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Hybrid Wind Solar Sources at Distribution Level using New Control Method for Power Quality Improvement

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Abstract— ***Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Seventy five percent of total global energy demand is supplied by the burning of fossil fuels. But increasing air pollution, global warming concerns diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation.***

This paper has presented a novel control of an existing grid interfacing inverter to improve the power quality at point of common coupling for a 3-phase 4-wire distributed generation system. The inverter is controlled to perform multifunction device by incorporating active power filter functionality.

The grid interfacing inverter can be effectively used to compensate the load reactive power, current unbalance and harmonic distortions in addition to active power injection from renewable energy sources. This enables the grid to supply/receive sinusoidal and balanced power at unity power factor. All these functions may be accomplished either individually or simultaneously. This new method is demonstrated with extensive MATLAB/simulink.

Index Terms—— ***Distribution generation (DG), Power quality (PQ), Renewable energy source (RES), Point of common coupling (PCC), Hysteresis Band (HB).***

I. INTRODUCTION

The utility is concerned due to high penetration level of intermittent RES in distribution systems as it may impose a threat to network in terms of stability, voltage regulation and power quality issues. Therefore with advancement in power electronics and digital control technology, the DG system operation with operation with improved PQ at PCC.

In a control strategies[1] for grid connected inverters based on p-q theory is proposed, this strategy both load and inverter current sensing is required to compensate the load harmonics and this strategies for inverter incorporating PQ solutions have been proposed.

In an inverter operates as active inductor at a certain frequency to absorb the harmonic currents. Shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in. Active power filter are extensively used to compensate the load harmonics and load unbalance at distribution level.

The nonlinear-load current harmonics may results in voltage harmonics and can create a serious PQ problem in the power system network at PCC, which may deteriorate the quality of power.

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This paper has presented a novel control of an existing grid interfacing inverter [6] to improve the power quality at point of common coupling for a 3-phase 4-wire distributed generation system. The grid interfacing inverter can be effectively used to compensate the load reactive power, current unbalance and harmonic distortions in addition to active power injection from renewable energy sources. The inverter is controlled to perform multifunction device by incorporating active power filter functionality. This enables the grid to supply/receive sinusoidal and balanced power at unity power factor at PCC.

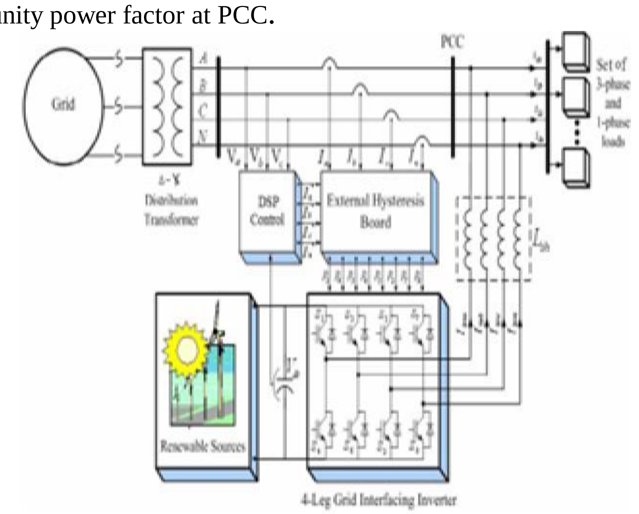

Fig: 1.schematic of proposed renewable based distributed generation system.

This paper is arranged as follows: section II describes the system under consideration and the controller for grid interfacing inverter. A digital simulation study is presented in section III. Section IV concludes the paper.

II. SYSTEM DESCRIPTION

The proposed system consists of RES connected to the dc-link of a grid interfacing inverter as shown in Fig1. The voltage source inverter is interfaced between RES to the grid and delivers the generated power. The RES may be DC or an AC source connected with rectifier coupled to dc-link.the dc capacitor decouples the RES from grid.

A. DC-Link voltage and Power control operation:

The DC-Link plays an important role which transfers the variable power from RES to grid.Fig:2 show the representation of power transfer from the renewable energy resources to the grid via the dc link. The power generated from RES needs power conditioning (ie.,dc/dc or ac/ac) before connecting on dc-link[3],[4] .

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The current injected by renewable into dc-link at voltage level V_{dc} shown as equation (1) and current injected into the power grid is given as equation (2).

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

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

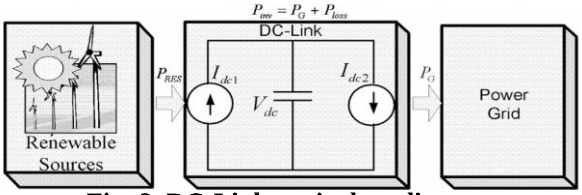

Fig: 2. DC-Link equivalent diagram

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

$$I_{dc2} = \frac{P_{inv}}{V_{dc}} = \frac{P_G + P_{Loss}}{V_{dc}} \qquad (2)$$

Where P_{inv},P_G,P_{Loss} are total power available at grid-interfacing-inverter side, active power supplied to the grid and inverter losses are negligible then P_{RES}=P_G.

B. Control of grid interfacing inverter

The control diagram of grid interfacing of grid interfacing inverter for a 3-phase 4-wire system shown in Fig: 3.

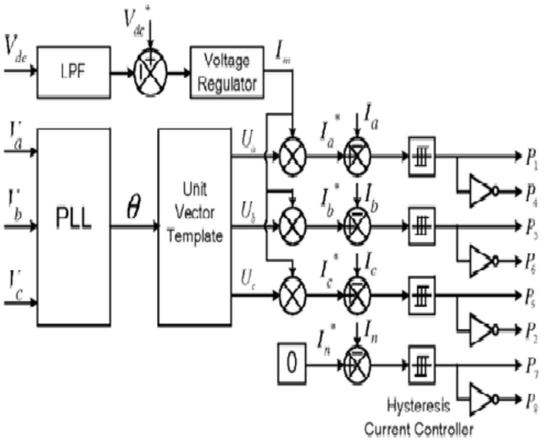

Fig: 3. Block diagram representation of grid interfacing inverter control.

The fourth leg of inverter is used to compensate the neutral current of load.

The main aim of control of proposed system is the grid to supply/receive sinusoidal and balanced power at unity power factor. 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 either the load connected to the PCC is nonlinear or unbalanced or the combination of both, the given control approach also compensates the harmonics, unbalance and neutral current.

The actual dc-link voltage (V_{dc}) is passed through first order low pass filter in order to eliminate the switching ripples. The difference between the actual and reference dc-link voltage is given to the voltage regulator in order to maintain constant dc-link voltage under varying generation and load. The dc-link voltage error V_{dcerr} is shown in equation (3).

$$V_{dcerr} = V_{dc}^* - V_{dc} \qquad (3)$$

Voltage regulator:

1. PI regulator:

The Fig 4: shows internal structure of voltage regulator.

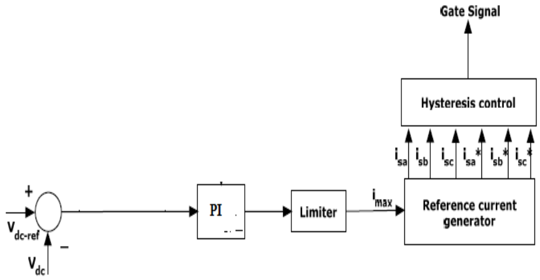

Fig: 4. PI controller circuit

The internal structure of control circuit consists of PI controller, limiter and 3-phase sine wave generator for reference current and switching generation.

The error signal is then processed through PI controller, which contributes to the zero steady state error in tracking the reference current signal.

The output of PI regulator will give active magnetizing current I_m expressed for nth sampling is shown in equation (4).

$$I_{m(n)} = I_{m(n-1)} + K_{PV_{dc}}\left(V_{dcerr(n)} - V_{dcerr(n-1)}\right) + K_{IV_{dc}} V_{dcerr(n)} \qquad (4)$$

Where $K_{PV_{dc}} = 10$ and $K_{IV_{dc}} = 0.05$ are proportional and integral gains of dc-voltage regulator.

The output signal from PI controller is multiplied with unit sine vectors in order to produce reference currents I_a^*,I_b^*,I_c^*,I_n^* shown in following equations (5)-(8).

$$I_a^* = U_a . I_m \qquad (5)$$

$$I_b^* = U_b . I_m \qquad (6)$$

$$I_c^* = I_c . U_c \qquad (7)$$

$$I_n^* = 0 \qquad (8)$$

Where U_a,U_b,U_c are produced as shown in Fig 3.the grid voltages are given to PLL where the voltages V_a,V_b,V_c get synchronized and produces an angle θ.and the angle is given to unit vector template[5] where it produces in terms of sine and expressed as equations (9)-(11).

$$U_a = \sin(\theta) \qquad (9)$$

$$U_b = \sin\left(\theta - \frac{2\pi}{3}\right) \qquad (10)$$

$$U_c = \sin\left(\theta + \frac{2\pi}{3}\right) \qquad (11)$$

And I_n is the Neutral current, present if any due to the loads is connected to the neutral conductor should be compensated by fourth leg of inverter and should not be drawn from the grid. so that reference current for grid neutral current is considered as zero.

The reference grid currents are compared with actual grid currents to compute the current errors as shown in equations (12)-(15).

$$I_{aerr} = I_a^* - I_a \qquad (12)$$

$$I_{berr} = I_b^* - I_b \qquad (13)$$

$$I_{cerr} = I_c^* - I_c \qquad (14)$$

$$I_n - I_n^* - I_n \qquad (15)$$

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This current error signal is given to the hysteresis current controller. This error is compared to hysteresis band which gives the error signal decides the operation of converter switches. In this current control circuit configuration, the grid currents are made follow the sinusoidal reference current, with in a fixed hysteretic band. If the current exceeds the upper limit of HB, the upper switch of the inverter arm is turned off and lower switch is turned on and vice versa if current exceeds the lower limit [2].

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_1 will 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 other remaining three legs can be derived.

2. Fuzzy logic controller:

Fig.5 shows the internal of the control circuit. Control scheme consists of fuzzy controller, a limiter and a 3-phase sine wave generator for the generation of reference currents and switching pulses.

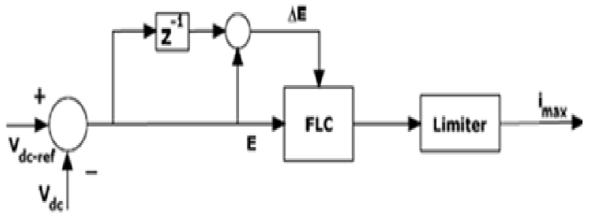


Fig. 5. Fuzzy controller circuit.

The actual capacitor voltage is compared with reference value. The error signal is then processed through a fuzzy controller [7], which contributes to the zero steady in tracking the reference current signal. Membership function values are assigned to the linguistic variables using seven fuzzy subset called negative big (nb) , negative medium (nm) , negative small (ns) , zero (z) , positive Small (ps) , positive medium (pm) , positive big (pb).Fuzzy associative memory for the proposed system is given in Table-1. Variable e and Δe are selected as the input variables for FLC where e is the error between the reference signal and actual signal of the system; Δe is the change in error in the sampling interval. Then the output variable of fuzzy logic controller is presented by the current by I_{max}.

Table 1.Rule Table of the Fuzzy Controller

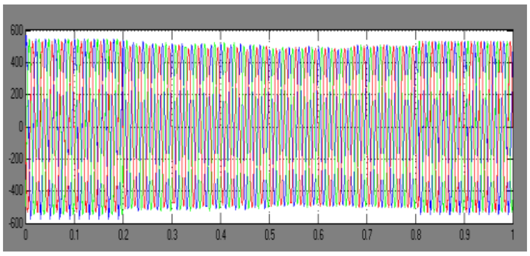
ε /Δε	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

III. SIMULATION RESULTS

An extensive simulation study is carried out by using MATLAB/simulink in order to verify the proposed control approach. a 4-leg current controlled voltage source inverter is actively controlled to achieve balanced sinusoidal grid currents at unity power factor (UPF) despite of nonlinear load at PCC under constant generation of renewable energy source.

Table 2.System Parameters

3-phase supply (rms)	415v
3-phase Non-linear load	R=50Ω,L=10mH
Dclink Capacitance &voltage	$C_{dc} = 3000\mu F, V_{dc} = 586.6V$
Coupling Inductance	$L_{sh} = 45mH$



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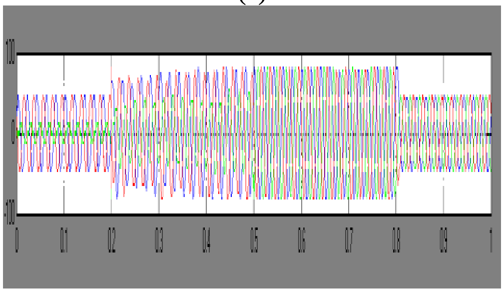

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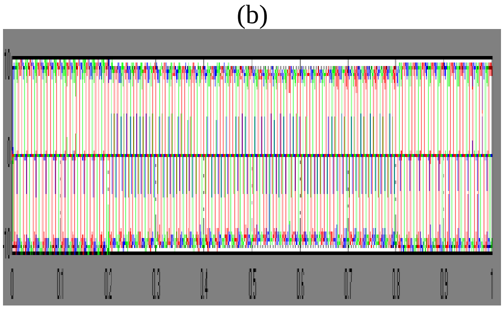

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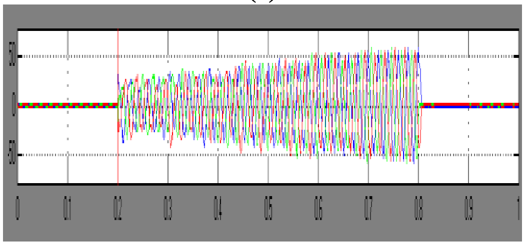
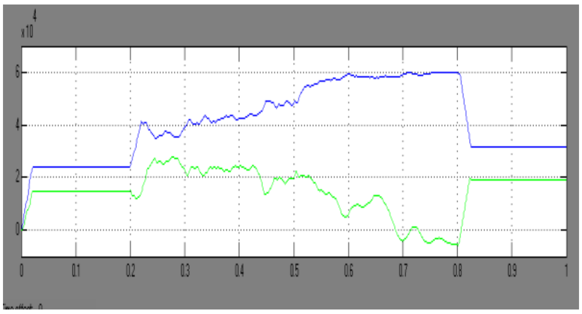


(d)

Fig 6: Simulation results a)grid voltages b)grid currents c)load currents d)inverter current under presence of both inverter and PI controller.



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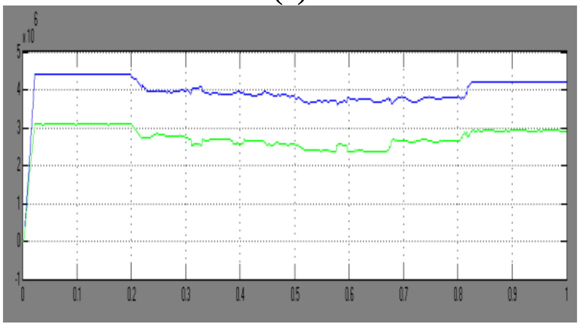

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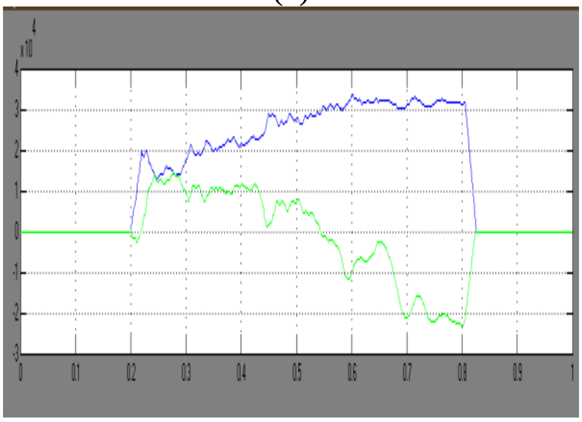

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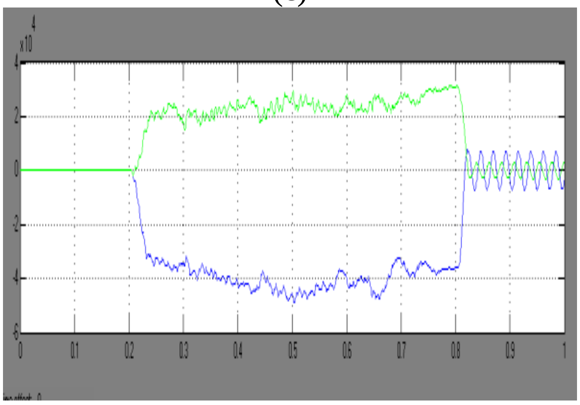

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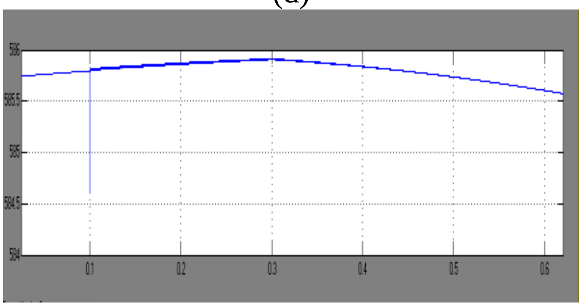

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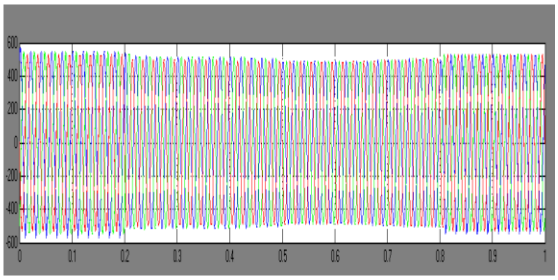
Fig 7: Simulation results a)PQ-grid b)PQ-load c)PQ-inverter d)PQ-connected between filter and grid e)DC-link voltage.



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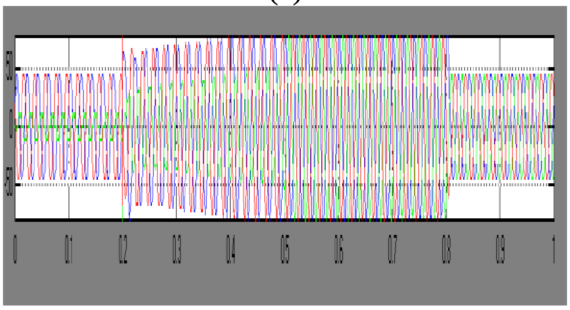

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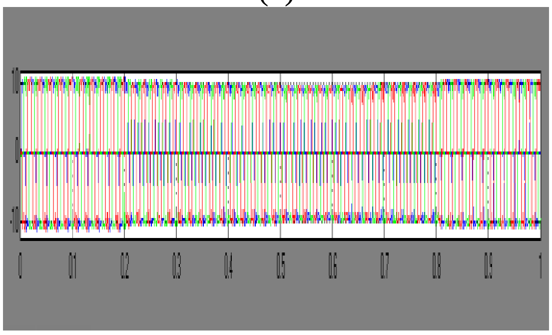

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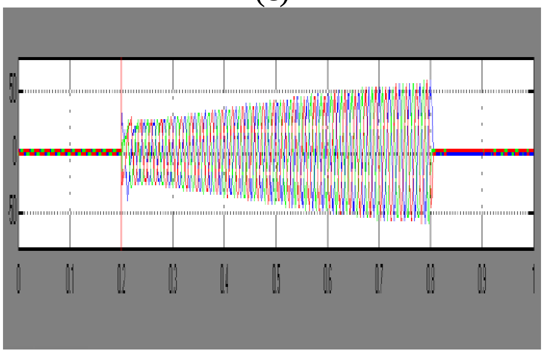

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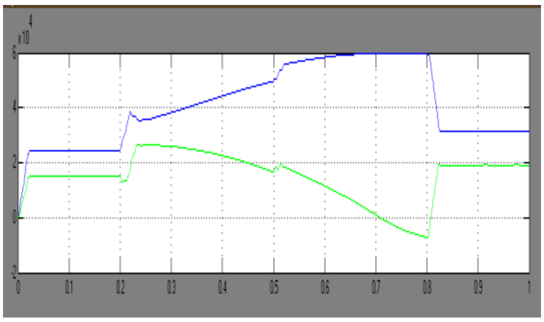
Fig 8: Simulation results a)grid voltages b)grid currents c)load currents d)inverter current under presence of both inverter and fuzzy controller.



(a)

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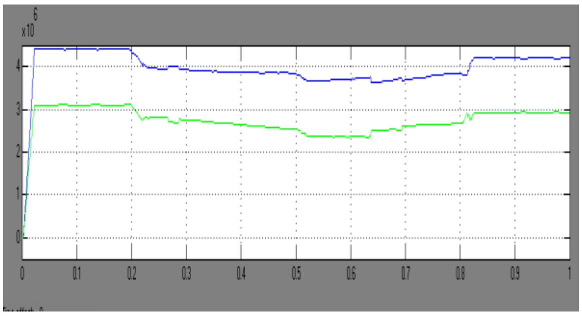

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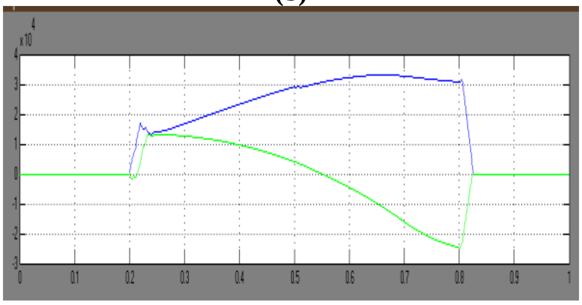

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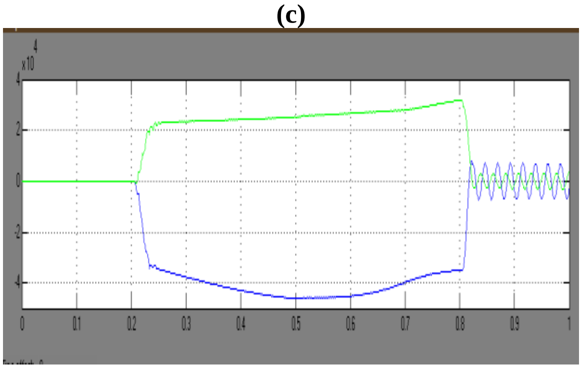

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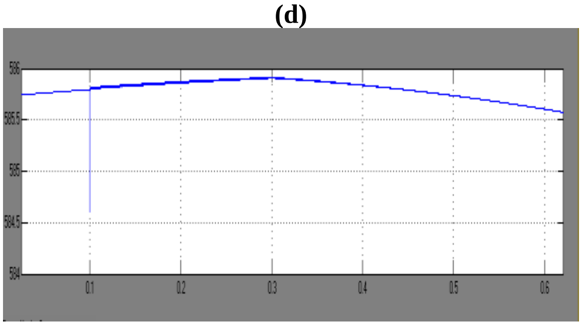

(e)

Fig 9: Simulation results a)PQ-grid b)PQ-load c)PQ-inverter d)PQ-connected between filter and grid e)DC-link voltage.

The waveforms of grid voltage (Va,Vb,Vc), gridcurrents(Ia,Ib,Ic,In),loadcurrents (Ila,Ilb,Ilc) and inverter currents(Iinva,Iinvb,Iinvc) are shown in fig 6.the corresponding active and reactive power of grid (Pgrid,Qgrid), load (Pload,Qload), and inverter (Pinv,Qinv) are shown in fig 7 with PI controller.

The waveforms of grid voltage (Va,Vb,Vc), gridcurrents(Ia,Ib,Ic,In),loadcurrents (Ila,Ilb,Ilc) and inverter currents(Iinva,Iinvb,Iinvc) are shown in fig 8.the corresponding active and reactive power of grid (Pgrid,Qgrid), load (Pload,Qload), and inverter (Pinv,Qinv) are shown in fig 9with PI controller.

Positive values of grid active-reactive powers and inverter active-reactive powers imply that these power flows from grid side towards PCC and from inverter towards PCC,respectively.the active and reactive powers absorbed by load are denoted by positive signs.thus from the simulation results, it is evident that the grid interfacing inverter can be effectively used to compensate the load reactive power,current balance and current harmonics in addition to atctive power injection from RES.This enables the grid to supply/receive sinusoidal and balanced power at UPF which can be shown in Fig 10.

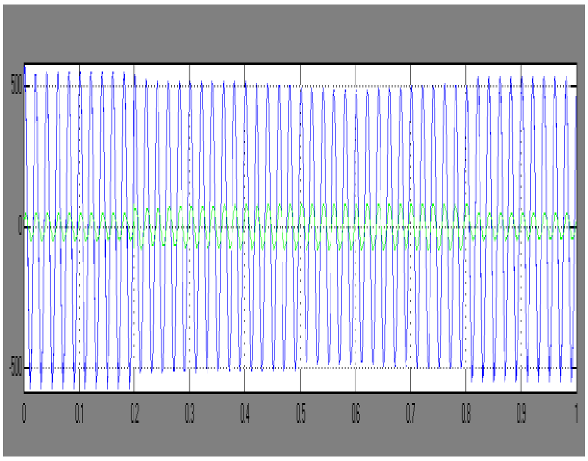

Fig 10: voltage and current at PCC

Here we are considereing four conditions
1.Non-linear unbalanced load without controller from t=0s-0.2s.
2.Non-linear unbalanced loadwith controller from t=0.2s-0.5s.
3.Non-linear balanced load with controller from t=0.5s-0.8s.
4.Non-linear balanced load without controller from t=0.8s-1s.

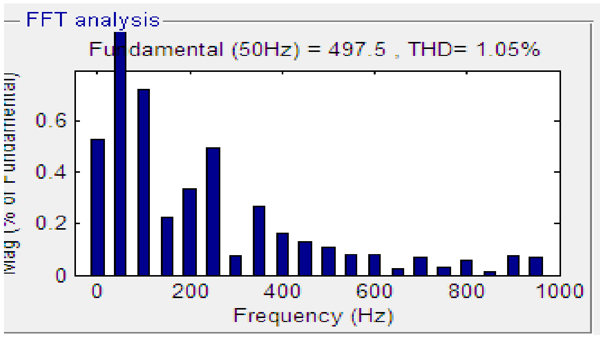

Fig 11: THD value of source voltage by using PI controller for one cycle is 1.05% .

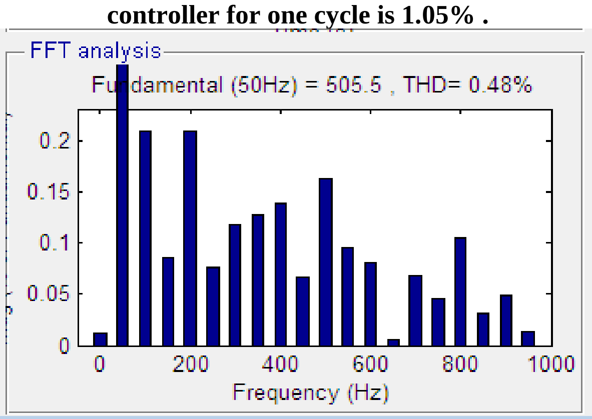

Fig 12: THD value of source current by using fuzzy controller for one cycle is 0.48%

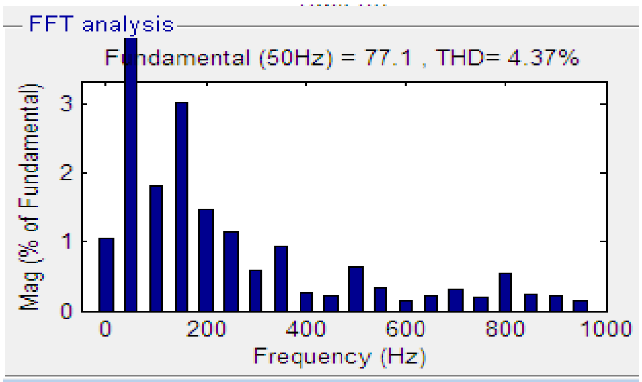

Fig 13:THD value of source current by using PI controller for one cycles is 4.37% .

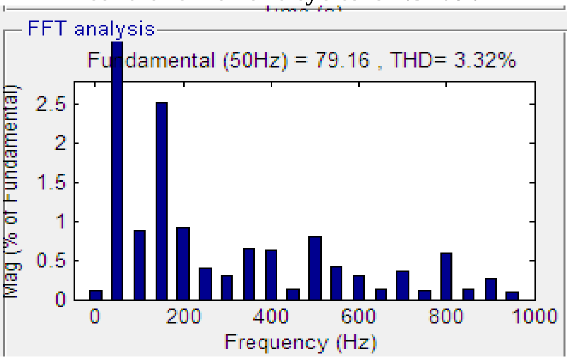

Fig 14: THD value of source current by using fuzzy controller for one cycles is 3.32% .

From Fig11,Fig13. We can see that THD value of source voltage and source current with PI Controller is 1.05% and 4.37% and Fig12,Fig14.shows the source voltage and source current with Fuzzy controller is 0.48% and 3.32%.here we can say that by using Fuzzy we can reduce 0.53% THD value of voltage and 1.05% reduction of THD value in source current using Fuzzy compare to PI Controller.

IV. CONCLUSION

This paper has presented a novel control of an existing grid interfacing inverter to improve the quality of power at PCC for a 3-phase 4-wireDGsystem. It has been shown that the grid-interfacing inverter can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. The grid-interfacing inverter with the proposed approach can be utilized to:

1) Inject real power generated from RES to the grid, and/or,

2) Operate as a shunt Active Power Filter (APF).

And it also proposes the implementation of a three-phase active power filter with two controllers.even though both the controllers capable of compensating current harmonics in 3-phase 4-wire systems,it can be seen that fuzzy logic controller has fast response and low THD values for both current and voltage values and unity power factor at PCC by reducing current harmmonics and reactive power demand .This all proofs can be seen by the above simulation results using MATLAB/Simulink.

ACKNOWLEDGMENT

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At present he is pursuing his research work in Osmania University on Dynamic State Estimation. He has published 5 research papers in International Journals. His area of interest is Power systems operation.