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Adaptive Fuzzy PID Based Control Strategy For 3Phase 4Wire Shunt Active Filter To Mitigate Current Harmonics Of Grid Interconnection Of Renewable Energy Based Distribution System

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ABSTRACT

This paper presents a new control strategy for controlling the shunt active power filter to compensate reactive power and to reduce the unwanted harmonics in the grid current. Shunt active filter act as a current source which is connected in parallel with a non-linear load and controlled to produce the required compensating current. The proposed control strategy is based on the fuzzy PID controller which is used for determining the reference compensating currents of the three-phase shunt active power filters. Simulations are carried out using MATLAB/SIMULINK to verify the performance of the proposed controller. The output shows the controller has fast dynamic response high accuracy of tracking DC voltage reference and robust to load parameters variations.

Index Terms: Active power filter (APF), fuzzy controller, Fuzzy PID controller, distributed generation (DG), distribution system, grid interconnection

I. INTRODUCTION

The non-renewable- energy decreases at a faster pace has made renewable energy as a future energy source. Renewable energy-based power generation systems has many advantages such as the development of clean energy, reduce global warming etc. But on the other hand, renewable energy intermittently when it is directly connected to the grid caused many power quality issues such as harmonics, voltage sags, break etc. [1].The distributed generation schemes are widely uses power electronic interface for grid connections, because of its fast response, harmonic compensation and reactive power compensation. Due to the widespread use of non-linear loads large amounts of harmonic currents are injected into the power systems. These harmonic currents flowing through the impedance of the supply system causing harmonic currents to pull by other loads connected to the PCC. The persistence of current harmonics and voltage in the power system increases the losses in the lines, decrease the power factor and may cause timing errors in sensitive electronic equipment. Three phases balanced non-linear loads such as motor drivers, silicon controlled rectifiers (SCR), large uninterruptible power supplies (UPS) produce harmonic currents and voltages that are harmonics of positive sequence as 7th, 13th, etc. and negative-sequence harmonics like 5th, 11th, etc. Single phase non-linear loads such as switch-mode power supplies in computer equipment produce harmonic currents and voltages which are third order zero-sequence harmonics, triplen harmonics like 3rd, 9th, 15th, 21st, etc. Unlike positive and negative-sequence harmonic currents, triplen harmonic currents do not cancel but add arithmetically at the neutral bus. This result's the neutral current that touches magnitudes as high as 1.73 times the phase current. In addition to the risk of cables and transformers overheating, the third harmonic can recede energy efficiency [2]. The method of current harmonics reduction reduces passive LC filters which are simple and low cost. However, these filters have drawbacks as well like large size, tuning and risk of resonance problems. As harmonic pollution is severe in power networks, power system engineer developed dynamic and adjustable solutions to the power quality problems. Such equipment is known as Active Filters (AF's) [3]. These filters are used to compensate the load current harmonics and improve the power factor.

In addition to eliminating the harmonic currents and improving the power factor, SAF can maintain the balance of electrical system under the unbalanced load condition and nonlinear loads [4-6]. In general, the performance of SAF is based on three design criteria [7-12]: i) the design of the power inverter; ii) the types of current regulators used; iii) the methods used to obtain the reference current. Several control techniques have been used to obtain the reference current. These techniques such as the theory of instantaneous reactive power [7], notch filters [9], the control flow based [10], the theory of balance of power [9] - [13], and the controller sliding mode have been used to improve the performance of active filters. However, most of these control techniques include a number of transformations and are difficult to implement.

In this study, a new control strategy is introduced that is based on Fuzzy PID controller. As PID is regarded as the standard control structures of the classical control theory, and fuzzy controllers have positioned themselves as a counterpart of classical PID controllers on the same dominant role at the knowledge rich spectrum (Åström and Hagglund 1995, Oh et al. 2004). PID controllers are designed for linear systems and they provide a preferable cost/benefit ratio. However, the presences of nonlinear effects limit their performances. Fuzzy controllers are successful applied to non-linear system because of their knowledge based nonlinear structural characteristics. Hybridization of these two controller structures comes to one's mind immediately to exploit the beneficial sides of both categories. Basically, in this design methodology, the classical PID and fuzzy controller have been combined by a blending mechanism that depends on a certain function of actuating error. Simulations are performed on MATLAB®/Simulink toolbox to illustrate the efficiency of the proposed method.

The paper is organized as follows: Section II describes the system description and controller for interfacing grid inverter. An Extensive Matlab simulation study is presented in Section III and Section IV concludes the paper

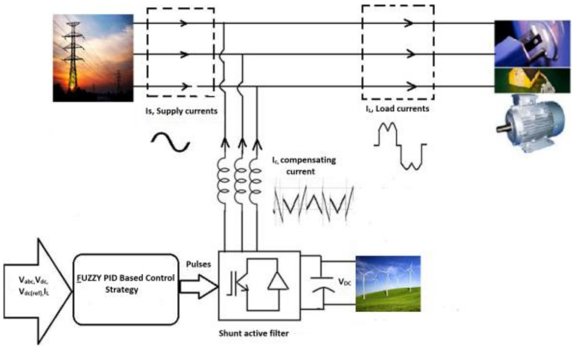


Fig. 1. Schematic of proposed renewable based distributed generation system.

II. SYSTEM DESCRIPTION

The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter as shown in Fig. 1. The shunt active filter is a key element of a system of DG, since it interconnects the renewable energy source to the grid and provides the generated power. The RES can be a DC source or an AC source coupled to the DC bus rectifier. Usually, the fuel cell and photovoltaic energy sources generate power at variable low dc voltage, while the variable speed wind turbines generate power at variable ac voltage. Thus, the power generated from these renewable sources needs power conditioning (i.e., dc/dc or ac/dc) before connecting on dc-link. The dc-capacitor decouples the RES from grid and also allows independent control of converters on either side of dc-link.

A. DC-Link Voltage and Power Control Operation

Due to the intermittent nature of the RES, the generated power is variable in nature. The dc-link plays an important role in the transfer of this power from variable renewable energy to the grid. RES are represented as current sources connected to the dc-link of a grid-interfacing inverter. Figure 2 shows a systematic representation of energy transfer from renewable energy sources to the grid via the DC-link. The current injected by renewable into dc-link at voltage level can be given as

$$I_{dc1}=P_{RES} / V_{dc} \qquad (1)$$

Where P_{REN} is the power generated from RES.

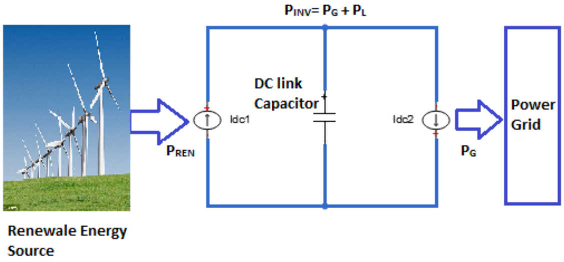


Fig. 2. DC-Link equivalent diagram

The current flow on the other side of dc-link can be represented as

$$I_{dc2}=P_{inv} /V_{dc}= (P_g+P_{loss}) / V_{dc} \qquad (2)$$

Where P_G and P_{Loss} are total power available at grid-interfacing inverter side, active power supplied to the grid and inverter losses, respectively. If inverter losses are negligible then $P_{REN}= P_{INV}$.

B. Control of Grid Interfacing Inverter:

The control diagram of grid- interfacing inverter for a 3-phase 4-wire system is shown in Fig. 3. The fourth leg of inverter is used to compensate the neutral current of load. While performing the power management operation, the inverter is actively controlled in such a way that it always draws/supplies fundamental active power from/ to the grid. If the load connected to the PCC is non-linear or unbalanced or the combination of both, the given control approach also compensates the harmonics, unbalance, and neutral current.

The duty ratio of inverter switches are varied in a power cycle such that the combination of load and inverter injected power appears as balanced resistive load to the grid.

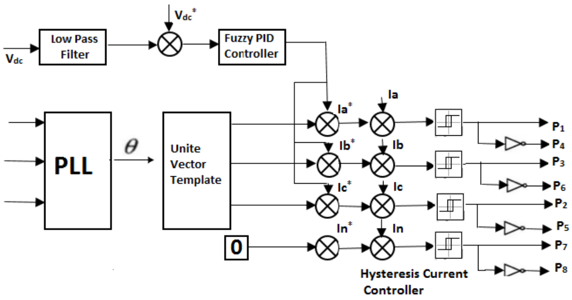


Fig. 3. Block diagram representation of grid-interfacing inverter control.

The regulation of dc-link voltage carries the information regarding the exchange of active power in between renewable source and grid. Thus the output of dc-link voltage regulator results in an active current I_M. The multiplication of active current component I_M with unity grid voltage vector templates (Ua, Ub, Uc) generates the reference grid currents (I*a, I*b, I*c). The reference grid neutral current (I*n) is set to zero, being the instantaneous sum of balanced grid currents.The grid synchronizing angle (ϴ) obtained from phase locked loop (PLL) is used to generate unity vector template as

$Ua = \sin(\Theta)$ (3)
$Ub = \sin(\Theta - 2\pi/3)$ (4)
$Uc = \sin(\Theta + 2\pi/3)$ (5)

The actual dc-link voltage (Vdc) is sensed and passed through a first-order low *Pass filter* (LPF) to eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals. The difference of this filtered dc-link voltage and reference dc-link voltage V^*dc is given to a Fuzzy PID controller to maintain a constant dc-link voltage under varying generation and load conditions. The dc-link voltage error Vdcerr (nth) at nth sampling Instant is given as

$Vdcerr(n) = V^*dc(n) - Vdc(n)$ (6)

The instantaneous values of reference three phase grid currents are computed as

$Ia^* = Im.\ Ua$ (7)
$Ib^* = Im.\ Ub$ (8)
$Ic^* = Im.\ Uc$ (9)

The neutral current, present if any, due to the loads connected to the neutral conductor should be compensated by forth leg of grid-interfacing inverter and thus should not be drawn from the grid. In other words, the reference current for the grid neutral current is considered as zero and can be expressed as

$I_N^* = 0$ (10)

The reference grid currents(Ia* Ib*, Ic*) are compared with actual grid currents(Ia, Ib, Ic) to compute the current errors as

$I_{acerr} = Ia^* - Ia$ (11)
$I_{bcerr} = Ib^* - Ib$ (12)
$I_{ccerr} = Ic^* - Ic$ (13)
$I_{ncerr} = I_N^* - I_N$ (14)

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses (P_1 to P_8) for the gate drives of grid-interfacing inverter.

C) Hysteresis current controller:

The hysteresis current control (HCC) is the simplest control method available so-forth to implement the shunt APF with three phase current controlled VSI and is connected to the AC mains for compensating the current harmonics and the VSI gate control signals are brought out from hysteresis band current controller where a hysteresis current controller is implemented with the closed loop control system and waveforms which are shown in figure 4. Here an error signal is used to control the switches in a voltage source inverter and the error is the only difference between the desired current and the current being injected by the inverter and when the error exceeds the upper limit of the hysteresis band the upper switch of the inverter arm is turned off and the lower switch is turned on as a result of which the current starts decaying. When the error crosses its defined lower limit of the hysteresis band then the lower switch of the inverter arm is turned off and the upper switch is turned on as a result of which the current gets back into the hysteresis band and the minimum and maximum values of the error signal are emin and emax respectively and the range of the error signal e max-emin directly controls the amount of ripple in the output current from the VSI.

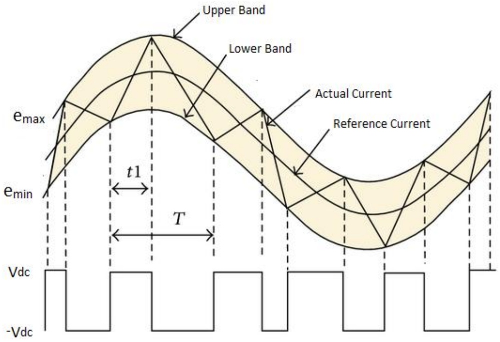


Fig. 4. Hysteresis current control

D) Proposed PID controller:

The structure of the fuzzy PID controller, which has two inputs and one rule base, is shown in Fig. 5. The inputs are the classical error (e) and the rate of the change of error ($e^{\cdot}$).

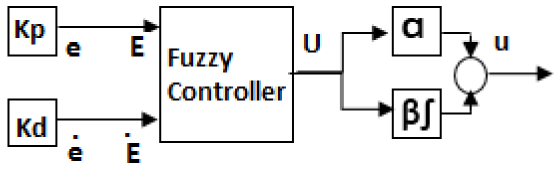


Fig. 5. The Fuzzy PID Controller structure

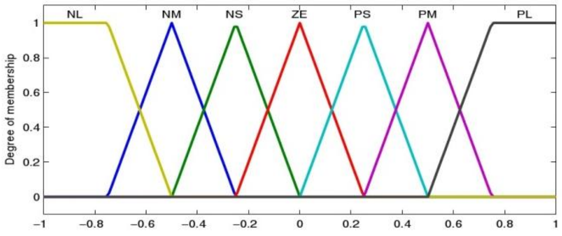


Fig. 6. The membership functions of e, and e

Triangular membership functions are used for input variables as it is shown in Fig. 6. For the output variable u, singleton membership functions are defined as in Fig. 7. The fuzzy PID controller rule base composed of 49 (7x7) rules as shown in Table 1. The control surface of the fuzzy PID controller is also given in Fig. 8.

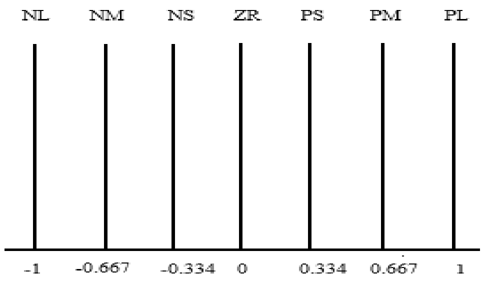


Fig. 7. The membership functions of u.

The parameters of the fuzzy controller are defined as Ke, Kd, α, and β

E/E	NL	NM	NS	ZR	PS	PM	PL
PL	ZR	PS	PM	PL	PL	PL	PL
PM	NS	ZR	PS	PM	PL	PL	PL
PS	NM	NS	ZR	PS	PM	PL	PL
ZR	NL	NM	NS	ZR	PS	PM	PL
NS	NL	NL	NM	NS	ZR	PS	PM
NM	NL	NL	NL	NM	NS	ZR	PS
NL	NL	NL	NL	NL	NM	NS	ZR

Table 1: PID type Fuzzy Controller Rule Base

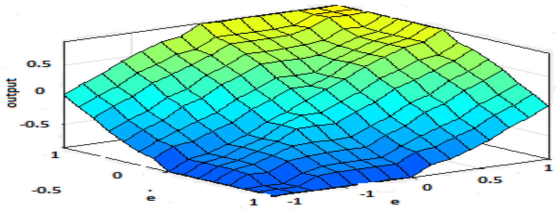


Fig. 8. The control surface of the fuzzy PID controller

III. MATLAB SIMULATION

In order to verify the proposed control approach to achieve multi-objectives for grid interfaced DG systems connected to a 3-phase 4-wire network, an extensive simulation study is carried out using MATLAB/Simulink.

Figure 9(a) shows the overall diagram of the system while figure 9(b) shows the proposed controlled strategy for controlling the shunt active filter. The simulation parameters used in this simulation are tabulated in Table II.

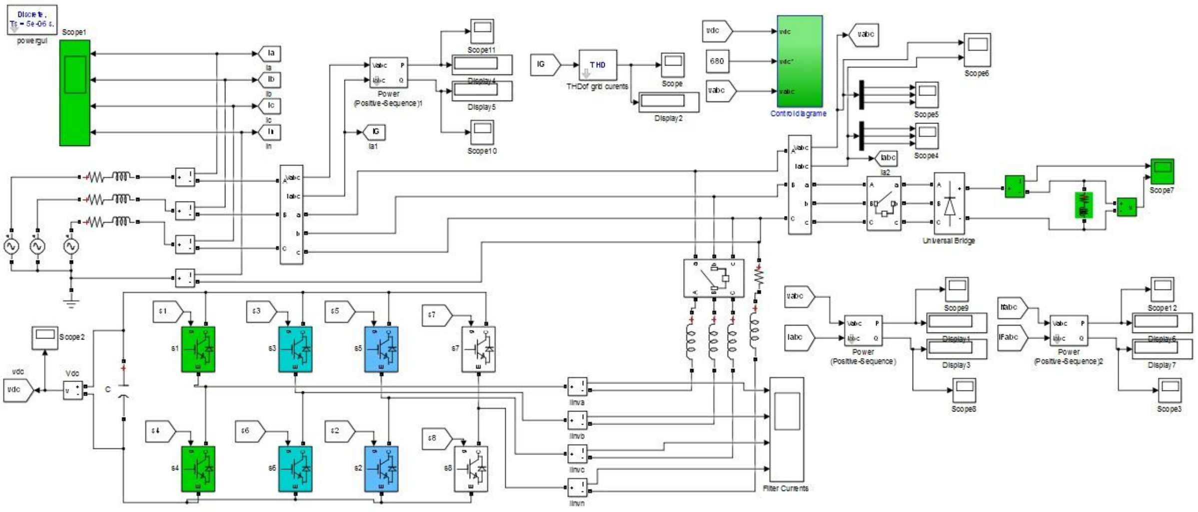


Fig. 9(a). Over diagram of the Grid interconnection of renewable energy based distribution system

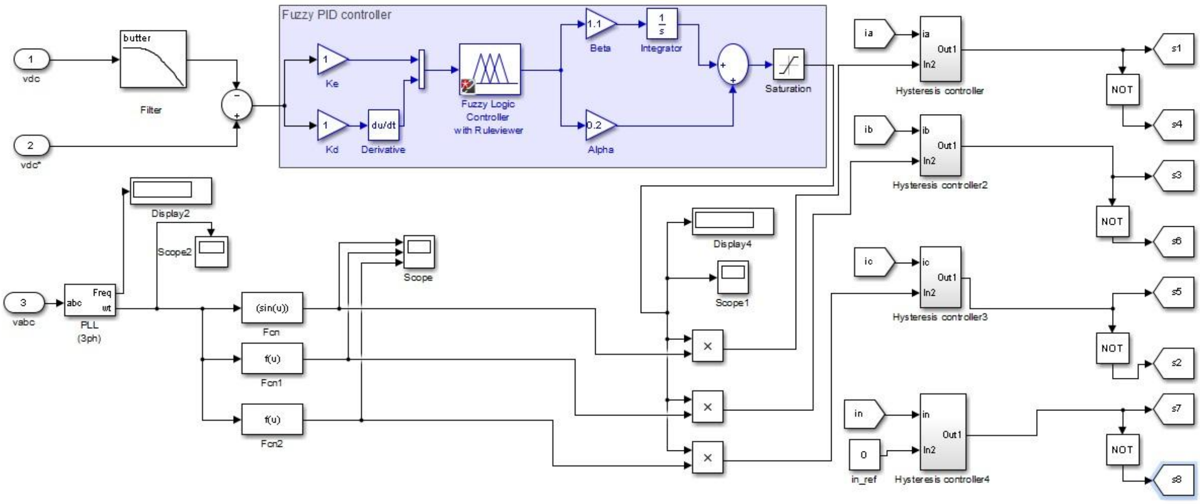
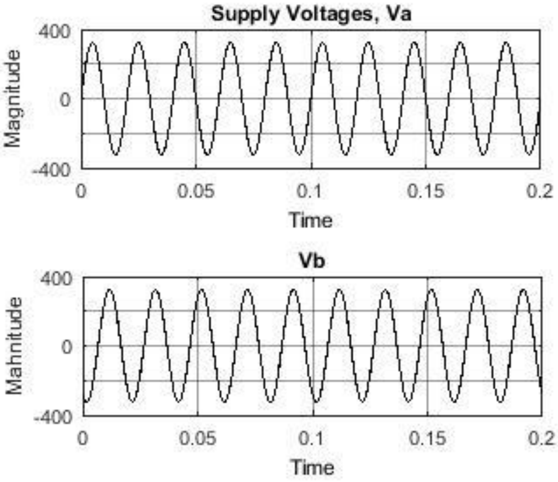


Fig. 9(b). Control strategy for controlling the shunt active filter

A 4-leg current controlled voltage source inverter is actively controlled to achieve balanced sinusoidal grid currents at unity power factor (UPF) despite of highly unbalanced nonlinear load at PCC under varying renewable generating conditions. A RES with variable output power is connected on the dc-link of grid interfacing inverter. A 3-phase 4-wire nonlinear load, whose unbalance, harmonics, and reactive power need to be compensated, is connected on PCC. The waveforms of grid voltage (V_a, V_b, V_c), Grid current(I_a, $I_{b,}$ I_c I_n), load currents (I_{la}, I_{lb},I_{lc}) and Inverter Currents (I_{na}, I_{nb}, I_{nc}, I_{nn}) are shown in the figure 10. The corresponding active-reactive powers of load (Pload, Qload), grid (Pgrid Qgrid), and inverter (Pinv, Qinv) are shown in Figure 11. Positive values of grid active-reactive powers and Inverter active-reactive powers imply that these Powers flow from grid side towards PCC and from inverter towards PCC, respectively.



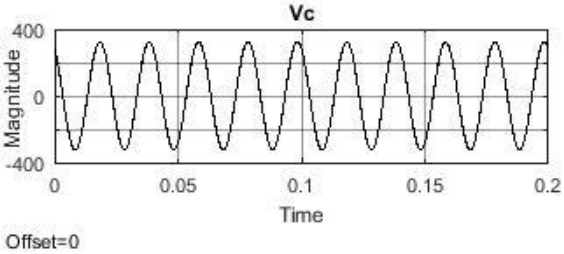


Fig. 10(a). Supply voltage before and after compensation

The active and reactive powers absorbed by the load are denoted by positive signs. Initially, the grid interfacing inverter is not connected to the network (i.e., the load power demand is totally supplied by the grid alone).Therefore, before time t=0.1 s, the grid current profile in Figure 10(b) is identical to the load current profile of Figure 10(c). At t=0.1s, the grid-interfacing inverter is connected to the network At this instant the inverter starts injecting the current in such a way that the profile of grid current starts changing from unbalanced nonlinear to balanced sinusoidal current as shown in Figure 10(b). Since the generated power is more than the load power demand the additional power is fed back to the grid.

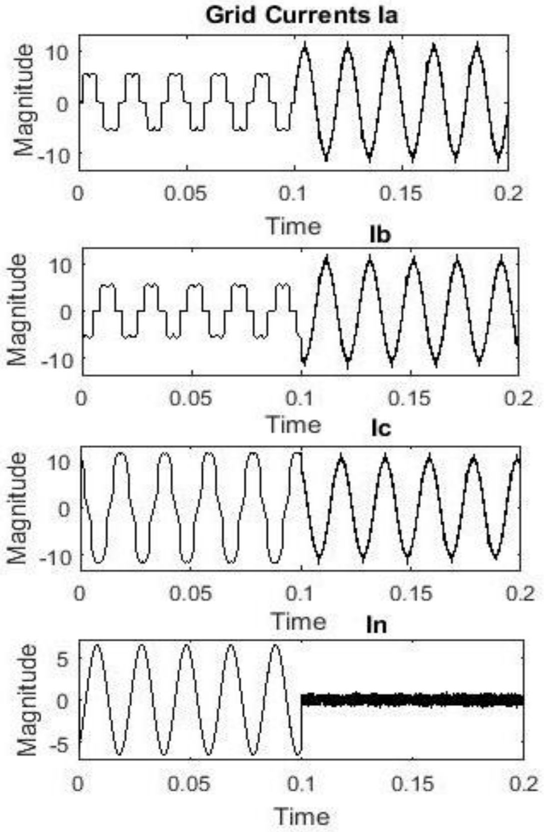


Fig. 10(b). Grid Currents before and after compensation

The negative sign of P grid , after a time 0.1 s suggests that the grid is now receiving power from RES. More- over, the grid interfacing inverter also supplies the load reactive power demand locally.

Thus, once the inverter is in operation the grid only Supplies/receives fundamental active power. This results in increased magnitude of inverter current. As the load power demand is considered as constant, this additional power generated from RES flows towards grid, which can be noticed from the increased magnitude of grid current. The fourth leg of the inverter provide the neutral compensating current. In case, if there is any current in the neutral wire it would force it to zero. Figure 10(d) shows the inverter currents in which the fourth leg current is shown. From the figure 11 It is observed that after 0.1 sec there is a change in Active power flow in filter side and supply side. Before 0.1 Sec the source is achieved from the proposed controller. Supplies total active power demanded by load. After 1 sec, the shunt active filter supplies some power required by load and rest of the active power is supplied from the source. Thus active power control is achieved from the proposed controller.

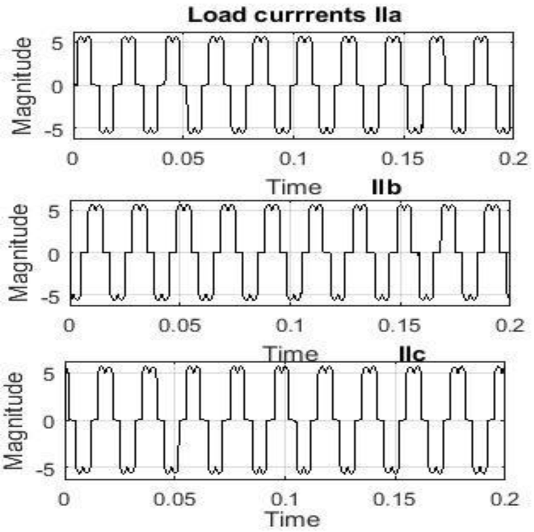


Fig. 10(c). Load Currents before and after compensation

The power factor correction, harmonic compensation and reactive power compensation is also obtained using this algorithm. Fig.4 shows the source voltage and source current after compensation thus supply current (grid) has become sinusoidal and is in phase with the supply voltage. Thus the power factor correction can also be achieved using this algorithm. Hence the power quality can be improved in the supply line even under when a distributed renewable source is connected to the line at PCC.

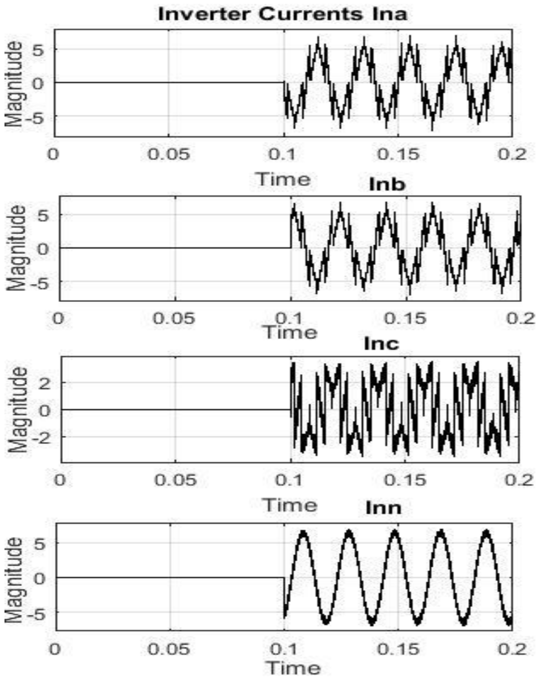


Fig. 10(d). Inverter Currents before and after Compensation

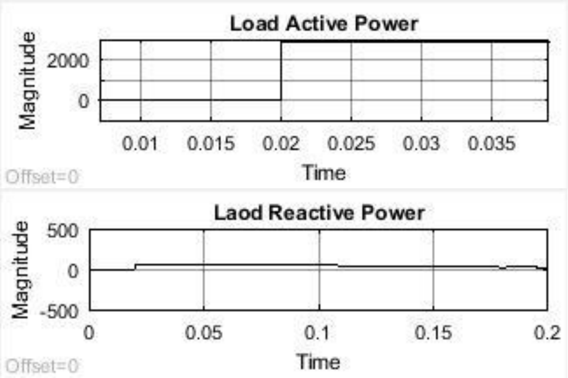


Fig. 11(a). Load Active and Reactive power before and after compensation

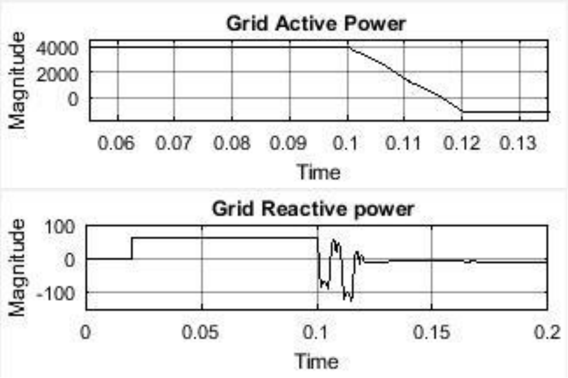


Fig. 11(b). Grid Active and Reactive power before and after compensation

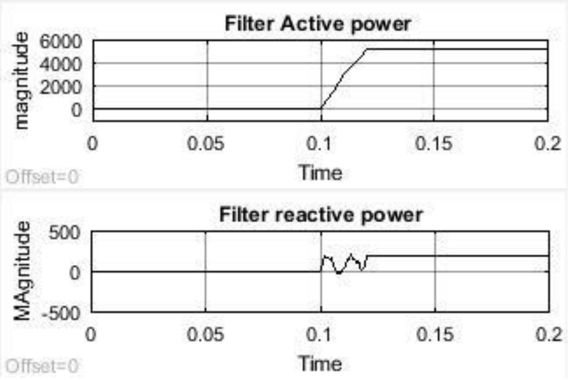


Fig. 11(c). Filter Active and Reactive power before and after compensation

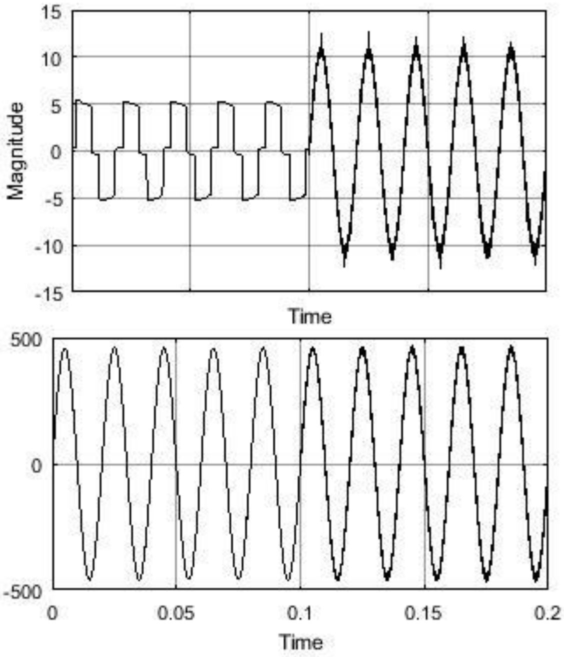


Fig. 12. Grid voltage and current before and after compensation for phase 'A' alone

	System parameter	Values
I	Source Voltage(Vs)	230 V RMS
II	System Frequency (f)	50hz
III	Source Impedance (Rs,Ls)	0.1Ω;0.15mH
IV	Load impedance(RL,LL)	100Ω;10mH
V	Filter Impedance (Rf,Lf)	0.4Ω;3.35mH
VI	DC link capacitance	4624μF
VII	Reference DC link voltage(Vdc,ref)	680 V

Table II. System parameters for simulation study.

IV. CONCLUSION

This paper has presented a new control strategy based on Fuzzy PID controller for controlling shunt active filter used for grid interfacing of distributed power generation scheme. The shunt active filter offer current harmonic elimination and reactive power compensation. In addition to its function as a filter it works as an interface between distributed power generation scheme and grid by injecting the real power produced by renewable energy source to grid as well as load. The performances of the proposed control algorithm have been validated using MATLAB/SIMULINK. The simulation results shown that after compensation the supply current is becoming sinusoidal and active power required by the load is shared by both grid and distributed power generation scheme.

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