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Fuzzy Controlled Grid Interfaced 4-Leg Inverter for Power Quality Improvement

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Abstract : This paper presents the interfacing of 3-phase, 4-leg inverter to the micro grid and feeding power to the load at the point of common coupling. This inverter receives power from renewable energy sources. The use of a four-leg voltage-source inverter allows the compensation of current harmonic components, as well as unbalanced current generated by single-phase nonlinear loads. The purpose of inverter is to inject power onto grid and acts as a shunt active filter. The closed loop fuzzy logic control strategy is used for achieving maximum benefits from these grid-interfacing inverters. This control concept is demonstrated with extensive MATLAB/Simulink. Finally the proposed scheme is applied for both balanced and unbalanced linear nonlinear loads.

Keywords : Micro Grid, Inverter, Fuzzy logic controller, Shunt active power filter.

1. INTRODUCTION

By the development of fuzzy controlled systems the technology has been emerged to the state equal to the human thinking. This fuzzy controlled logic became major application in house hold/ residential and industrial usages. This has been adopted into electrical system for better maintenance and to overcome many problems. RES Systems also became into existence with development of technology to overcome greenhouse effect and many other problems [1]. But some problems are a raised in the electrical systems due inherent nature of the RES systems like wind turbines and PV Cells. By integrating the RES system to the present power system the usage of fossil fuels can be reduced. During integration some technical challenges like Voltage Stabilization, Power Quality problems should be considered. Power quality is the major issue where the customer is observed/ considered, which is greatly affected during the operation of transmission and distribution network.

Active Power Filters are implemented with 3-phase, 4-leg Voltage Source Inverter [2]-[6]. In previous days these are controlled in closed loop by pre tuned controllers like PI or PID controllers [7], [8]. Based on equivalent linear model PI controllers are designed while predictive controllers are designed by using non-linear model which is close to the real and accurate model, which improves the performance of the APF connected to it specially during the transient operations which follows the current signal while maintaining constant dc voltage. Induction motor drives were ran [9]-[10] so far using this control. The main advantage of the proposed model is that, as it fit perfectly in APF applications, since power converter output parameters are well known [10]. Converter output ripple filter generates the output parameters and power system equivalent impedance as shown in Fig.1. The converter output ripple filter is part of

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the active power filter design and the power system impedance is obtained from well- known standard procedures [8], [9]. In the case of unknown system impedance parameters, an estimation method can be used to derive an accurate R–L equivalent impedance model of the system [10].

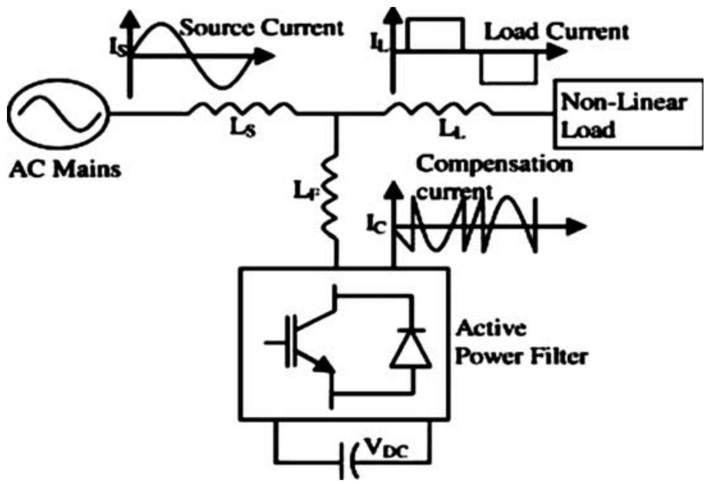

Fig. 1. Basic structure of proposed inverter.

In this paper the authors adopted the features of APF in the inverter interfacing RES with Grid. Here, the main aim is to utilize maximum rating of the inverter which has not been utilized previously due to intermittent nature of the RES. By use of fuzzy logic control the grid interfaced inverter can be effectively utilized to perform the following operations 1) transfer of active power from RES to grid; 2) current harmonic compensation at PCC; 3) demand support of load reactive power; 4) current unbalance neutral current compensation in case of this inverter system. All these objectives can be operated either individually or simultaneously.

2. SYSTEM DESCRIPTION

Dc-link of a grid interfacing inverter is connected to the RES is shown in Fig.2. In this the voltage source inverter is the major element in DG system as interface with the RES to grid and delivers the generated power. The RES may be a DC source or an A source with rectifier coupled to dc- link. The power generated by these RES systems need to be conditioned before it is connected to the dc-link [6]-[8]. The dc- capacitor decouples the RES from grid and also allows independent control of converters on either side of dc- link.

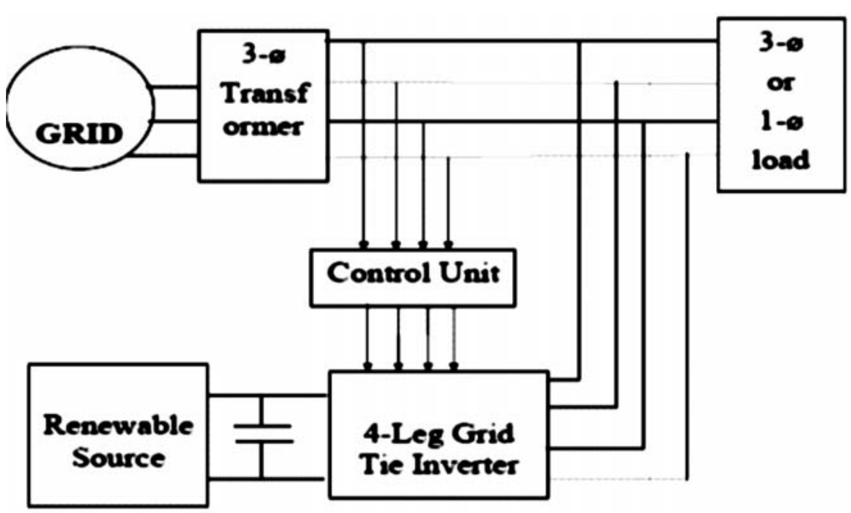

Fig. 2. Schematic of proposed renewable based distributed generation system.

A. DC-Link Voltage and Power Control Operation

The generated power is of variable nature due the intermittent nature of the RES system. The dc-link plays a major role in connecting RES system to Grid. RES are represented as current sources connected to the dc-link of a grid- interfacing inverter. Fig.3 shows the systematic representation of power transfer from the renewable energy resources to the grid via the dc-link. The current injected by renewable into dc-link at voltage level Vdc can be given as follows

$$I_{dc1} = \frac{P_{RES}}{V_{dc}} \tag{1}$$

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

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

$$I_{dc2} = \frac{P_{inv}}{V_{dc}} = \frac{P_G + P_{LOSS}}{V_{dc}}$$

Where P_{inv}, 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 $P_{RES} = P_G$.

B. Grid Interfacing Inverter Control

Fig. 4 shows the control diagram of grid interfacing inverter with 3-phase, 4-wire system. The fourth leg of the inverter is to compensate the neutral current of load. The main aim of proposed model is to regulate the power at PCC during;

(1) $P_{RES} = 0$; (2) $P_{RES} < P_L$; and (3) $P_{RES} >$ PL. During the power management process the inverter is actively controlled it draws or supplies active power to or from grid.

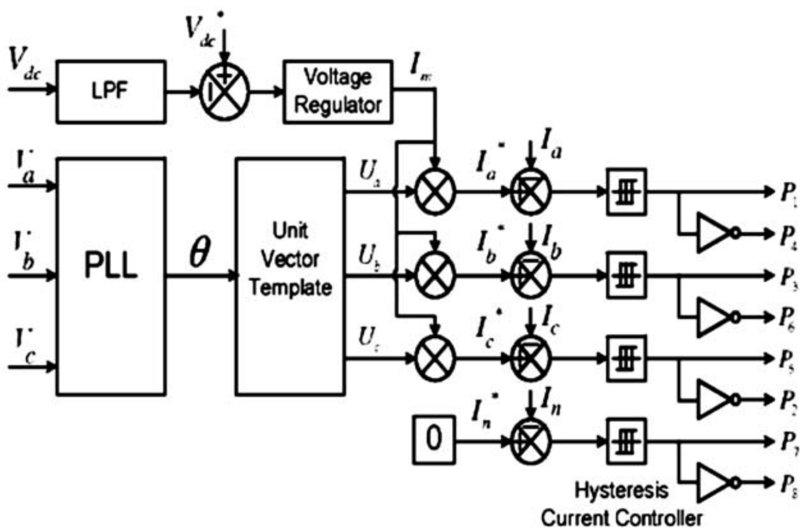

Fig. 3. Block diagram representation of grid- interfacing inverter control.

This also compensates neutral current, harmonics and unbalance if the load is connected is non-linear or unbalanced at the PCC. 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. By regulating the dc-link voltage carries the information regarding the exchange of active power between RES and grid. Thus the output of dc-link voltage regulator results in an active current (I_m). By multiplying active current component (I_m) with unity grid voltage vector templates (Ua, Ub, and Uc) generates the reference grid currents. 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 [9]–[11].

$$Ua = \sin(\theta) \tag{3}$$

$$Ub = \sin\left(\theta - \frac{2\pi}{3}\right) \tag{4}$$

$$Uc = \sin\left(\theta + \frac{2\pi}{3}\right) \tag{5}$$

To remove switching ripples present on the dc-link voltage and ingenerated reference current signal is passed through the first order low-pass filter. The difference of this filtered dc-link voltage and reference dc-link voltage (V*dc) is given to a discrete- PI regulator to maintain a constant dc-link voltage under varying generation and load conditions. The dc-link voltage error Vdceer(n) at nth sampling instant is given as:

$$V_{dcerr(n)} = V^{*}_{dc(n)} - V_{dc(n)} \tag{6}$$

The output of discrete-PI regulator at th sampling instant is expressed as

$$I_{m(n)} = I_{m(n-1)} + K_{PVdc}\,(V_{dcerr(n)} - V_{dcerr(n-1)}) + K_{IVdc}\,V_{dcerr(n)} \tag{7}$$

Where $K_{PVdc} = 10$ and $K_{IVdc} = 0.05$ are proportional and integral gains of dc-voltage regulator. The instantaneous values of reference three phase grid currents are computed as

$$I^{*}_{a} = I_{m}.U_{a} \tag{8}$$

$$I^{*}_{b} = I_{m}.U_{b} \tag{9}$$

$$I^{*}_{c} = I_{m}.U_{c} \tag{10}$$

The fourth leg of the grid interfacing inverter compensates the neutral current present in conductor due to the loads. The inverter reference current for the grid neutral current is considered as zero and can be expressed as

$$I^{*}_{n} = 0 \tag{11}$$

The reference grid currents (Ia, Ib, Ic and In) are compared with actual grid currents (Ia,Ib, Ic and In) tocompute the current errors as

$$I_{aerr} = I^{*}_{a} - I_{a} \tag{12}$$

$$I_{berr} = I^{*}_{b} - I_{b} \tag{13}$$

$$I_{cerr} = I^{*}_{c} - I_{c} \tag{14}$$

$$I_{nerr} = I^{*}_{n} - I_{n} \tag{15}$$

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses (P1 to P8) for the gate drives of grid- interfacing inverter. The average model of 4-leg inverter can be obtained by the following state space equations

$$\frac{dI_{inva}}{dt} = \frac{(V_{Inva} - V_{a})}{L_{sh}} \tag{16}$$

$$\frac{dI_{Inva}}{dt} = \frac{(V_{Invb} - V_{b})}{L_{sh}} \tag{17}$$

$$\frac{dI_{Invc}}{dt} = \frac{(V_{Invc} - V_{c})}{L_{sh}} \tag{18}$$

$$\frac{dI_{Invn}}{dt} = \frac{(V_{Invn} - V_n)}{L_{sh}} \tag{19}$$

$$\frac{dV_{dc}}{dt} = \frac{(I_{invad} + I_{invbd} + I_{Invcd} + I_{invnd})}{C_{dc}} \tag{20}$$

Where V_{Inva}, V_{Invb}, V_{Invc} and V_{Invn} are the three-phase ac switching voltages generated on the output terminal of inverter.

These inverter output voltages can be modeled in terms of instantaneous *dc* bus voltage and switching pulses of the inverter as

$$V_{Inva} = \frac{(P_1 - P_2)}{2} V_{dc} \tag{21}$$

$$V_{Inva} = \frac{(P_3 - P_6)}{2} V_{dc} \tag{22}$$

$$V_{Inva} = \frac{(P_5 - P_2)}{2} V_{dc} \tag{23}$$

$$V_{Inva} = \frac{(P_7 - P_8)}{2} V_{dc} \tag{24}$$

Similarly the charging currents V_{Invad}, V_{Invbd}, V_{Invcd} and V_{Invnd} on *dc* bus due to the each leg of inverter can be expressed as

$$I_{Invad} = I_{Inva} (P_1 - P_4) \tag{25}$$
$$I_{Invbd} = I_{Invb} (P_3 - P_6) \tag{26}$$
$$I_{Invcd} = I_{Invc} (P_5 - P_2) \tag{27}$$
$$I_{Invad} = I_{Inva} (P_7 - P_8) \tag{28}$$

The switching pattern of each IGBT inside inverter can be formulated on the basis of error between actual and reference current of inverter, which can be explained as: If I_{Inva} < (I*Inva-hb), then upper switch S1will be OFF (P1 = 0) and lower switch S4 will be ON (P4 = 1) in the phase "*a*" leg of inverter. If I_{Inva} > (I*Inva-hb), then upper switchS1 will be ON (P1 =1) and lower switch S4 will be OFF (P4 = 0) in the phase "*a*" leg of inverter Where hb is the width of hysteresis band. On the same principle, the switching pulses for the other remaining three legs can be derived.

3. FUZZY CONTROLLER

Fig. 4 shows the internal structure of the control circuit. Fuzzy control model consists of limiter, 3-phase sine wave generator for reference current signal and hysteresis control for generation of gate signals. By regulating the dc-link voltage the estimated current signal is generated. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal. Fuzzy controller converts the linguistic signals into automatic control signals, which are constructed by expert experience or knowledge database. Firstly, input voltage V_{dc} and the input reference voltage $V_{dc\text{-}ref}$ have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current Imax. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in Fig.5. The fuzzy controller is characterized as follows:

1. Seven fuzzy sets for each input and output;
2. Fuzzification using continuous universe of discourse;
3. Implication using Mamdani's "min" operator;
4. De-fuzzification using the "centroid" method.

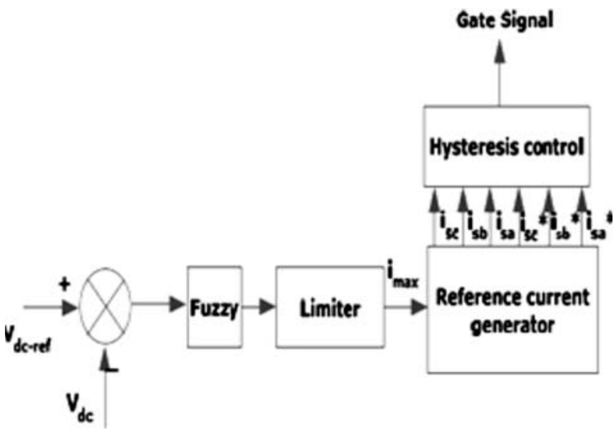

Fig. 4. Conventional fuzzy controller.

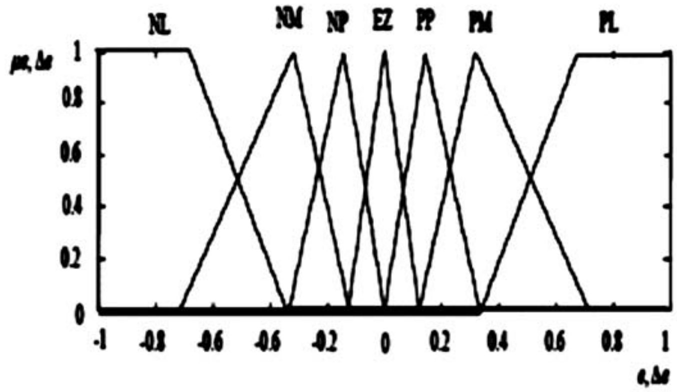

Fig. 5. Membership functions.

Fuzzification : The process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification.

De-fuzzification : The rules of FLC generate required output in a linguistic variable (Fuzzy Number), according to real world requirements, linguistic variables have to be transformed to crisp output (Real number).

Database : The Database stores the definition of the membership Function required by fuzzifier and defuzzifier.

Rule Base : The elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in- put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with „Vdc" and „Vdc-ref" as inputs.

Table 1. Rule Base Table.

Δe \ e	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

4. MATLAB MODELEING AND SIMULATION RESULTS

By using MATLAB/Simulink simulation is done in two cases Implementation of proposed converter using 1. PI controller and 2. By using fuzzy logic controller.

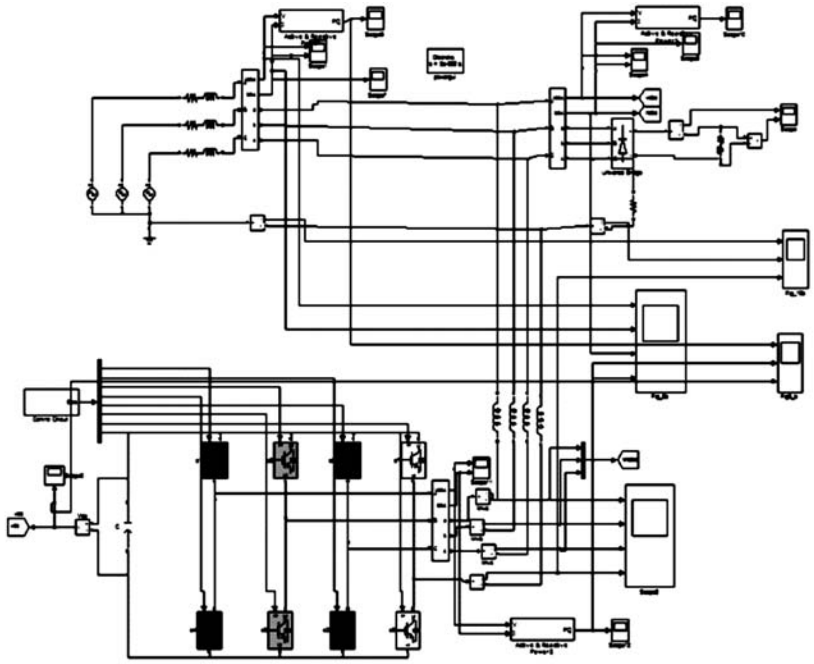

Fig. 6. Matlab/Simulink Model of proposed Circuit.

Fig. 6 shows the complete MATLAB model of proposed power circuit along with control circuit. The power circuit as well as control system are modeled using Power System Block set and Simulink.

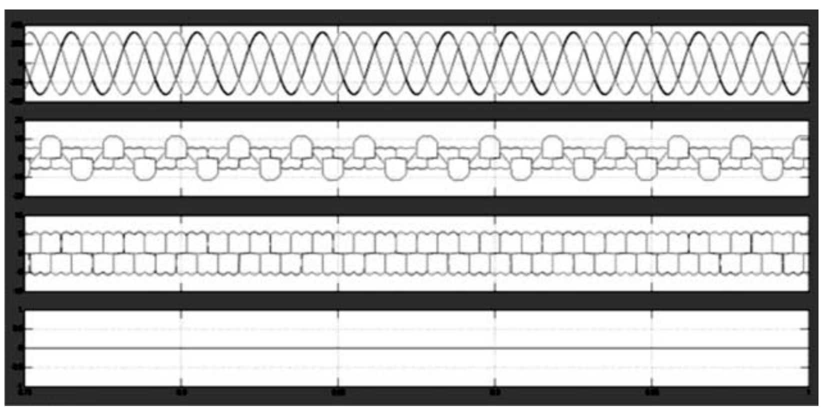

Fig. 7. Source Voltage, Source Current, Load Current, Compensation Current.

Fig.7 shows the Source Voltage, Source Current, Load Current, and Compensation Current of proposed power distribution model operating under without APF, without compensation source currents equals to load currents, for effective concerns need power compensation scheme.

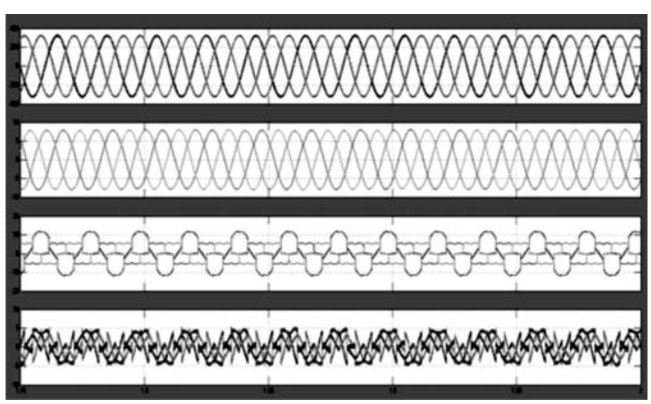

Fig. 8. Source Voltage, Source Current, Load Current, Compensation Current under PI Controller.

Fig.8 shows the Source Voltage, Source Current, Load Current, and Compensation Current of proposed power distribution model operating under APF, with compensation source currents goes to pure sinusoidal nature and improves power quality features at PCC level.

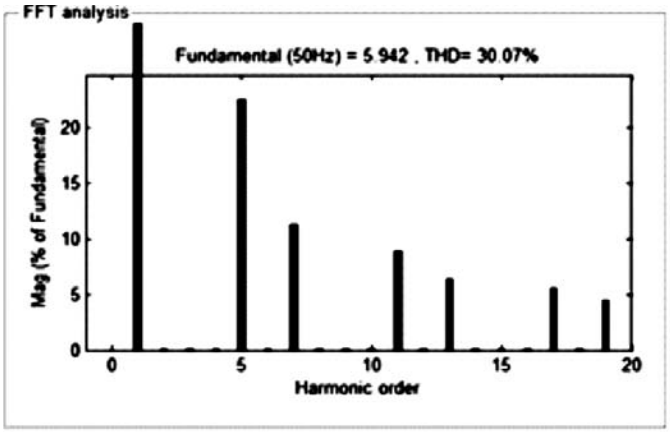

Fig. 9. Without APF Model

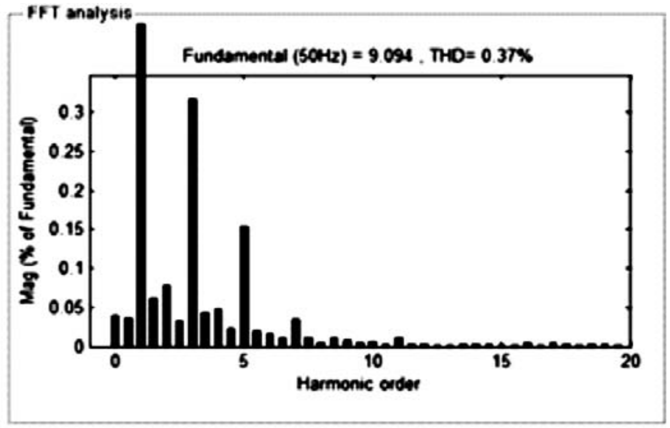

Fig. 10. THD for inverter using PI controller.

Fig. 10, 11 and 12 shows the THD analysis of the source current using with & without APF under PI controller, we get 30.07% and 0.37%.

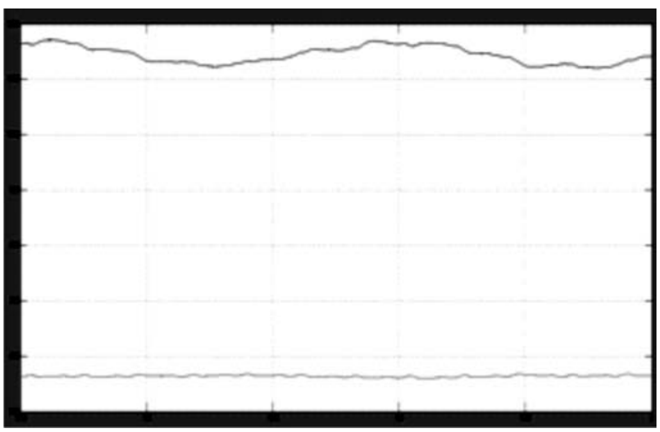

Fig. 11. Source Active & Reactive power.

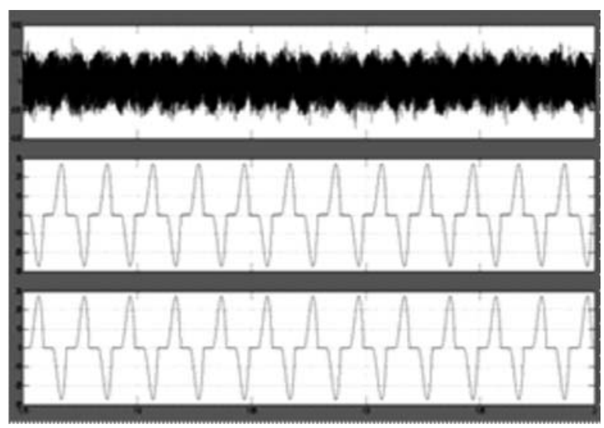

Fig. 12. Source Neutral Current, Load Neutral Current and Compensator Neutral Current.

Case2 : Implementation of proposed converter using fuzzy logic controller

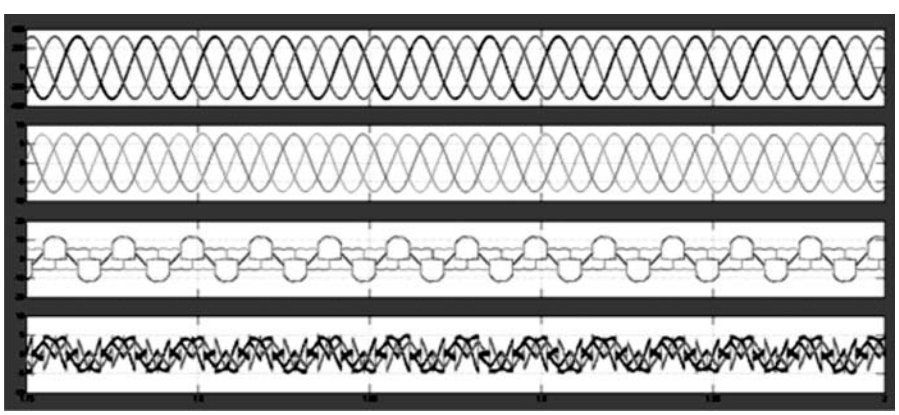

Fig. 13. Source Voltage, Source Current, Load Current, Compensation Current under Fuzzy Controller.

Fig.13 shows the Source Voltage, Source Current, Load Current, and Compensation Current of proposed power distribution model operating under APF using Fuzzy Controller, with compensation source currents goes to pure sinusoidal nature and improves power quality features at PCC level.

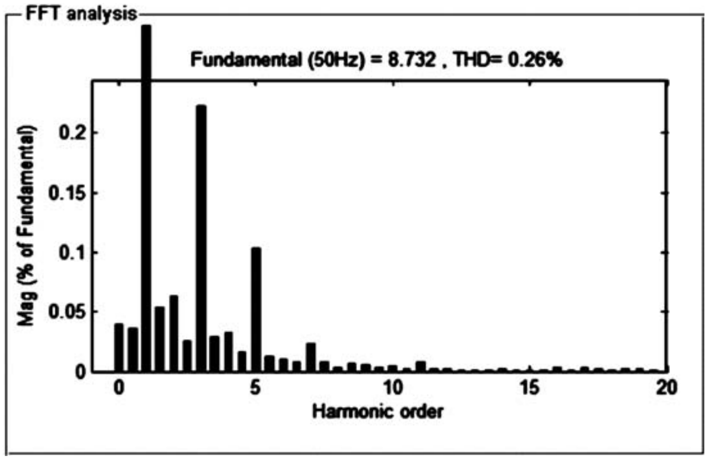

Fig. 14. THD for inverter using Fuzzy controller.

Fig.14. shows the THD analysis of the source current using without APF under Fuzzy controller, we get 0.26%.

5. CONCLUSION

Shunt active power filter are implemented for harmonic and reactive power compensation of non-linear load by using both PI and fuzzy logic controllers. A circuit has been developed and simulated in MATLAB using the fuzzy based and PI controller based shunt APF. This paper has presented a novel control of an existing grid interfacing inverter using conventional PI controller & fuzzy logic controller to improve the quality of power at PCC for a 3-phase 4-wire DG system. Normal operation of real power transformer is obtained effective utilization of grid-interfacing inverter. By using normal controller the THD value obtained is 0.37% but using fuzzy controller THD value is 0.26% which are satisfactory for improving power quality at consumer premises. Finally Matlab/Simulink based model is developed and simulation results are presented.

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