb\_\beta} \end{bmatrix} = \begin{bmatrix} i_{Lb}(\omega t + \varphi L) \\ i_{Lb}[(\omega t + \varphi L)] + \pi/2 \end{bmatrix} \tag{6}$$

The instantaneous power can be broken down into active power and reactive power using the above definitions for a balanced three phase system.

$$p_{L,abc} = v_{L,abc\alpha} * i_{L,abc\_\alpha} + v_{L,abc\_\_\beta} * i_{L,abc\beta} \tag{7}$$

$$q_{L,ryb} = v_{L,abc\_\_\alpha} * i_{L,abc\_\beta} + v_{L,abc\_\beta} * i_{L,abc\alpha} \tag{8}$$

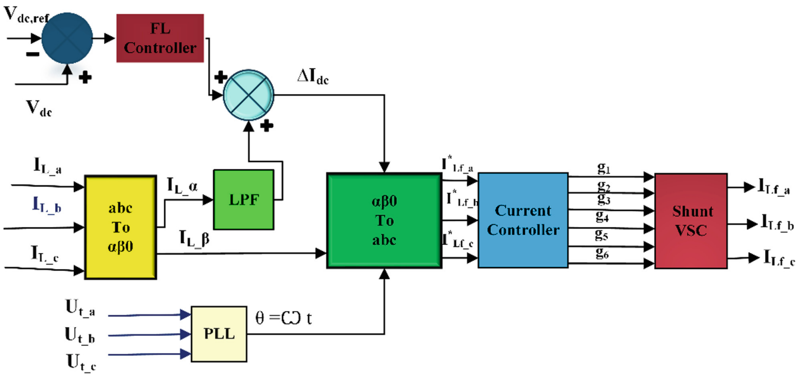

Fig.2. Control method for Shunt APF

On the distribution side, a parallel connection is made for the Shunt APF. Current sensors detect the flow of electricity from the Shunt APF side to the load side and back again. These signals are transformed from one reference frame to another using the modified SRF control approach, which includes ABC and αβ0 reference frames as examples.

4 Solar PV System

Figure 3 shows a basic equivalent circuit model of a PV cell. The voltage produced by a PV cell is proportional to its photocurrent, which is in turn largely governed by the load current and the strength of solar irradiation.

As can be seen in Fig. 3, the power output of a solar cell is regulated by a series circuit consisting of a diode, series and shunt resistors Rs and Rsh, and I_S source current of PV.

$I_{pv} = I_S - I_D - I_{SH}$,

Where I = o/p current.

$\boldsymbol{I_{pv}}$= current Produced by solar cell.

I_S = photo generated current.

I_D = diode current.

I_{SH} = shunt current.

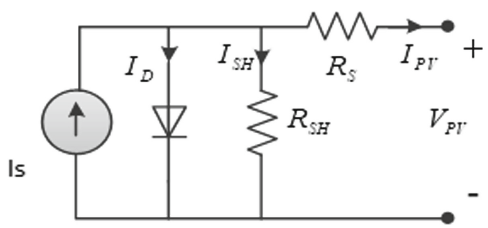

Fig. 3. Circuit diagram of a PV cell

The voltage is given by:

$$V_J = V_{pv} + I_{pv} R_S$$

where

V_J = voltage across both diode & resistor R_{SH}, Vpv = output voltage (volts), I = output current (amperes), R_S = series resistance (Ω).

$$I = I_L - I_o \left\{ \exp\left[\frac{q(V + IR_s)}{nkT} \right] - 1 \right\} - \frac{V + IR_s}{R_{SH}}$$

5 Control Method

FLC analyses input information using a continuous scale of zero to one for a number of linguistic factors. With a fuzzy logic control system, the controller's actions are determined by fuzzy rules formulated with the help of fuzzy set theory. Using a fuzzy logic controller, PQ issue can be mitigated. The steps of an FLC are fuzzing, decision making, and defuzzification. The process of fuzzification takes a sharp number and makes it fuzzy. Figure 4 block diagram of FLC. The fuzzy sets are formed using 7*7 rule MF's for the inputs error E, change in error CE are shown in Fig. 5 and 6.

A fuzzy logic control with seven membership functions have been chosen to implement the FLC approach. The error voltage V(k) and its incremental variation ΔV(k) are the inputs, and they are derived from the DC link voltage, which is given by:

$$\mathrm{V(k)} = \mathrm{V_{dc}} * -\mathrm{V_{dc}(k)} \tag{9}$$

$$\Delta\mathrm{V(k)} = \mathrm{V(k)} - \mathrm{V(k-1)} \tag{10}$$

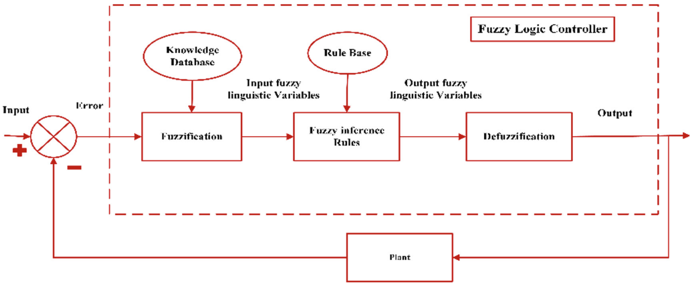

Fig. 4. Control diagram of FLC

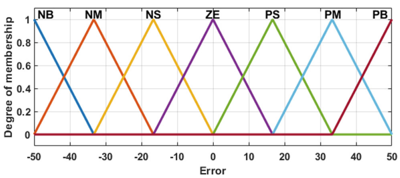

Fig.5. Error Membership functions

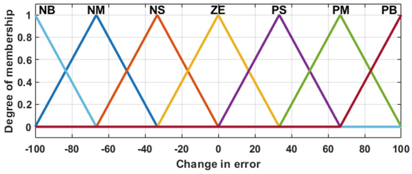

Fig.6. Change in Error Membership Functions

Table 1. Rule base table for Fuzzy Logic Controller

Error / Change In Error	PS	PB	ZE	NS	NB
PB	PB	PB	PB	PS	ZE
PS	PB	PB	PS	ZE	NS
ZE	PS	PB	ZE	NS	NB
NS	ZE	PS	NB	NB	NB
NB	NS	ZE	NB	NB	NB

6 Results and Discussions

The input current becomes near to the sinusoidal after the implementation of FLC based Grid integrated DG with Shunt APF using FLC shown in Fig. 7. In Fig. 7 three waveforms obtained the Source Current, Filter current and Load current respectively. From the wave form after injecting the filter current load current become near to the sinusoidal and reduced the distortions (Figs. 8 and 9).

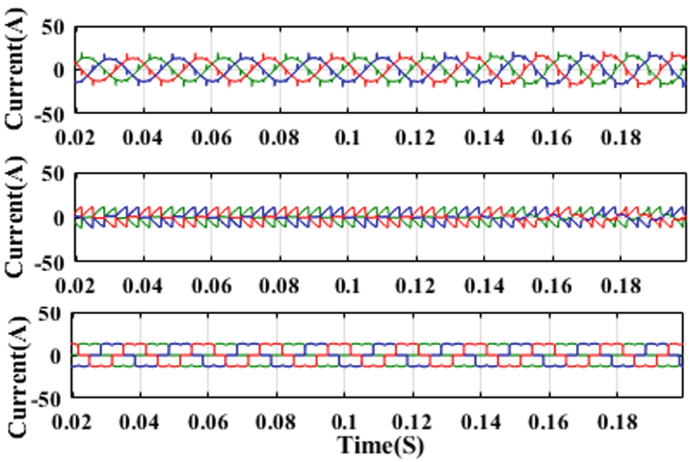

Fig.7. Output waveform of source current I_s, filter current I_{filter} and load current of FLC

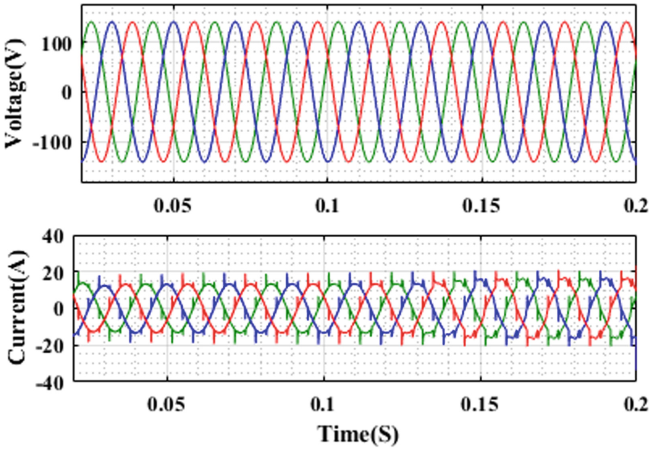

Fig.8. Output waveform of source voltage V_S and source current I_S of FLC

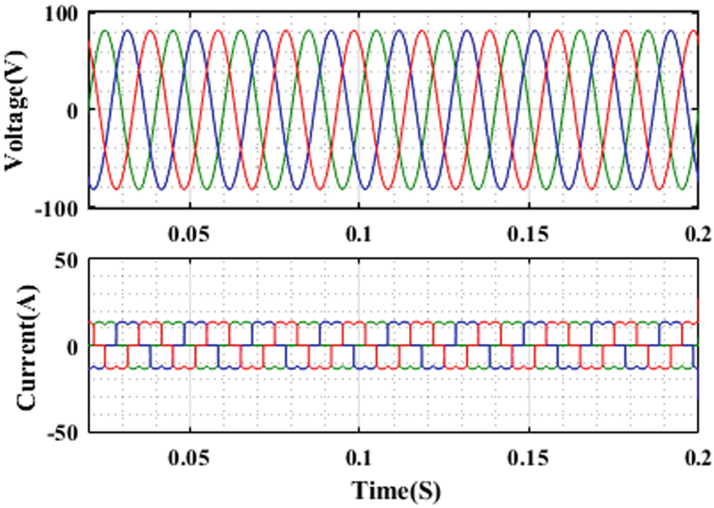

Fig.9. Output waveform of load voltage V_L and load current I_L of FLC

Comparison results of THD for source current I_S, source voltage V_S, load voltageV_L and load current $I_L$with FLC shown in Table 2. From the Table it is observed that THD for I_S changed from 16.63% to 8.35% using FLC.The THD for Vs reduced from 6.14% to 4.21% using FLC and also THD for IL and VL are reduced from 10.30% to 8.21% and 15.14% to 11.5% respectively.

Comparison results of THD

	Total Harmonic Distortion THD(%)			
Controllers	Is	V_S	I_L	V_L
Shunt APF with PI	16.63	6.14	10.30	15.14
Shunt APF with FLC	8.35	4.21	8.21	11.5

7 Conclusion

This paper addresses one of the power quality problems that is current harmonics for grid integrated DG system using shunt APF based on FLC. Shunt APF based on PI Controller cannot give accurate output for nonlinear load in distributed generation system and it give THD of load current and Load voltage are 10.30% and 15.14%. FLC give THD of the load current and Load voltage are 8.21% and 11.5% respectively. As compared to a PI Controller, fuzzy logic controller (FLC) based grid integration distribution generation system with Shunt APF give better result.

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