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PV BASED GRID INTERCONNECTION AT DISTRIBUTION LEVEL WITH POWER QUALITY IMPROVEMENT FEATURES

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Abstract--- *Renewable energy resources (RES) are being increasingly connected in distribution systems utilizing power electronic converters. This paper presents a control strategy for achieving maximum benefits from these grid-interfacing inverters 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 reactive power demand and load neutral current 3) reducing the total harmonic distortion value (THD). With such a control, the combination of grid-interfacing inverter and the 3-phase 4-wire linear and non-linear unbalanced load at point of common coupling (PCC) appears as balanced linear load to the grid. In this paper, PV-cell is a new control concept which is demonstrated with extensive MATLAB/Simulink software.*

Keywords--- *Active Power Filter (APF), Distributed Generation (DG), Distribution System, Grid Interconnection, Power Quality (PQ), Photo voltaic cell.*

I.INTRODUCTION

Renewable sources of energy acquire growing importance due to its enormous consumption and exhaustion of fossil fuel. Also, solar energy is the most readily available source of energy and it is free. Moreover, solar energy is the best among all the renewable energy sources since, it is non-polluting. Photo voltaic arrays are used in many applications such as water pumping, street lighting in rural town, battery charging and grid connected PV systems. 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. The market liberalization and government's incentives have further accelerated the renewable energy sector growth. 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 [2]. 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.

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 in [5]. In [6], 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.

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. However, in this paper authors have incorporated 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. It is shown in this paper that the grid-interfacing inverter can effectively be utilized to perform following important functions: 1) transfer of active power harvested from the renewable resources (solar); 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. The PQ constraints at the PCC can therefore be strictly maintained within the utility standards without additional hardware cost.

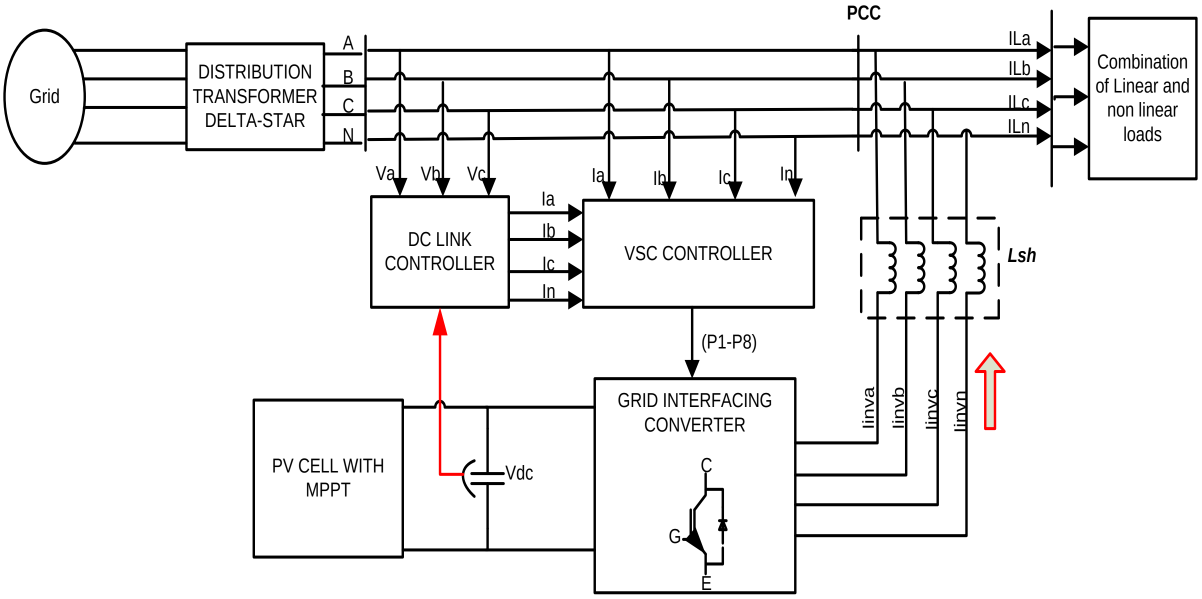

Fig.1. Schematic of proposed renewable energy based distributed generation system.

II. SYSTEM DESCRIPTION

A. Topology

Active power filters are power electronic devices that cancel out unwanted harmonic currents by injecting a compensation current which cancels harmonics in the line current. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. Generally, four-wire APFs have been conceived using four leg converters. This topology has proved better controllability than the classical three-leg four-wire.

B. Voltage Source Converter(VSC)

A Voltage Source Converter (VSC) is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. It also converts the DC voltage across storage devices into a set of three phase AC output voltages. It is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, is said to be in capacitive mode. So, it will compensate the reactive power through AC system. The type of power switch used is an IGBT in anti-parallel with a diode. The three phase four leg VSI is modeled in Simulink by using IGBT. As in the Fig.1 the system consist of an RES connected to the dc-link of a grid-interfacing inverter. The voltage source inverter interfaces the renewable energy source to the grid. The RES is DC source with rectifier coupled to dc- link with fuel cell and photovoltaic. Usually the fuel cell integration is provided by using a unidirectional DC/DC converter (to obtain regulated high voltage DC), an inverter and a filter in order to accommodate the DC voltage to the required AC voltage (single phase or three phases).

1. DC Voltage and Power Control Operation

Because of the intermittent nature of RES, the generated power is of variable nature. The dc-link connected aids in transferring this variable power from RES to the grid. RES are represented as current sources connected to the dc-link of a grid-interfacing inverter. The current injected by renewable into dc-link at voltage level Vdc can be given as

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

Where P_{RES} is the power generated from RES. The current flow on the other side of dc-link can be represented as,

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

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

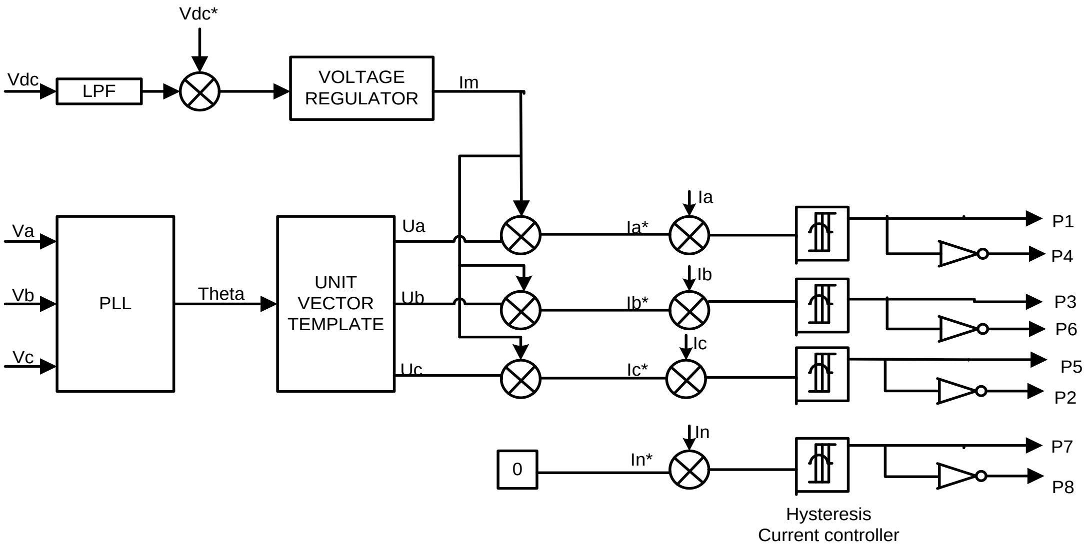

Fig.2. Block diagram representation of grid-interfacing inverter control.

2. Control of Grid Interfacing Inverter

The control diagram of grid- interfacing inverter for a 3-phase 4-wire system is shown in Fig. 2. To compensate the neutral current of load, a fourth leg is provided to the inverter. The proposed approach is mainly concerned about the regulation of power at PCC during three conditions like, when 1) $P_{RES} = 0$; 2) P_{RES} < total power (P_L); and 3) $P_{RES} > P_L$. During the power management operation, the inverter is 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. By the control, duty ratio of inverter switches are varied in a power cycle in order to get the combination of load and inverter injected power to be appearing as balanced resistive load to the grid. The exchange of active power in between renewable source and grid can be obtained from the regulation of dc-link voltage.

Thus the output of dc-link voltage regulator results in an active current (I_m). The multiplication of this 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, and I^*_c) for the control process. The reference grid neutral current (I^*_n) is set to zero, being the instantaneous sum of balanced grid currents. Phase locked loop (PLL) is used to generate unity vector template from which the grid synchronizing angle (θ) is obtained.

$$U_a = \sin(\theta) \quad (3)$$

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

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

To eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals, the actual dc-link voltage (V_{dc}) is sensed and passed through a first-order low pass filter (LPF). 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 error in the dc-link voltage $V_{dcerr\,(n)}$ at the sampling instant is given by:

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

III. HYSTERSIS CURRENT CONTROL

The hysteresis current control (HCC) is the easiest control method to implement; it was developed by Brod and Novotny in 1985. The shunt APF is implemented with three phase current controlled VSI and is connected to the ac mains for compensating the current harmonics. The VSI gate control signals are brought out from hysteresis band current controller. A hysteresis current controller is implemented with a closed loop control system and waveforms are shown in Fig .3. An error signal is used to control the switches in a voltage source inverter. This error is the difference between the desired current and the current being injected by the inverter. If 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, the current starts decaying.

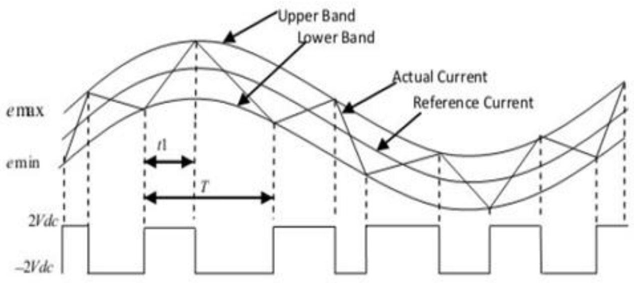

Fig.3. Waveform of Hysteresis current controller

If the error crosses the lower limit of the hysteresis band, the lower switch of the inverter arm is turned off and the upper switch is turned on. As a result, the current gets back into the hysteresis band. The minimum and maximum values of the error signal are e_{min} and e_{max} respectively. The range of the error signal e_{max} -e_{min} directly controls the amount of ripple in the output current from the VSI.

IV. SIMULATION RESULTS

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. 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. An unbalanced 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 grid currents 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.

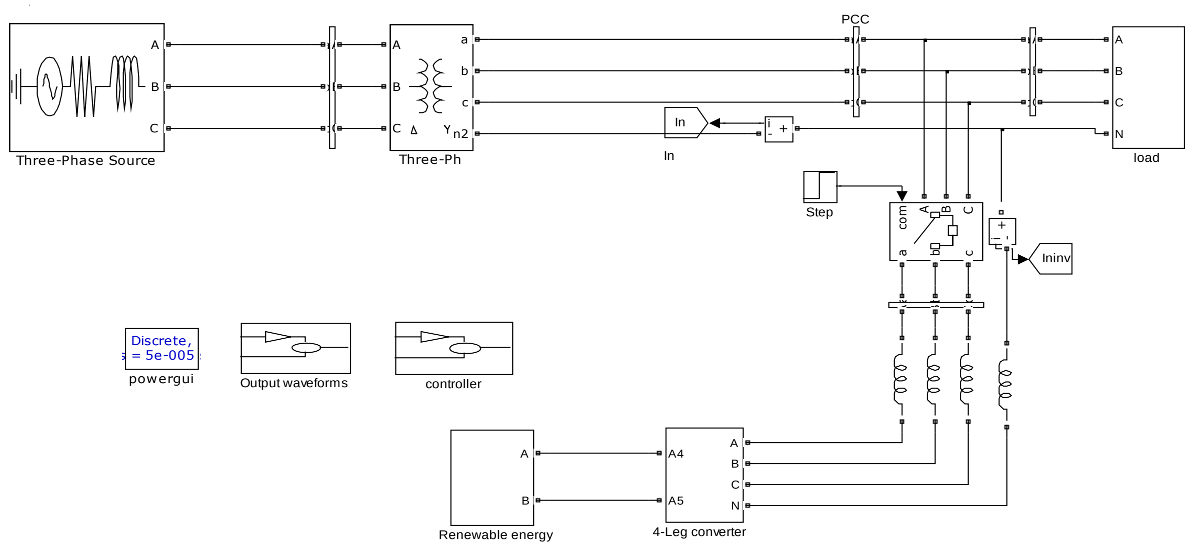

Fig.4 simulink model of circuit diagram.

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=0.72 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 Fig. 5(b). As the inverter also supplies the active power from RES is increased to evaluate the performance of system under variable power generation from RES. 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 as indicated by its profile.

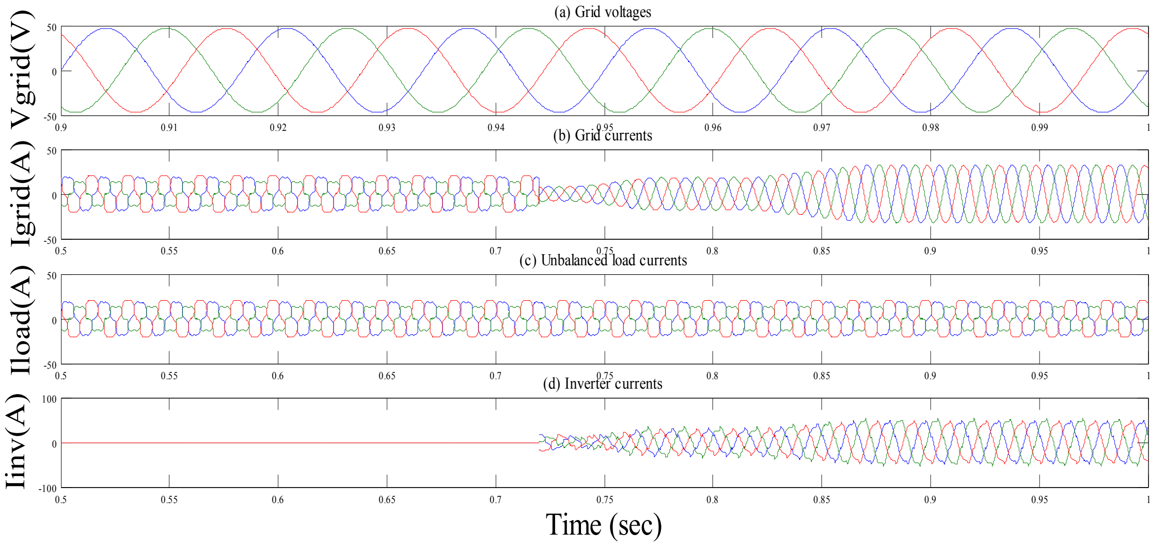

Fig.5(a) Grid voltages, (b) Grid Currents (c) Unbalanced load currents, (d) Inverter Currents.

The active and reactive power flows between the inverter, load and grid during increase and decrease and of energy generation from RES can be noticed from fig.5 The dc-link voltage across the grid- interfacing inverter Fig. 6(d) during different operating condition is maintained at constant level in order to facilitate the active and reactive power flow. Thus from the simulation results, it is evident that the grid-interfacing inverter can be effectively used to compensate the load reactive power, current unbalance and current harmonics in addition to active power injection from RES. This enables the grid to supply/ receive sinusoidal and balanced power at UPF.

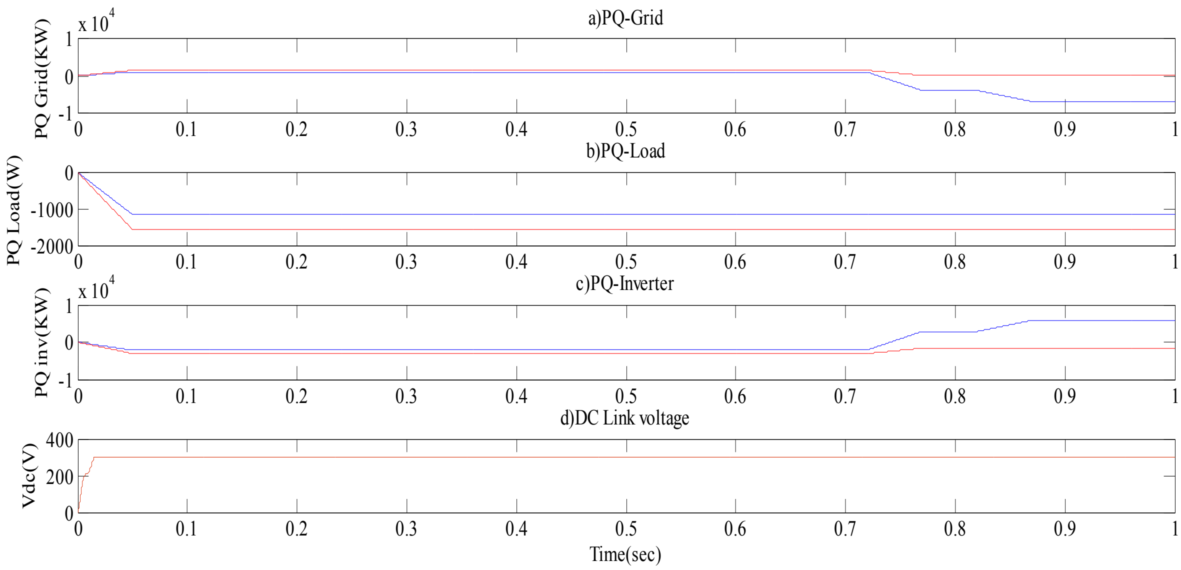

Fig.6(a) PQ-Grid, (b) PQ-Load, (c) PQ-Inverter, (d) dc-link voltage.

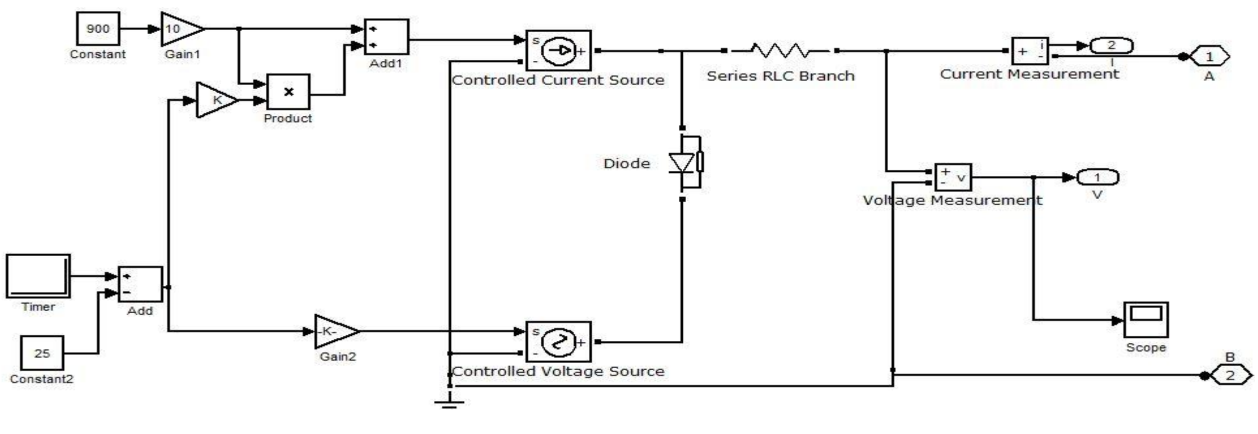

Fig.7 PV cell Simulink circuit.

Fig.7 shows the PV cell Simulink circuit with the help of a voltage controller. The inputs for PV cell are irradiations and temperature. The irradiation of PV cell is taken as 900 and its value is kept constant throughout the operation and the operating temperature is 25

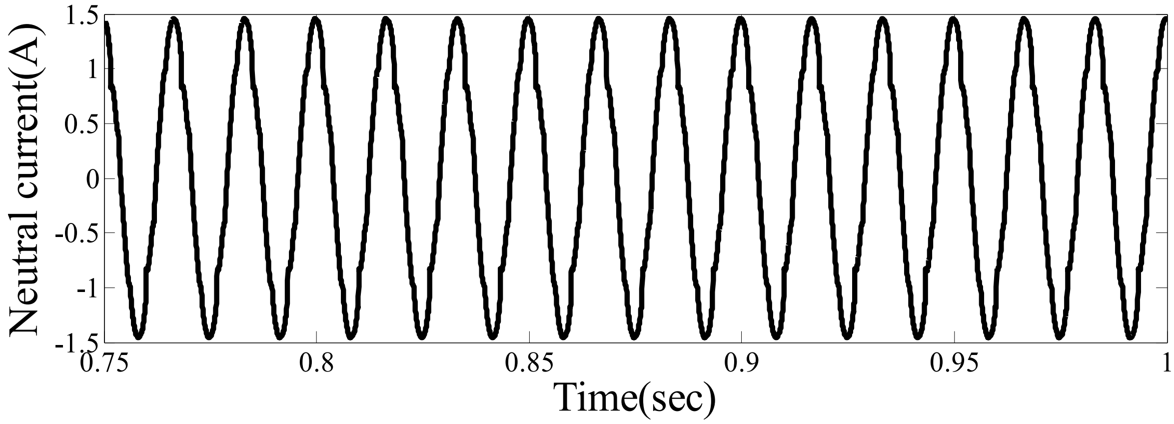

Fig.8. Neutral current.

Fig.8 shows the neutral current which is compensated. The neutral current is present when the system is unbalanced. In a balanced system the the neutral current is zero, to compensate the neutral current the inverter 4th leg is used.

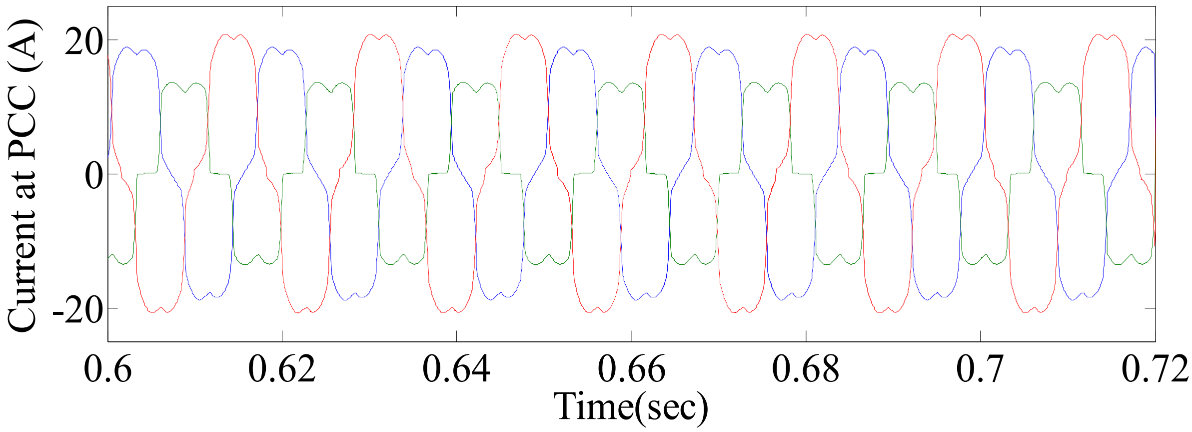

Fig.9. Current at PCC from time 0.65 to 0.72.

Fig.9 shows the current at point of common coupling (PCC), from time 0 to 0.72 the current waveform is similar to the load current. At this time the grid only supplies the total power to the load.

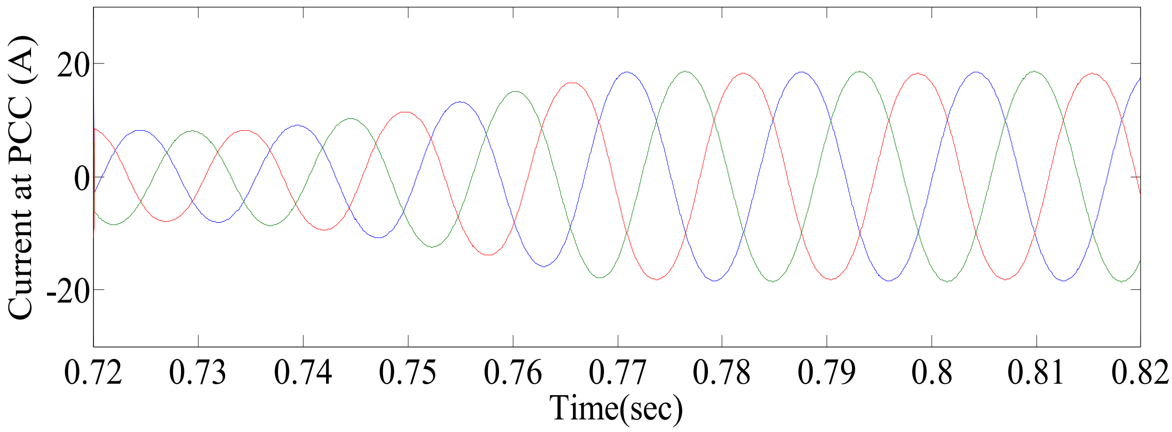

Fig.10. Current at PCC from time 0.72 to 0.82.

Fig.10 shows the current at point of common coupling from time 0.72 to 0.82 at this time the current will changed from unbalanced to balanced. And increased the magnitude of the current so that the load power will be supplied by RES and grid.

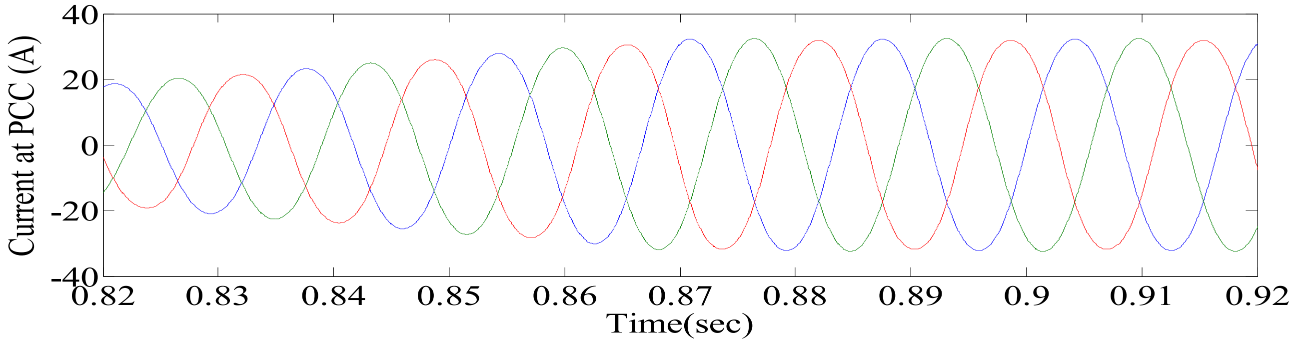

Fig.11. Current at PCC from time 0.82 to 0.92.

Fig.11 shows the current at point of common coupling from time 0.82 to 0.92. At this time the renewable energy generates excess power so that the magnitude of the current increase and the increased power will be fed back to the grid. The inverter will inject the fundamental power to the grid and load.

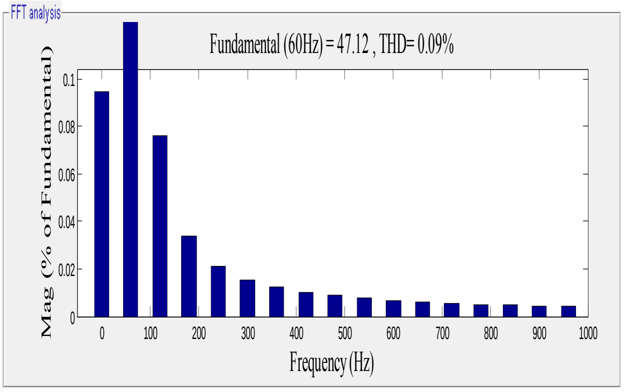

Fig.12(a).THD value of phase a grid voltage.

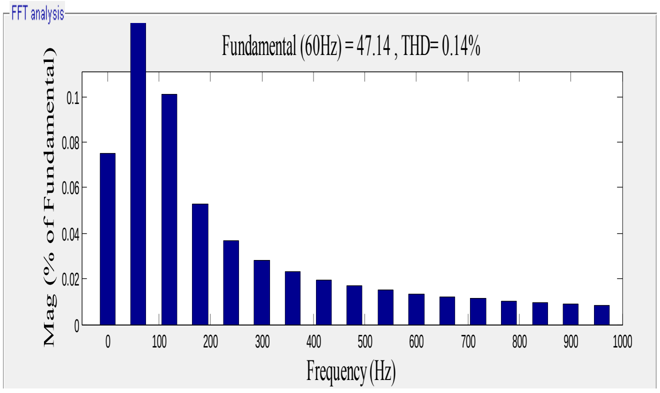

Fig.12(b).THD value of phase b grid voltage.

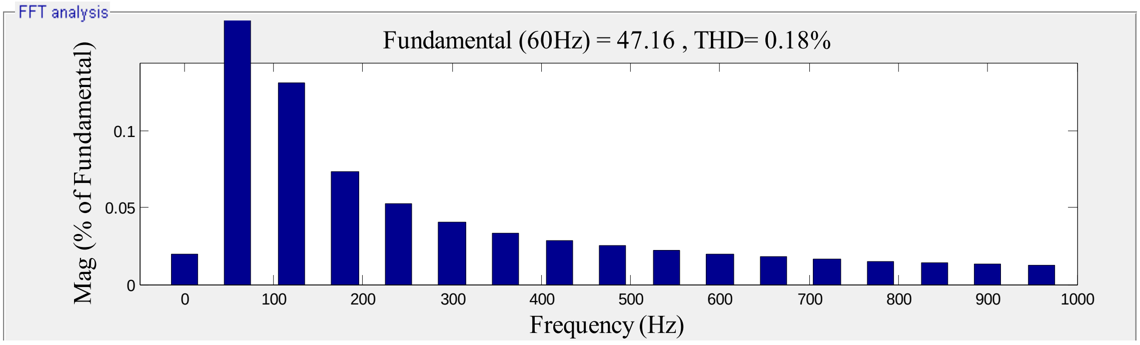

Fig.12(c).THD value of phase c grid voltage.

Fig 5.12 shows the total harmonic distortion (THD) of three phase grid voltages with percentage of 0.09%, 0.14%, 0.18% for a,b,c phases. It shows for the fundamental frequency of 60Hz. The FFT shows 1 out of 60 cycles for selected signals. The x-axis shows the frequency and the y-axis shows the magnitude of fundamental values. By controlling grid interfacing inverter in such a way to compensate the harmonics below 5% at grid side and maintain balanced system.

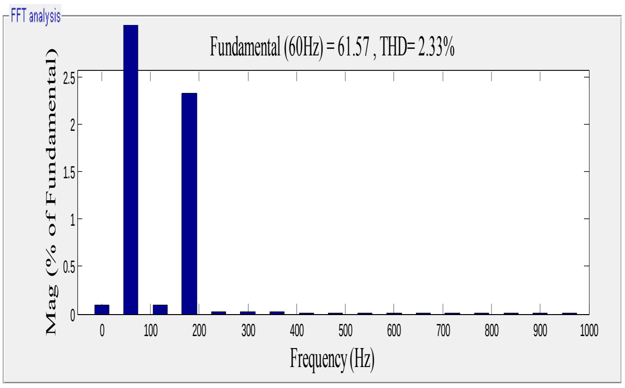

Fig.13(a).THD value of phase a grid current.

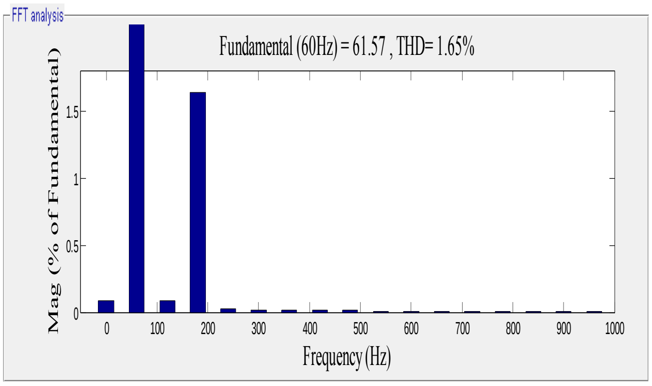

Fig.13(b).THD value of phase b grid current.

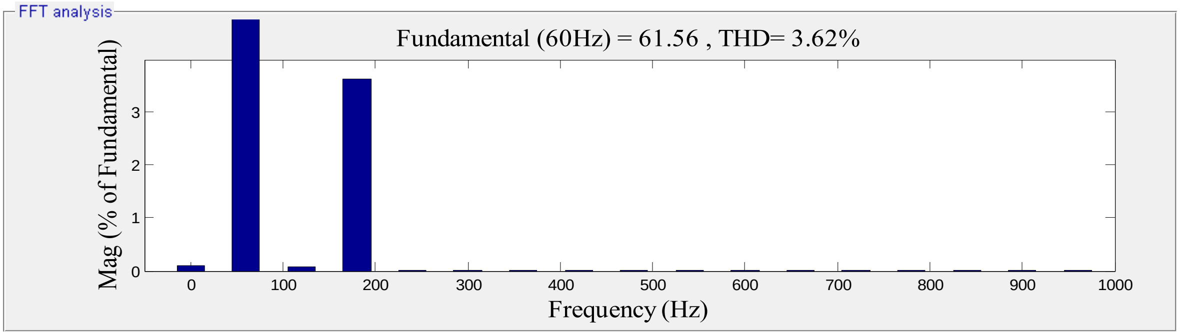

Fig.13(c).THD value of phase c grid current.

Fig.13 shows the grid current THD's are reduced to 2.33%, 1.65%, 3.62% for a,b,c phases respectively. It shows for the fundamental frequency of 60Hz. The FFT shows 1 out of 60 cycles for selected signals. The x-axis shows the frequency and the y-axis shows the magnitude of fundamental values. By controlling grid interfacing inverter in such a way to compensate the harmonics below 5% at grid side and maintain balanced system.

V.CONCLUSION

To improve the power quality at point of common coupling with 3-phase 4-wire distributed generation, it has been shown that the grid interfacing inverter can be effectively utilized for power conditioning without affecting its normal operating of real power transfer. The grid interfacing inverter with the proposed approach can be utilized to: I) Inject real power generated from RES to the grid, II) Operate as a shunt Active Power Filter. The photovoltaic cell supply only active power. This approach thus eliminates the need for additional power conditioning equipment to improve the quality of power at PCC.

The MATLAB/SIMULINK simulation model of the system with the connection of renewable energy sources is shown and validated. The control circuit is operated with phase lock loop, proportional integral controller and hysteresis controller which is used to generate the gating pulses for the 4-leg inverter and is carried out at load side with non-linear unbalanced load. Thus 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. The total harmonic distortion (THD) value is below 5% at grid side.

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