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Renewable Energy Interconnection at Distribution Level to Improve Power Quality

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Abstract *- Electrical utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Maximum amount of energy demand is supplied by the non-renewable sources, but increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it look towards renewable energy sources. This paper presents a grid interfacing inverter that compensates power quality problems and it can also interface renewable energy sources with the electric grid. The grid interfacing inverter can effectively be utilized to perform following functions such as transfer of active power harvested from the renewable resources, load reactive power demand support, current harmonic compensation at PCC and current unbalance and neutral current compensation in case of 3-phase 4-wire system. In this paper PI controller and fuzzy logic controller are used individually for controlling the DC capacitor voltage. The grid interface inverter configuration with IGBT is designed and the graphic models of the Grid interfacing inverter is developed using the MATLAB/SIMULINK.*

I. INTRODUCTION

The 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 [1][2], the DG systems can now be actively controlled to enhance the system operation with improved PQ at Point of Common Coupling (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. 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 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.

A control strategy for renewable interfacing inverter based on 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 [3]. Active Power Filter (APF) is extensively used to compensate the load current harmonics and load unbalance at distribution level. This results in an additional hardware cost. Another solution is to incorporate the features of APF in the, conventional inverter interfacing renewable with the grid, without any additional hardware cost. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to intermittent nature of RES [4]. The grid-interfacing inverter can effectively be utilized to perform functions as transfer of active power harvested from the renewable resources (wind, solar, etc.), load reactive power demand support, current harmonics compensation at PCC , 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. The PQ constraints at the PCC can therefore be strictly maintained within the utility standards without additional hardware cost.

II. System Description

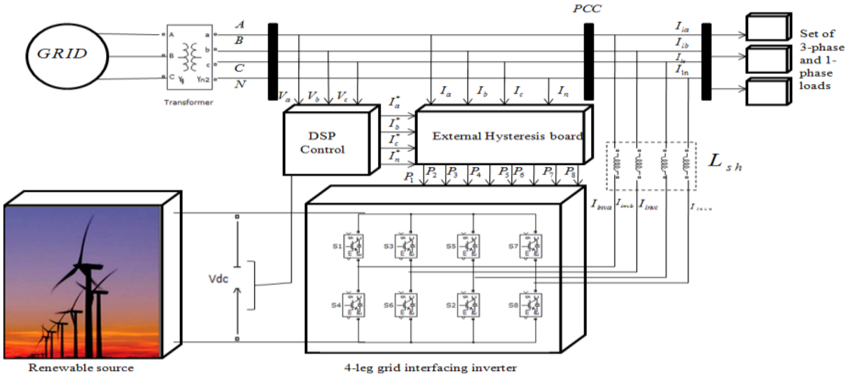


Fig.1. Schematic of proposed renewable based distributed generating system

In this paper, it is shown that using an adequate control strategy, with a four-leg four-wire grid interfacing inverter, it is possible to mitigate disturbances like voltage unbalance. The topology of the investigated grid interfacing inverter and its interconnection with the grid is presented in Fig. 1. It consists of a four-leg four-wire voltage source inverter. 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. In this type of applications, the inverter operates as a current controlled voltage source. Fourth leg is used for neutral connection. The RES may be a DC source or an AC source with rectifier coupled to dc-link. In this paper wind energy is used as a RES, the variable speed wind turbines generate power at variable ac voltage. Thus, the power generated from these renewable sources needs to convert in dc before connecting on dc-link [5]–[7]. The simulink model of wind farm is given in Fig2. Wind farm generates a variable ac supply, this variable ac supply is converted into dc by connecting a rectifier at output side.

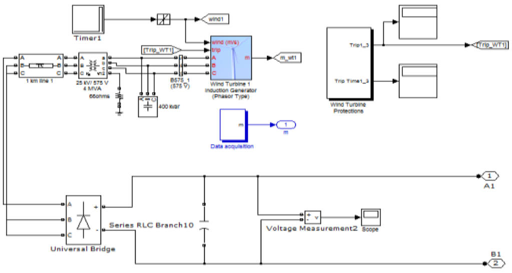


Fig.2. Simulink design of wind energy system

Under non-sinusoidal and/or unbalanced system voltages, it is impossible to implement a shunt active filter that satisfies simultaneously constant real power drained from the network, sinusoidal compensated current and proportionality between the system voltage and the compensated current. This method will overcome the two of the three concerns mentioned above. The Clarke Transformation is no longer used and the power definitions of the p-q theory are not directly used. This method uses the abc-line currents, which avoids the Clarke Transformation. The measured currents from the nonlinear load, together with a robust synchronizing circuit (PLL control circuit) form a concise controller for shunt active filter. The proposed controller forces the shunt active filter to compensate the load current such that the current drained from the network becomes sinusoidal and balanced (contain only the fundamental positive-sequence component), even under distorted and/or unbalanced system voltage.

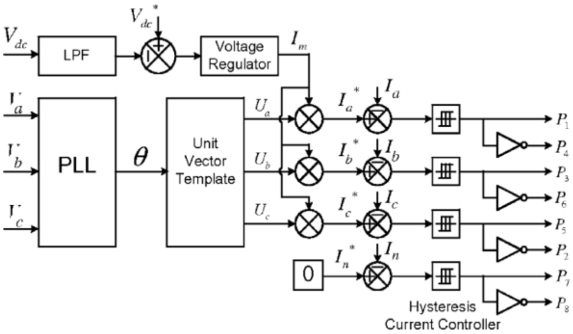


Fig.3.Block diagram representation of grid interfacing Inverter

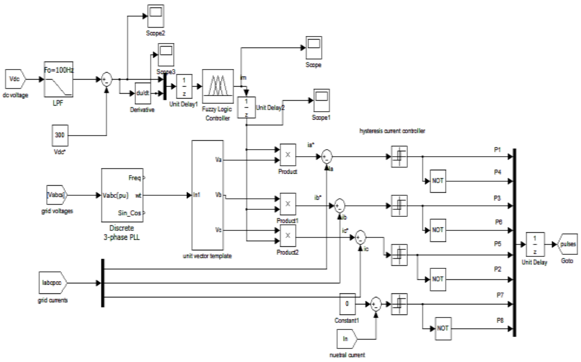


Fig.4.Simulink diagram of grid interfacing inverter using fuzzy controller

2.1.Control Strategy

The controller requires [8] the three-phase grid current (I_a,I_b, I_c), the three-phase voltage at the PCC (V_a, V_b, V_c) and the DC-link voltage (V_{DC}). As shown in Fig. 3, the sinusoidal waveform and the phase of the grid current reference (I_a*, I_b*, I_c*) comes from the line voltage thanks to a PLL.

$$U_a = \sin(\theta) \qquad (1)$$

$$U_b = \sin(\theta - 2\pi/3) \qquad (2)$$

$$U_c = \sin(\theta + 2\pi/3) \qquad (3)$$

The magnitude I_m of the same current is obtained by passing the error signal between the DC-link voltage (V_{DC}) and a reference voltage (V_{DC}*) through a PI controller or fuzzy controller. Using this magnitude and phase displacement of 120° and 240° respectively, the reference three-phase grid currents i_a*,i_b* and i_c* can be expressed as:

$$I_a^* = I_m \sin(\theta) \qquad (4)$$

$$I_b^* = I_m \sin(\theta - 2\pi/3) \qquad (5)$$

$$I_c^* = I_m \sin(\theta + 2\pi/3) \qquad (6)$$

2.2. PI controller*:*

The actual dc link voltage is sensed and passed through a first order low pass filter (LPF) to eliminate the presences 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 (Vdc*) 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 Vdcerr(n) at nth sampling instant is given as

$$V_{\mathrm{dcerr}(n)} = V^*_{\mathrm{dc}(n)} - V_{\mathrm{dc}(n)}. \qquad (7)$$

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

$$I_{m(n)} = I_{m(n-1)} + K_{PV_{\mathrm{dc}}}\left(V_{\mathrm{dcerr}(n)} - V_{\mathrm{dcerr}(n-1)}\right) + K_{IV_{\mathrm{dc}}} V_{\mathrm{dcerr}(n)} \qquad (8)$$

2.3. Fuzzy Logic Controller (Flc)

The disadvantage of PI controller is its inability to react to abrupt changes in the error signal, ε, because it is only capable of determining the instantaneous value of the error signal without considering the change of the rise and fall of the error, which in mathematical terms is the derivative of the error denoted as Δε. To solve this problem, [9][10] Fuzzy logic control as it is shown in Fig 4 is proposed. The determination of the output control signal, is done in an inference engine with a rule base having if-then rules in the form of

"IF ε is .... AND Δε is ...., THEN output is ...."

With the rule base, the value of the output is changed according to the value of the error signal ε, and the rate-of- error Δε. The structure and determination of the rule base is done using trial-and-error methods and is also done through experimentation.

TABLE.1
FLC RULES

ε	**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**

2.4.Switching control

As shown in Fig. 3, the hysteresis control has been used to keep the controlled current inside a defined band around the references. The status of the switches is determined according to the error. When the current is increasing and the error exceeds a certain positive value, the status of the switches changes and the current begins to decrease until the error reaches a certain negative value. Then, the switches status changes again. Compared with linear controllers, the non-linear ones based on hysteresis strategies allow faster dynamic response and better robustness with respect to the variation of the non-linear load. A drawback [11] [12] of the hysteresis strategies is the switching frequency which is not constant and can generate a large side harmonics band around the switching frequency.

III. Simulation Results

An extensive simulation study is carried out using MATLAB/Simulink in order to verify the proposed control strategy. To achieve balanced sinusoidal grid currents at unity power factor, the 4-leg grid interfacing inverter is actively controlled under non varying renewable generating condition. The wave forms of grid voltages, grid currents, unbalanced load current and inverter currents under absence of inverter and presence of inverter are shown in fig.5 & fig.6. The corresponding active and reactive powers of grid (PQ grid), load (PQ load) and inverter (PQ inv) under absence of inverter and presence of inverter are shown in fig.9 & fig.10. Under varying renewable generating condition , the wave forms of grid voltages, grid currents, unbalanced load current and inverter currents are shown in fig.7 & fig.8. The corresponding active and reactive powers of grid (PQ grid), load (PQ load) and inverter (PQ inv) are shown in fig.11 & fig.12.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. The active and reactive powers absorbed by the load are denoted by positive signs. Before t=0.72s, the grid interfacing inverter is not connected to network, hence the grid currents are same as unbalanced nonlinear load currents. At t=0.72s, the grid interfacing inverter is now connected to network. The grid current starts changing to sinusoidal balanced from unbalanced nonlinear current shown in fig. 7 & fig.8. At this instant active power is injecting by the inverter from RES from fig.11 & fig.12. The load power demand is less than the generated power and the additional power in fed back to the grid. The grid is receiving power from RES after 0.72s and it is indicated by –ve sign. At t=0.92s, generation of power from RES is reduced. The active and reactive power flows between the inverter, load and grid during increase and decrease of energy generation from RES. Total Harmonic Distortion (THD) of grid currents for 60 cycles using PI controller and FLC are shown in fig. 13& fig. 14. THD is less for fuzzy logic controller its value is 9.01%. THD of grid currents for single cycle using PI controller and FLC are shown in fig. 15 & fig. 16. THD is less for fuzzy logic controller compared to PI controller its value is 1.72%. By comparing all above waveforms it is clear that the fuzzy controller has high accuracy, fast response to load parameter variation and improvement in settling time.

TABLE.2

SYSTEM PARAMETERS

3-phase supply (r.m.s)	V= 170 v; 50 hz
3-phase non linear load	R=26.66Ω; L=10mH
1-phase linear load(A_N)	R=36.66Ω; L=10mH
1-phase nonlinear load (C-N)	R=26.66Ω; L=10 mH
Dc link capacitance & voltage	Cdc= 3000 μ F; Vdc=300v
Coupling inductance	Lsh=20mH

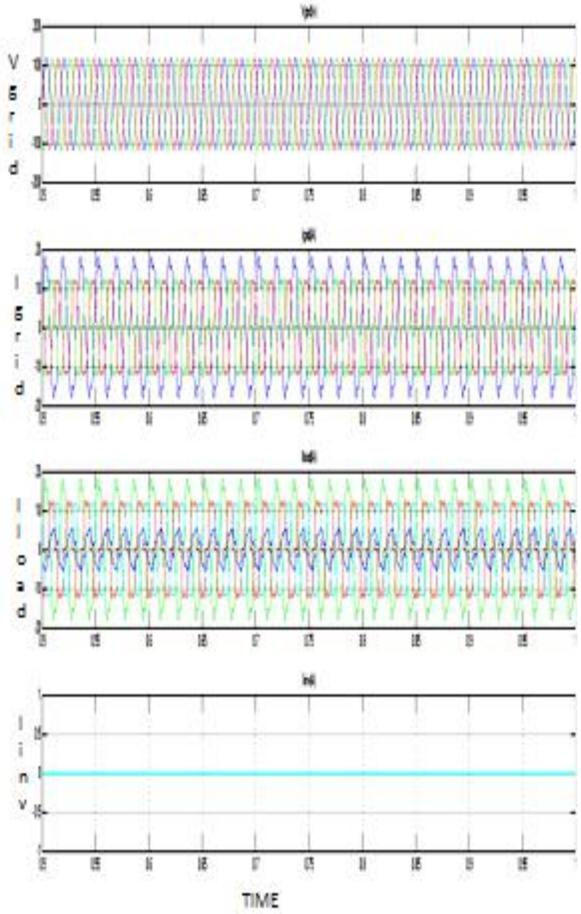


Fig.5.simulation results a) grid voltages, b) grid currents, c) load currents, d) inverter currents under absence of inverter

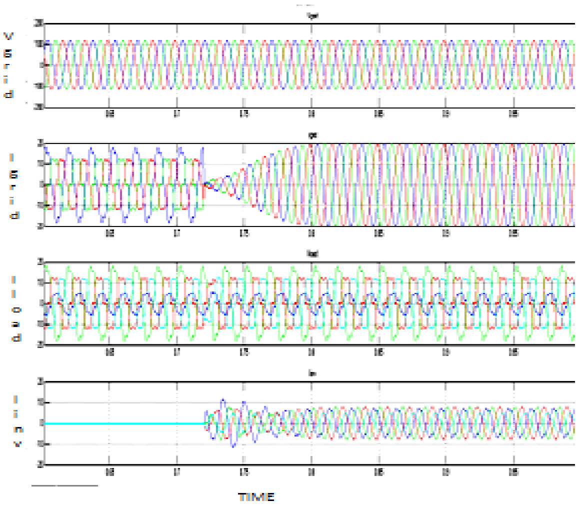


Fig.6.simulation results a) grid voltages, b) grid currents, c) load currents, d) inverter currents under no voltage variations from RES

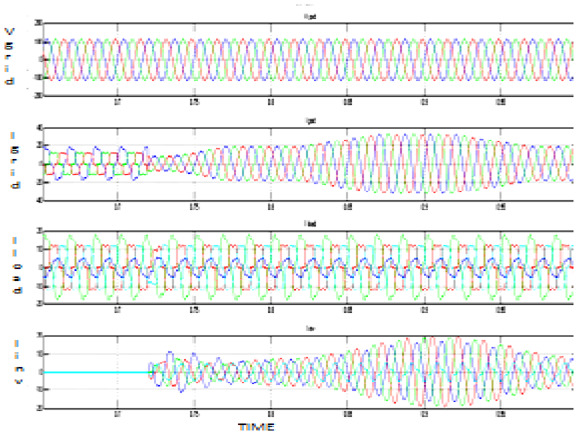


Fig.7.simulation results a) grid voltages, b) grid currents, c) load currents, d) inverter currents using PI controller

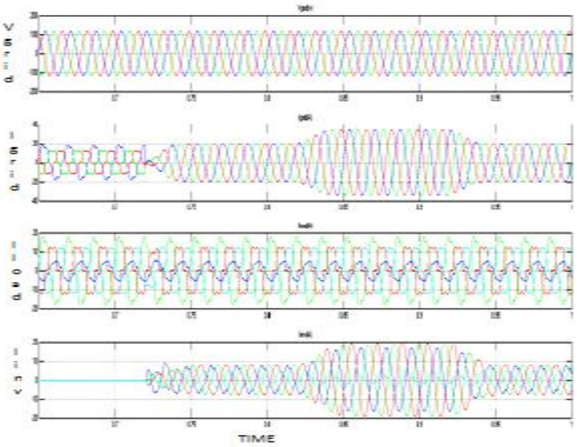


Fig.8..simulation results a) grid voltages, b) grid currents, c) load currents, d) inverter currents using fuzzy logic controller

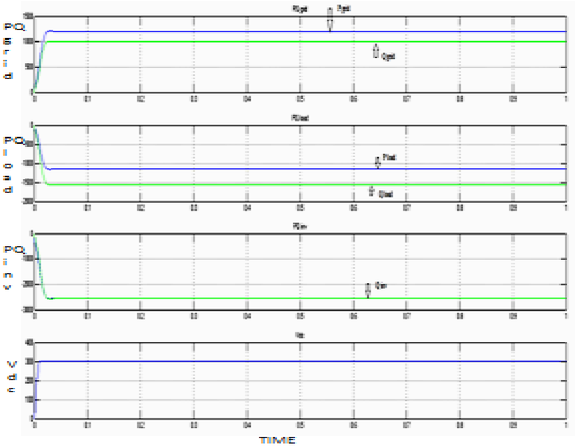


Fig.9. Simulation results a) PQ-grid, b) PQ-load,c) PQ-inv, d) dc link voltage under absence of inverter

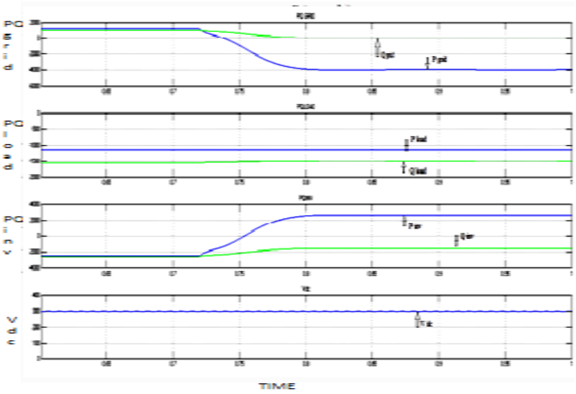


Fig.10. Simulation results a) PQ-grid, b) PQ-load,c) PQ-inv, d) dc link voltage under no voltage variations from RES

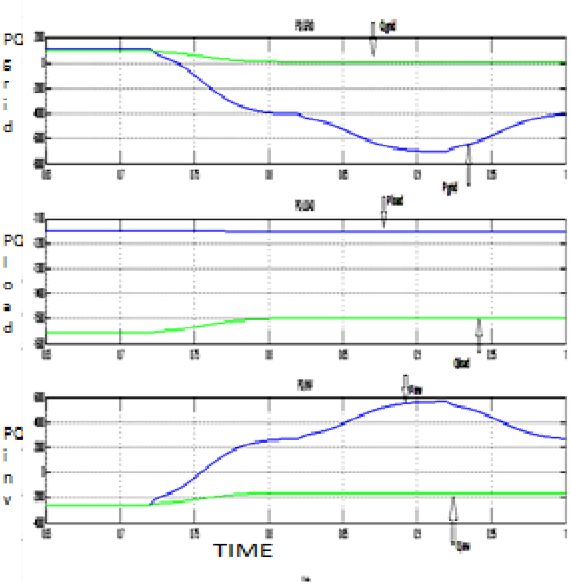


Fig.11. Simulation results a) PQ-grid, b) PQ-load,c) PQ-inv using PI controller

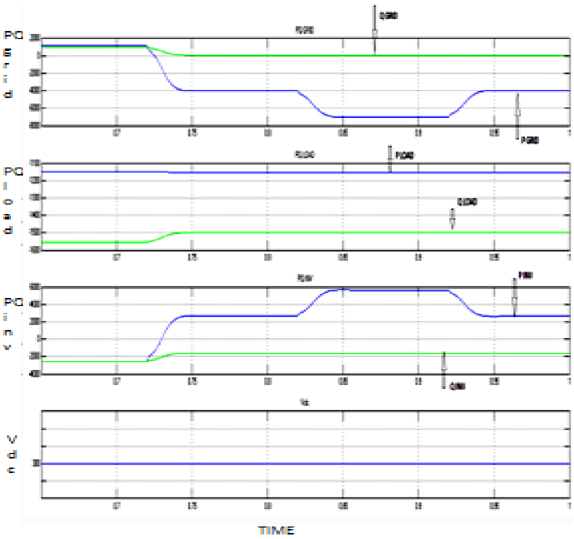
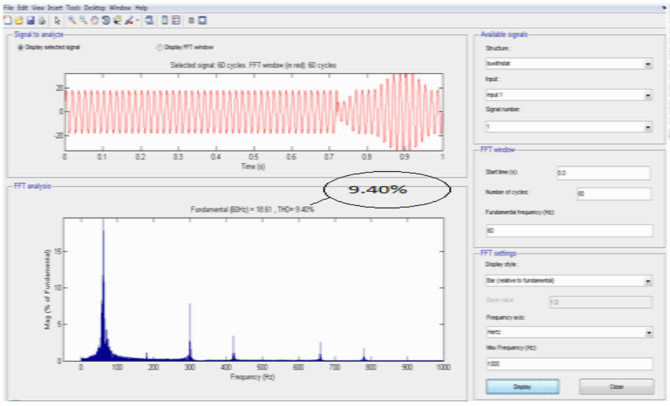


Fig.12. Simulation results a) PQ-grid, b) PQ-load,c) PQ-inv, d) dc link voltage using fuzzy logic controller.



● Display selected signal ○ Display FFT window

Selected signal: 60 cycles. FFT window (in red): 60 cycles

9.40%

Fundamental (60Hz) = 18.61 , THD= 9.40%

Input: input 1

Signal number: 1

Start time (s): 0.0

Number of cycles: 60

Fundamental frequency (Hz): 60

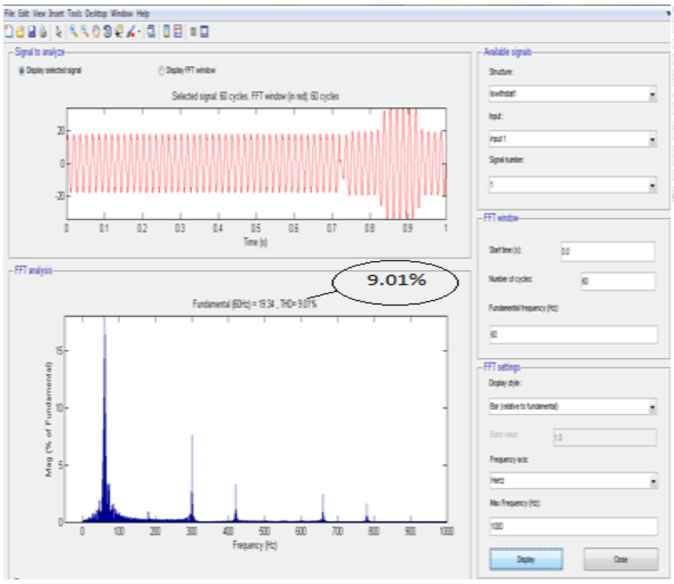
Display style: Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000

Fig.13. FFT analysis of grid current with PI controller for 60 cycles.



● Display selected signal ○ Display FFT window

Selected signal: 60 cycles. FFT window (in red): 60 cycles

9.01%

Fundamental (60Hz) = 19.34 , THD= 9.01%

Input: input 1

Signal number: 1

Start time (s): 0.0

Number of cycles: 60

Fundamental frequency (Hz): 60

Display style: Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000

Fig.14.. FFT analysis of grid current with fuzzy logic controller for 60 cycles.

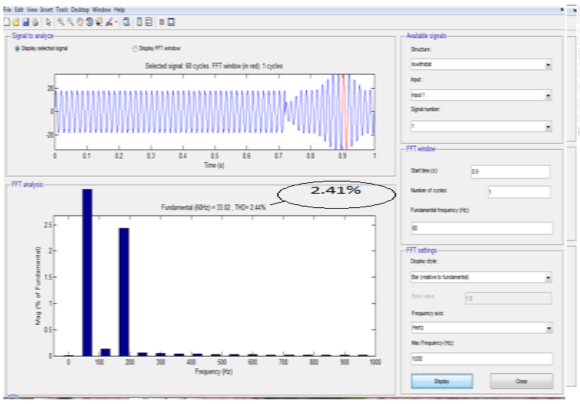


Fig.15.. FFT analysis of grid current with PI controller for single cycle.

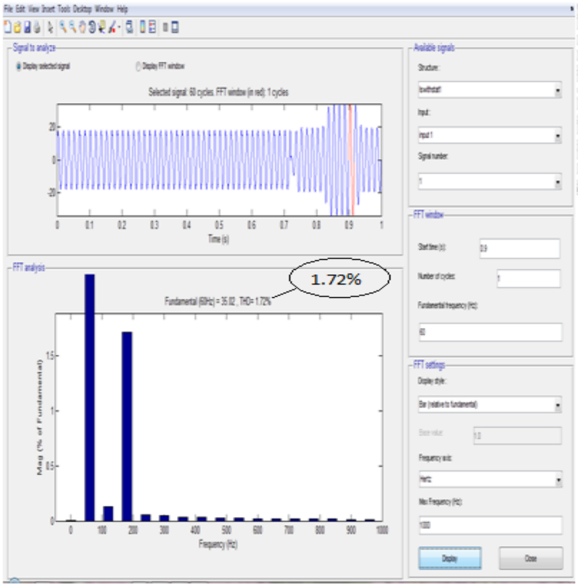


Fig.16.. FFT analysis of grid current with fuzzy logic controller for single cycle.

IV. .Conclusion

This papaer presents a novel method to improve the power quality at point of common coupling for a 3-phase 4-wire DG system using PI controller and fuzzy logic controller for grid interfacing inverter. The grid interfacing inverter is effectively utilized for power conditioning. This approach eliminates the additional power conditioning equipment to improve power quality at PCC. The grid interfacing inverter with the proposed approach can be utilized to inject real power generation from RES to the grid, and operate as a shunt Active Power Filter (APF). The current unbalance, current harmonics and load reactive power, due to unbalanced and non-linear load connected to the PCC, are compensated effectively such that the grid side currents are always maintained as balanced and sinusoidal at unity power factor. Moreover, the load neutral current is prevented from flowing into the grid side by compensating it locally from the fourth leg of inverter. When the power generated from RES is more than the total load power demand, the grid-interfacing inverter with the proposed control approach not only fulfils the total load active and reactive power demand (with harmonic compensation) but also delivers the excess generated sinusoidal active power to the grid at unity power factor. THD of grid currents are decreased up to 1.72% and settling of the system is improved hence proposed fuzzy logic controller has fast response, high accuracy of tracking the DC-voltage reference, and strong robustness to load sudden variations.

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