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Fuzzy Controller Based Grid Connected Res At Distribution Level with Power Quality Improvement

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Abstract- *The design of a fuzzy logic controller using the voltage as feedback for significantly improving the dynamic performance of converter. Renewable energy resources (RES) are being increasingly connected in distribution systems utilizing power electronic converters. This paper presents a new control strategy for achieving maximum benefits from these grid-interfacing inverters using the closed loop P-I controller and fuzzy logic controller, when installed in 3-phase 4-wire distribution systems. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. The inverter can thus be utilized as: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. All of these functions may be accomplished either individually or simultaneously. The THD and power factor variations for both PI-controller and fuzzy logic controller are also shown. This new control concept is demonstrated with extensive MATLAB/Simulink .Finally the proposed shceme is applied for both balanced, unbalanced linear and non linear loads.*

Index Terms— *power quality (PQ), Fuzzy Logic Controller (FLC), Renewable energy sources (RES), point of common coupling (PCC), Distributed generation (DG), proportional controller (P-I).*

1. INTRODUCTION

Power quality is one of the most important topics that electrical engineers have been noticed in recent years. Voltage sag is one of the problems related to power quality. This phenomenon happens continuously in transmission and Distribution systems. During a voltage sag event, amplitude of the effective load voltage decrease from 0.9 of the nominal load voltage to 0.1 in very short time (less than one minute). Short circuit, transformer energizing, capacitor bank charging etc are causes of voltage sag. Voltage sag has been classified in 7 groups of A-G [1]. According to this classification most of voltage sags are companion with a phase angle jump (types C, D, F and G). Phase angle jump for power electronics systems such as ac-ac and ac-dc converters, motor drives etc is harmful [2]. Therefore, phase angle jump compensation is one of the voltage sag mitigation goals.

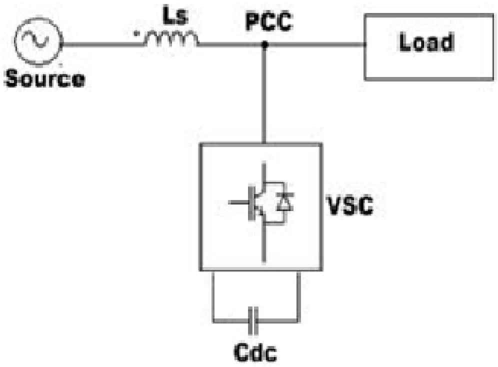


Fig.1. shows the basic structure of proposed inverter

Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to enhance the system operation with improved PQ at PCC. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may deteriorate the quality of power [1], [2].

Generally, current controlled voltage source inverters are used to interface the intermittent RES in distributed system. Recently, a few control strategies for grid connected inverters incorporating PQ solution have been proposed. In [3] an inverter operates as active inductor at a certain frequency to absorb the harmonic current. But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in [4].

In [5], a control strategy for renewable interfacing inverter based on P–Q theory is proposed. In this strategy both load and inverter current sensing is required to compensate the load current harmonics. The non-linear load current harmonics may result in voltage harmonics and can create a serious PQ problem in the power system network. Active power filters (APF) are extensively used to compensate the load current harmonics and load unbalance at distribution level. This results in an additional hardware cost.

Conventionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic appliances however recently there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances [3]. With respect to their successful methodology implementation, this kind of methodology implemented in this paper is using fuzzy logic controller with feed back by introduction of voltage respectively. The introduction of change in voltage in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal. The fuzzy logic controller serves as intelligent controller for this propose.

It is shown in this paper that the grid-interfacing inverter with fuzzy logic control technique can effectively be utilized to perform following important functions: 1) transfer of active power harvested from the renewable resources (wind, solar, etc.),2) load reactive power demand support; 3) current harmonics compensation at PCC; and 4) current unbalance and neutral current compensation in case of 3-phase 4-wire system. Moreover, with adequate control of grid-interfacing inverter, all the four objectives can be accomplished either individually or simultaneously.

2. SYSTEM DESCRIPTION

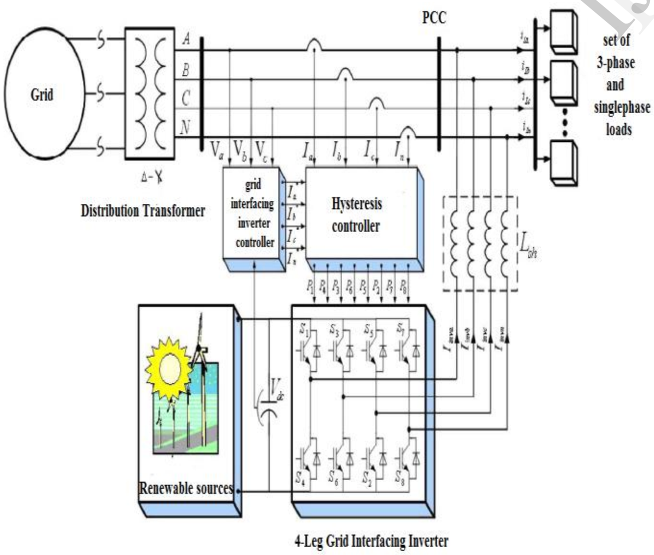


Fig.2. Schematic of proposed renewable based distributed generation system.

The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter as shown in Fig.2. The voltage source inverter is a key element of a DG system as it interfaces the renewable energy source to the grid and delivers the generated power. The RES may be a DC source or an A source with rectifier coupled to dc-link. 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 [6]–[8].

A. DC-Link Voltage and Power Control Operation

Due to the intermittent nature of RES, the generated power is of variable nature. The dc-link plays an important role in transferring this variable power from renewable energy source to the 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[5]. The current injected by renewable into dc-link at voltage level Vdc can be given as

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

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

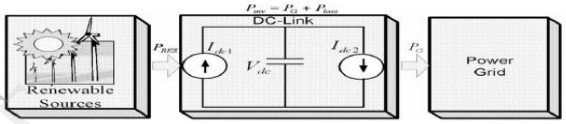


Fig.3. DC-Link equivalent diagram.

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

$$I_{dc2} = \frac{P_{inv}}{V_{dc}} = \frac{P_G + P_{LOSS}}{V_{dc}} \tag{2}$$

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. Control of Grid Interfacing Inverter with P-I controller

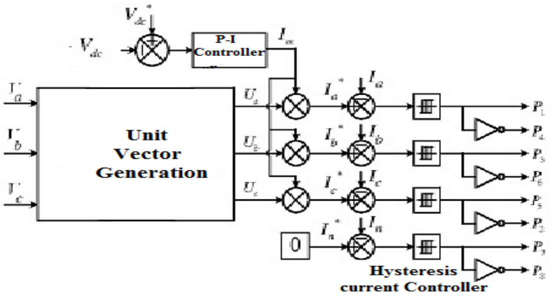


Fig.4. Block diagram representation of grid-interfacing inverter control.

The control diagram of grid- interfacing inverter for a 3-phase 4-wire system is shown in Fig.4. The fourth leg of inverter is used to compensate the neutral current of load. The main aim of proposed approach is to regulate the power at PCC during:1) $P_{RES} = 0$; 2) $P_{RES} <$ Total load power (P_L) ;

and 3) $P_{RES} > P_L$. 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. 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 (U_a,U_b, and U_c) generates the reference grid currents$(I_a^*, I_b^*, \text{ and } I_c^*)$. The reference grid neutral current (I^*n) is set to zero, being the instantaneous sum of balanced grid currents. The grid synchronizing angle (θ) and the unit vector generation is done by new control strategy [5]-[9]-[11].

$$U_a = Sin(\theta) \tag{3}$$

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

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

The difference of 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 $V_{dceer}(n)$ 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

$$I_{m(n)} = I_{m(n-1)} + K_{PV_{dc}}(V_{dcerr(n)} - V_{dcerr(n-1)}) + K_{IV_{dc}}\ V_{dcerr(n)} \tag{7}$$

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 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

$$I_n^* = 0 \tag{11}$$

The reference grid currents (I^*_a, I^*_b,I^*_c and I^*n) are compared with actual grid currents (I_a,I_b,I_c and In) to compute 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 (P_1 *to* P_8*)* for the gate drives of grid-interfacing inverter.

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 $I_{Inva} < (I^*_{Inva} - h_b)$, then upper switch S_1will be OFF (P_1 =0) and lower switch S_4 will be ON (P_4=1) in the phase "a" leg of inverter. If $I_{Inva} > (I^*_{Inva} - h_b)$, then upper switch S_1 will be ON (P_1 =1) and lower switch S_4 will be OFF (P_4=0) in the phase "a" leg of inverter Where h_b is the width of hysteresis band. On the same principle, the switching pulses for the other remaining three legs can be derived.

3. RENEWABLE ENERGY RESOURCES

Renewable energy resources are the ones that are persistently available and renewing itself with the time. Industrialization and increasing world population has remarked the use of renewable energy resources. Solar power, wind power, biomass, tide power, wave power, geothermal power is known ones.

A) Wind Power

Wind turbines are used to convert the wind power into electric power. Electric generator inside the turbine converts the mechanical power into the electric power. Wind turbine systems are available ranging from 50W to 2-3 MW.

The energy production by wind turbines depends on the wind velocity acting on the turbine. Wind turbines can be classified with respect to the physical features (dimensions, axes, number of blade), generated power and so on.

On the other hand, power production capacity based classification has four subclasses.

- Small Power Systems
- Moderate Power Systems
- Big Power Systems
- Megawatt Turbines

4. CONTROL STRATEGY

The unit vector generation is important for getting exact shape and magnitude of source current. in this section source side sensing and source side control was taken.

$$V_{La} = V_{\max} \sin \omega t \qquad (16)$$

$$V_{Lb} = V_{\max} \sin(\omega t - 120^{o}) \qquad (17)$$

$$V_{Lc} = V_{\max} \sin(\omega t - 240^{o}) \qquad (18)$$

$$V_{\max} = \sqrt{\frac{2}{3}(V_{La}^{2} + V_{Lb}^{2} + V_{Lc}^{2})} \qquad (19)$$

The unit vectors are

$$U_{a} = \frac{V_{La}}{V_{\max}} \qquad (20)$$

$$U_{b} = \frac{V_{Lb}}{V_{\max}} \qquad (21)$$

$$U_{c} = \frac{V_{Lc}}{V_{\max}} \qquad (22)$$

5. FUZZY CONTROLLER

The internal structure of the control circuit is shown in fig.5.The control scheme consists of Fuzzy controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals [12]. The peak value of reference currents is estimated by regulating the DC link voltage. 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.

A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules 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 $I_{\max}$. 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.6.and A FLC Control method for proposed converter shown in Fig.7.

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.

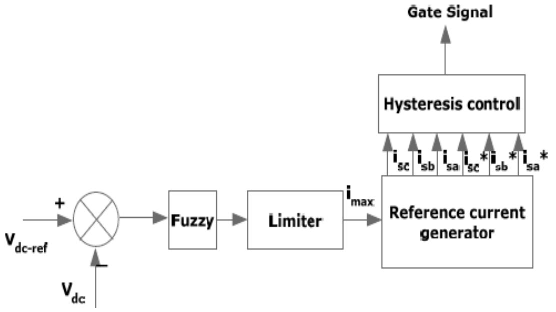


Fig.5.Conventional fuzzy controller

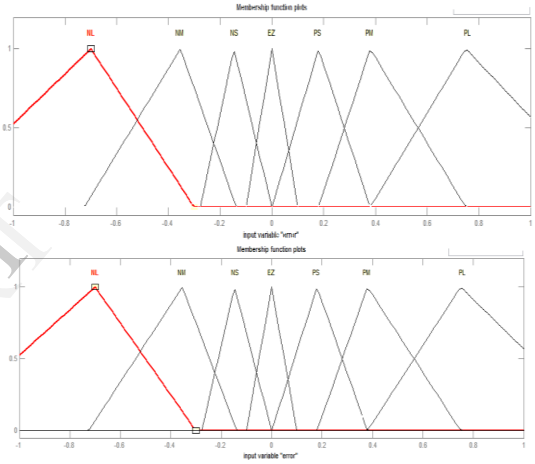


Fig.6. Membership functions for Input and output

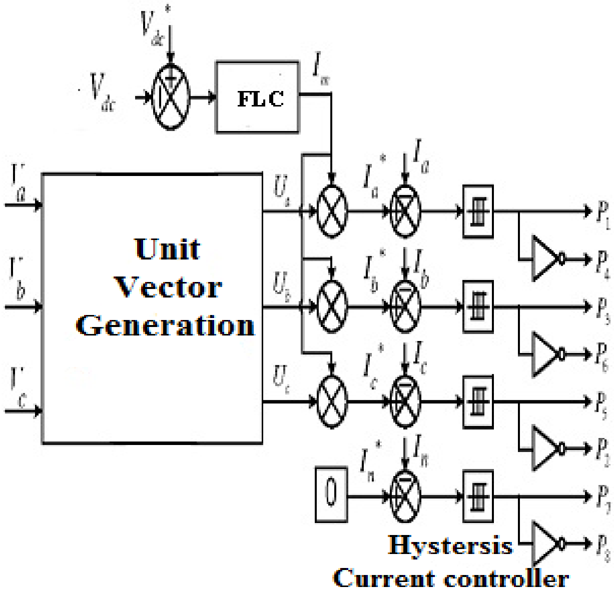


Fig.7. A FLC Control method for proposed converter

Fuzzification: the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification [13].

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)[14]. 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 below Table with 'V_{dc}' and 'V_{dc-ref}' as inputs.

e Δe	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

6. MATLAB MODEL AND SIMULATION RESULTS

Here the simulation is carried out in two cases 1.Implementation of proposed converter using conventional PI controller. 2. Implementation of proposed converter using fuzzy logic controller.

Case-1: Implementation of proposed converter using conventional PI controller with wind model.

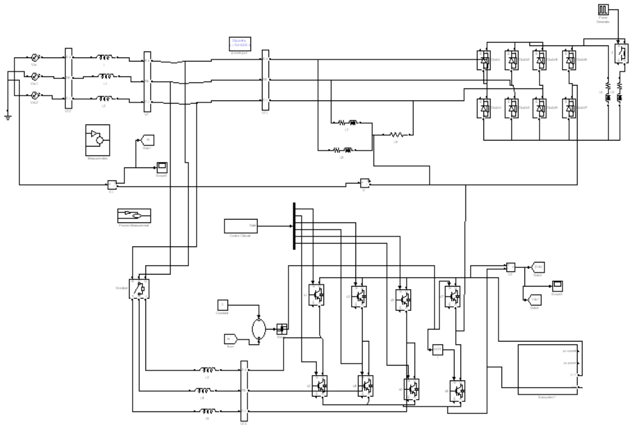


Fig.8. Matlab/Simulink Model of Proposed Power Circuit

The complete MATLAB model of proposed power circuit along with control circuit is shown in Fig.8. The power circuit as well as control system are modeled using Power System Block set and Simulink. Performance of proposed converter connected to a weak supply system is shown in Fig.9.

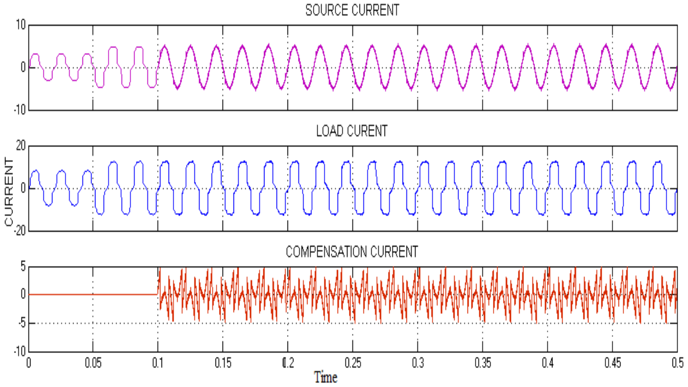


Fig.9.Simulation results for Source current, Load current Inverter injected current (compensation current) with Unbalanced Non Linear Load using PI controller.

Fig.9.shows the source current, load current and compensator current respectively. Here compensator is turned on at 0.1 seconds.

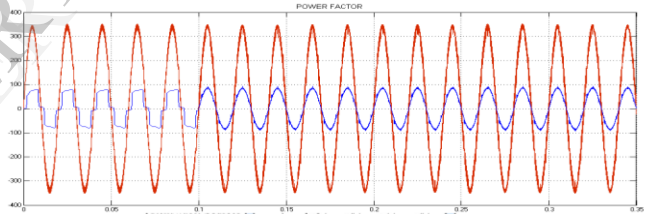
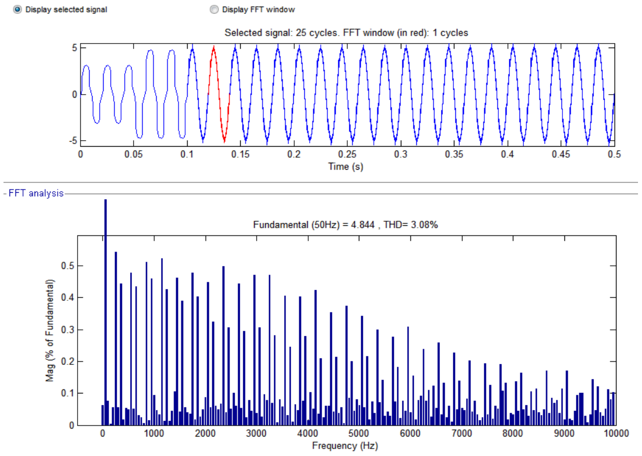


Fig.10. Simulation results of power factor(V&I) for un-balanced Non linear Load.

It is clear that after compensation power factor is unity and it is shown in Fig.10.


● Display selected signal
○ Display FFT window

Selected signal: 25 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 4.844 , THD= 3.08%

Fig.11. THD using PI controller

The THD analysis of the source current using the PI controller is shown in Fig.11, and it is 3.08%.

Case-2: Implementation of proposed converter using fuzzy logic controller:

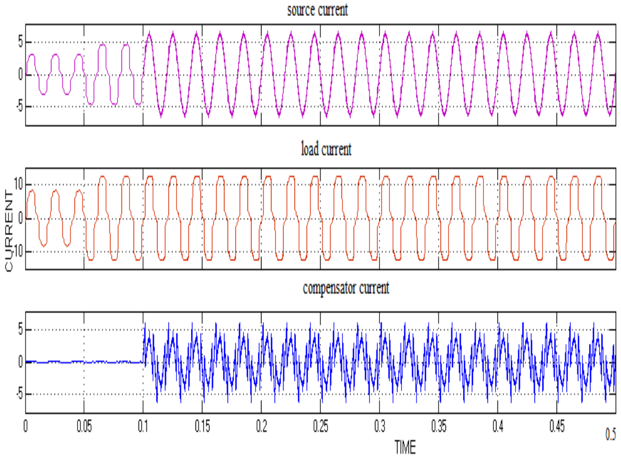


Fig.12. Simulation results for Un Balanced Non Linear Load using fuzzy controller (a) Source current. (b) Load current. (c) Inverter injected current.

The simulation results of proposed converter using fuzzy logic controller, Source current, load current, compensating current respectively is shown in Fig.12.

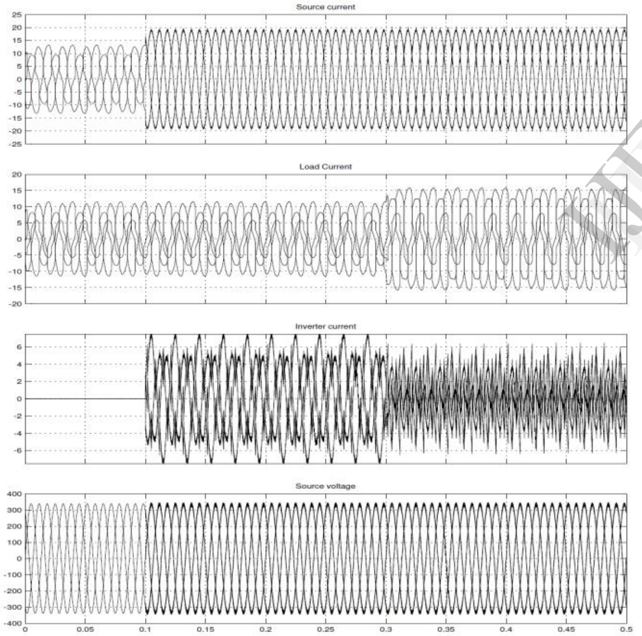


Fig.13.shows the simulation result of proposed converter using fuzzy logic controller with different loading.

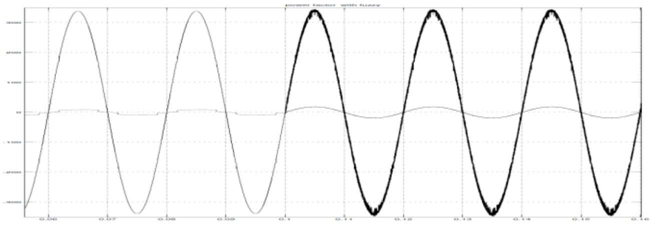


Fig.14.shows the power factor(V&I).

It is clear from the Fig.14 after compensation power factor is unity.

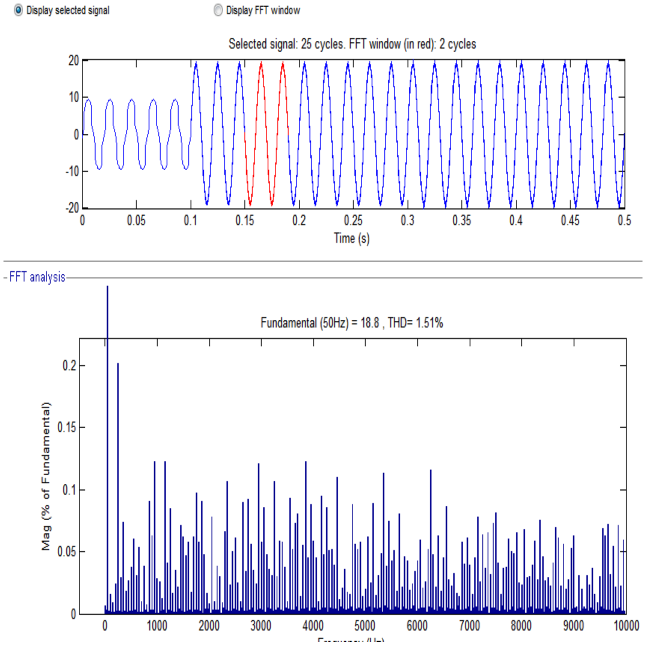


Fig.15. THD using fuzzy controller

The THD analysis of the source current using the fuzzy controller is shown in Fig.15, and it is 1.51%.

7. CONCLUSION

As conventional fossil-fuel energy sources diminish and the world's environmental concern about acid deposition and global warming increases, renewable energy sources (solar, wind, tidal, and geothermal, etc.) are attracting more attention as alternative energy sources. Both PI controllers based and fuzzy logic controller VSI based shunt active power filter are implemented for harmonic and reactive power compensation of the non-linear load. A circuit has been developed to simulate the fuzzy logic based and PI controller based shunt active power filter in MATLAB. 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. Proposed compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The latter feature enables its application for compensation of dips coming from the supplying network. The simulation results show that the performance of converter system has been found to be satisfactory for improving the power quality at the consumer premises. The power factor is improved with fuzzy controller. By using conventional controller we get THD value is 3.08%, but using the fuzzy logic controller THD value is 1.51%. Finally Matlab/Simulink based model is developed and simulation results are presented

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