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A CONTROL APPROACH FOR GRID INTERFACING INVERTER IN 3 PHASE 4 WIRE DISTRIBUTION SYSTEM WITH POWER-QUALITY IMPROVEMENT FEATURES

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Abstract: *With the increase in load demand, the Renewable Energy Sources (RES) are increasingly connected in the distribution systems which utilizes power electronic Converters/Inverters. Nowadays, 3-phase 4-wire distribution power system has been widely used in residential and office buildings, manufacturing facilities, schools etc This paper presents a novel control strategy for achieving maximum benefits from the grid-interfacing inverters when installed in 3-phase 4-wire distribution systems. The inverter can thus be utilized as: 1) power converter to inject power to the grid, and 2) shunt APF to compensate current unbalance, load current harmonics and load neutral current. All of these functions may be accomplished either individually or simultaneously. This new control concept is demonstrated with extensive MATLAB/Simulink simulation studies*

Keywords: *Active power filter (APF), distributed generation (DG), grid interconnection, power quality(PQ),renewable energy*

I. INTRODUCTION

Due to increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards Renewable Energy Sources (RES) as a future energy solution. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation since the past decade, there has been an enormous interest in many countries on renewable energy for power generation. 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. The widespread increase of non-linear loads nowadays, significant amounts of harmonic currents are being injected in to power systems.

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. In [8] Power quality problems associated with distributed power (DP) inverters, implemented in large numbers onto the same distribution network, are investigated. The general objective is to investigate the power quality problems and the interaction of the inverters with the distribution network. 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 [11], a control method is presented which enables equal sharing of linear and nonlinear loads in three-phase power converters connected in parallel, without communication between the converters. But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance

The loads based on power electronic devices generally pollute the nearby network by drawing non sinusoidal currents from the source. The rapid switching of electronic devices creates additional problems. This makes voltages and currents at point of common coupling (PCC) highly distorted. One of the best solutions to compensate both current and voltage related problems, simultaneously, is the use of Unified Power Quality Conditioner (UPQC). Reference [6] is based on a unified approach for load and source compensation using Unified Power Quality Conditioner (UPQC).Performance of this UPQC has been evaluated with a typical industrial load with realistic parameters supplied by a polluted distribution network.

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 [3]–[5].In [3] an overview of the structures for the DPGS based on fuel cell, photovoltaic, and wind turbines are presented. In addition, control structures of the grid-side converter are presented, and the possibility of compensation for low-order harmonics is also discussed. In [5], the behavior of grid-coupled DG units during voltage dips in low voltage distribution grids will be investigated. The impact of DG units on the retained grid voltage (the lowest rms voltage during the event) is strongly dependent on the voltage level, and thus the grid impedance, of the concerned grid. This will focus on small-scaled DG units connected to the low voltage distribution grid.

In [4] new trends in power-electronic technology for the integration of renewable energy sources and energy-storage systems are presented. This describes the current technology and future trends in variable-speed wind turbines and also present power-conditioning systems used in grid-connected photovoltaic (PV) generation plants. The continuously decreasing prices for the PV modules lead to the increasing importance of cost reduction of the specific PV converters. Energy storage in an electricity generation and supply system enables the decoupling of electricity generation from demand

In this paper, a approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is performed. It is shown that the grid-interfacing inverter can effectively be utilized to perform following important functions: 1) transfer of active power harvested from the renewable resources 2) current harmonics compensation at PCC; and 3) current unbalance and neutral current compensation in case of 3-phase 4-wire system. The PQ constraints at the PCC can therefore be strictly maintained within the utility standards without additional hardware cost.

II. SYSTEM MODELING

The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter as shown in Fig. 1. This topology has proved better controllability than the classical three-leg four-wire. The RES may be a DC source or an AC source with rectifier coupled to dc-link.The dc-link capacitor decouples the dc source from grid and also allows independent control of converters on either side of dc-link. The voltage source inverter is a key element of a DG system as it interfaces the source to the grid and delivers the generated power.

Active power filters are power electronic devices that cancel out unwanted harmonic currents by injecting a compensation current which cancels harmonics from the nonlinear harmonics is achieved with the voltage source inverter in the current controlled mode and an interfacing filter. 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 loads. The current wave form for canceling the PQ constraints at the PCC can be strictly maintained within the utility standards without additional hardware cost. The desired current waveform is obtained by accurately controlling the switching of the insulated gate bipolar transistors (IGBT's) in the inverter. The driving voltage across the interfacing inductance determines the maximum di/dt that can be achieved by the filter .A large inductor is better for isolation from the power system and protection from transient disturbances. However, the larger inductor limits the ability of the active filter to cancel higher order harmonics.

2.1 DC Link Capacitor

The dc-capacitor decouples the source from grid and also allows independent control of converters on either side of dc-link. Here the DC link is connected between a constant DC source and three phase 4 leg grid interfacing inverter. The switching network on the output side generates very large transients at the switching frequency. The Ripple effects the life and reduces the energy in the DC source (Battery, Fuel Cell).The capacitor provides a low impedance path for harmonics/transients (ripple).The DC link capacitor helps to keep these transients from radiating back to the input.

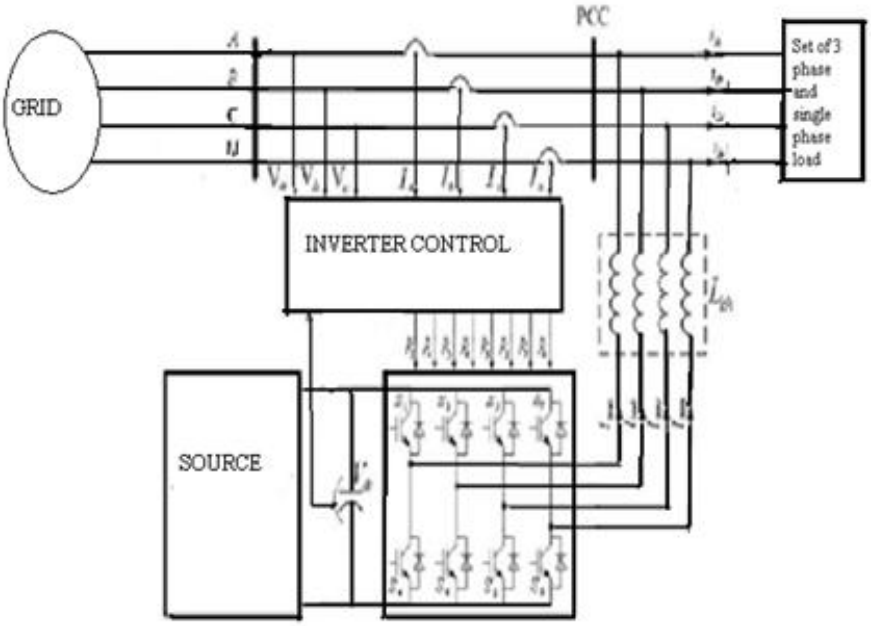

Fig.1. Schematic of renewable based distributed generation system.

2.2 Voltage Source Converter (VSC)
The voltage source inverter is a key element of a DG system as it interfaces the source to the grid and delivers the generated power. In this a 3 three phase 4 leg voltage source converter is used. The fourth leg of inverter is used to compensate the neutral current of load. 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.

2.3 L filter
The output filter reduces the harmonics in generated current caused by semiconductor switching. The L-filter is the first order filter with attenuation 20 dB/decade over the whole frequency range. Therefore the application of this filter type is suitable for converters with high switching frequency, where the attenuation is sufficient. On the other side inductance greatly decreases dynamics of the whole system converter.

2.4 Grid
Grid energy storage refers to the methods used to store electricity on a large scale within an electrical power system. Electrical energy is stored during times when production (from power plants) exceeds consumption and the stores are used at times when consumption exceeds production. In this way, electricity production need not be drastically scaled up and down to meet momentary consumption – instead, production is maintained at a more constant level.

2.5 Non linear load
Applies to those ac loads where the current is not proportional to the voltage. The nature of non-linear loads is to generate harmonics in the current waveform. This distortion of the current waveform leads to distortion of the voltage waveform. Under these conditions, the voltage waveform is no longer proportional to the current

III. PROPOSED CONTROL OF GRID INTERFACING INVERTER
The control diagram of grid- interfacing inverter for a 3-phase 4-wire system is shown in Fig. 2. The fourth leg of inverter is used to compensate the neutral current of load. 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.

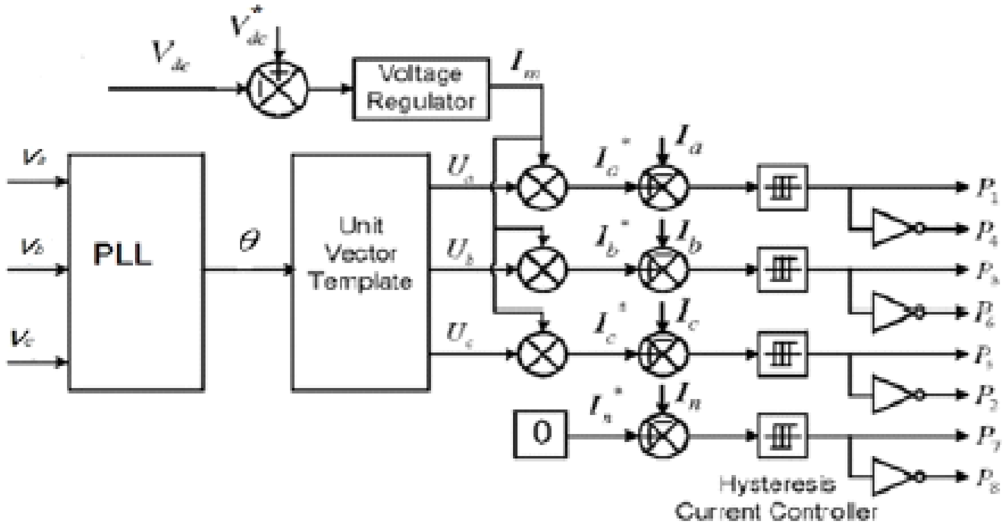

Fig. 2. Block diagram representation of grid-interfacing inverter control

3.1 Phase-Locked Loop

A phase-locked loop or phase lock loop (PLL) is a control system that generates an output signal whose phase is related to the phase of an input signal. While there are several differing types, it is easy to initially visualize as an electronic circuit consisting of a variable frequency oscillator and a phase detector. The oscillator generates a periodic signal. The phase detector compares the phase of that signal with the phase of the input periodic signal and adjusts the oscillator to keep the phases matched.

The grid synchronizing angle (Θ) obtained from phase locked loop (PLL) is used to generate unity vector template as

Ua =Sin(θ) (1)

Ub = Sin(θ -2Π/3) (2)

Uc =Sin(θ +2Π/3) (3)

3.2 PI Controller

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. The difference of the 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 output of the PI controller is denoted as Im. The dc-link voltage error Vdcerr(n) at n^{th} sampling instant is given as:

$$V_{dcerr(n)} = V_{dc}^* - V_{dc(n)} \quad (4)$$

The output of discrete-PI regulator at n^{th} sampling instant is expressed as

$$I_{m(n)} = I_{m(n-1)} + K_{PV_{dc}}(V_{dcerr(n)} - V_{dcerr(n-1)}) + K_{IV_{dc}} V_{dcerr(n)} \quad (5)$$

where $K_{PV_{dc}} = 10$ and $K_{IV_{dc}} = .05$ are proportional and integral gains of dc-voltage regulator.

The reference current templates (Ia*,Ib*,and Ic*) are obtained by multiplying the peak value (Im) by the three-unit sine vectors (Ua , Ub and Uc) in phase with the three source voltages. These unit sine vectors are obtained from the three sensed line to neutral voltages. The reference grid neutral current (In*) is set to zero, being the instantaneous sum of balanced grid currents. Multiplication of magnitude Im with phases (Ua ,Ub, and Uc) results in the three phase reference supply currents (Ia*,Ib*,and Ic*).

The instantaneous values of reference three phase grid currents are compute as

Ia* = Im . Ua (6)

Ib* = Im . Ub (7)

Ic* = Im . Uc (8)

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

In* = 0 (9)

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

Iaerr =Ia* - Ia (10)

Iberr =Ib* - Ib (11)

Icerr =Ic* - Ic (12)

Inerr =In* - In (13)

These error signals are given to hysteresis current controller then generates the switching pulses for six IGBTs of the grid interfacing inverter.

3.3 Hysteresis current control

The hysteresis current control (HCC) is the simplest control method available so forth to implement the shunt APF with three phase current controlled VSI and is connected to the AC mains for compensating the current harmonics and the VSI gate control signals are brought out from hysteresis band current controller where a hysteresis current controller is implemented with the closed loop control system and waveforms which are shown in figure 3.

Here a error signal is used to control the switches in a voltage source inverter and the error is the only difference between the desired current and the current being injected by the inverter and when 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 of which the current starts decaying. When the error crosses its defined lower limit of the hysteresis band then the lower switch of the inverter arm is turned off and the upper switch is turned on as a result of which the current gets back into the hysteresis band and the minimum and maximum values of the error signal are emin and emax respectively and the range of the error signal e max -emin directly controls the amount of ripple in the output current from the VSI.

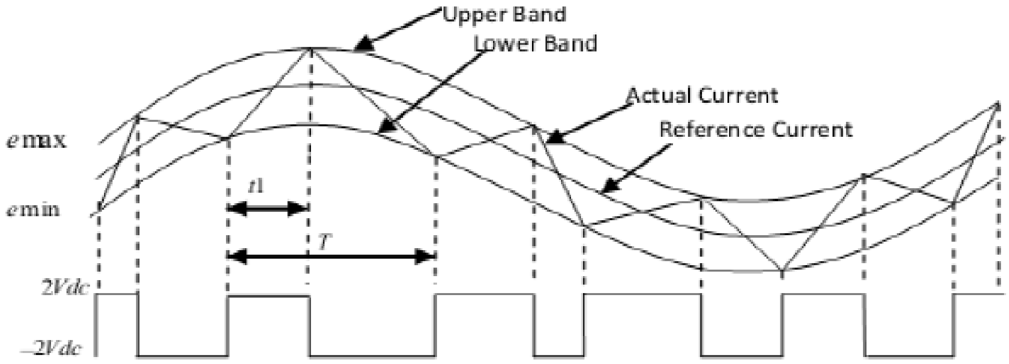

Figure 3Waveform of Hysteresis current controller

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.Here 3 cases are simulated

Case 1: When Balanced load directly connected to grid without RES

Case2: When Unbalanced load directly connected to grid without RES

Case3 : When Unbalanced load connected to grid with grid interfacing inverter control

4.1 System Parameters

- Grid(3 phase supply) in r.m.s Vg=170V(r.m.s),50Hz
- 3 phase load R=26.66Ω
- 1-Phase Non linear Load (A-N) R=36.66Ω ,L=10mH
- 1-Phase Non linear Load (C-N) R=26.66Ω ,L=10mH
- Dc link voltage Vdc =300V
- Coupling inductance Lsh=5 mH
- DC link capacitance Cdc=3000μF

4.2 Balanced load directly connected to grid without RES

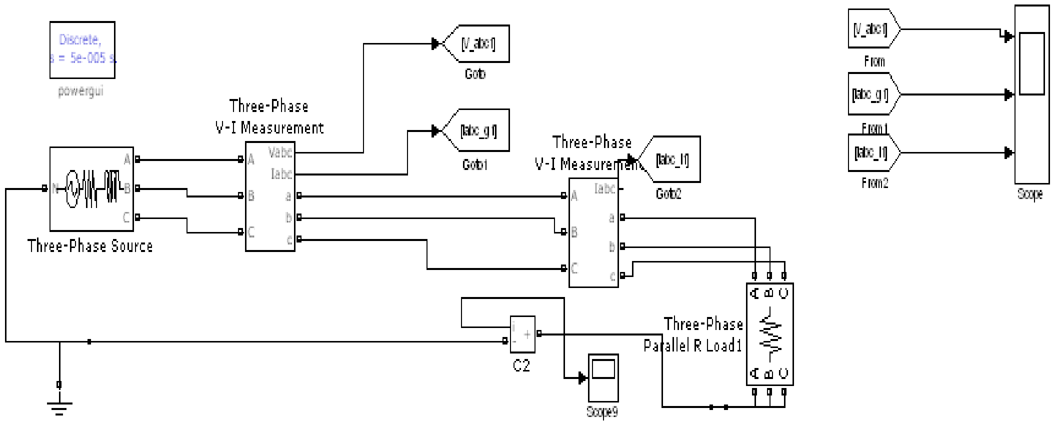

Figure 4. Simulink model when balanced load directly connected to grid without RES

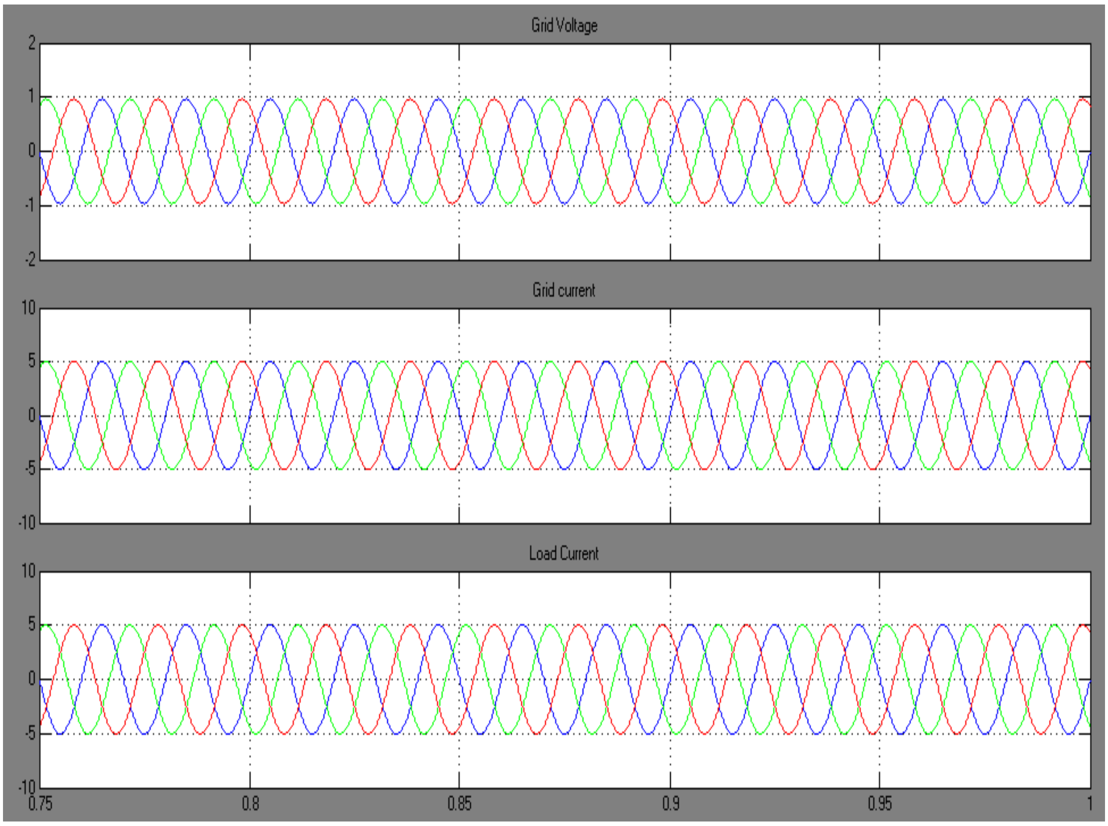

Figure 5. Simulation results: (a) Grid voltages, (b) Grid Currents (c) load currents when balanced load directly connected to grid without RES

The waveforms of grid voltage, grid currents and load current are shown in figure 5. It shows that the grid voltage grid currents and load currents are balanced when balanced nonlinear load connected directly to the grid.

4.3 Unbalanced load directly connected to grid without RES

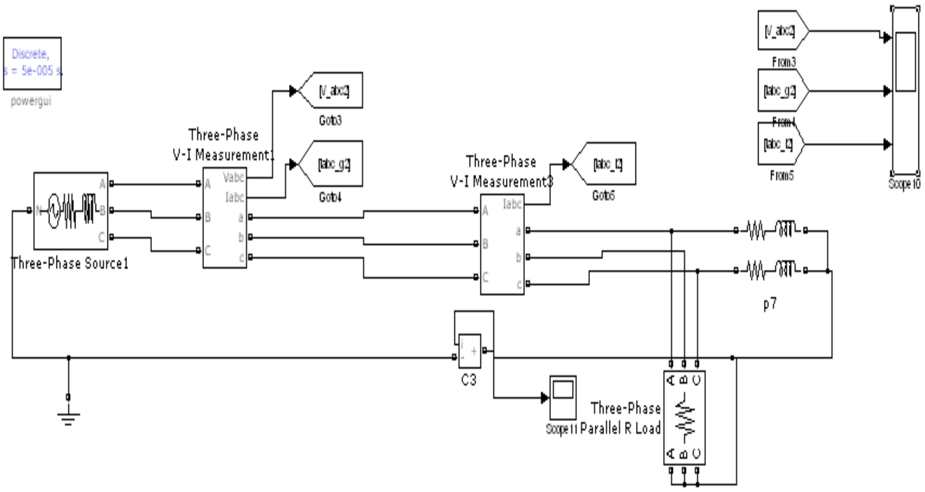

Figure 6. simulink model when unbalanced load directly connected to grid without RES

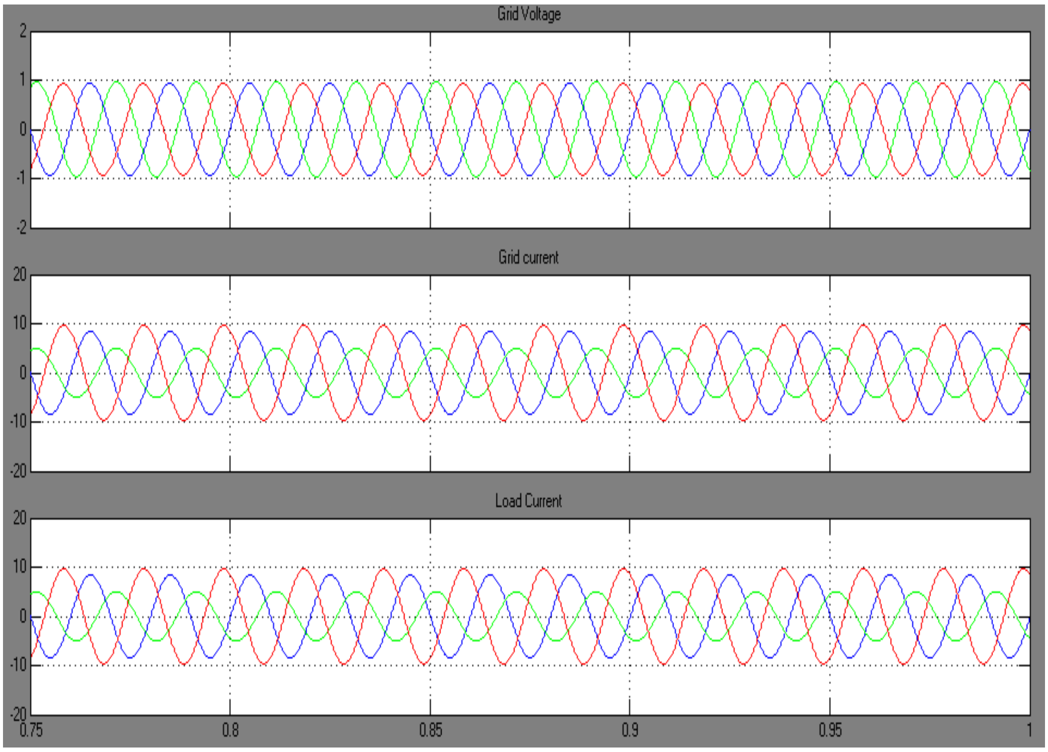

Figure 7. Simulation results: (a) Grid voltages, (b) Grid Currents (c) load currents when unbalanced load directly connected to grid without RES

The waveforms of grid voltage, grid currents and load current when unbalanced load directly connected to grid without inverter are shown in figure 7. It shows that the grid currents and load currents are become unbalanced when a set of 3 phase balanced linear and 1 phase unbalanced nonlinear loads are connected directly to the grid.

4.4 Unbalanced load connected to grid with grid interfacing inverter control

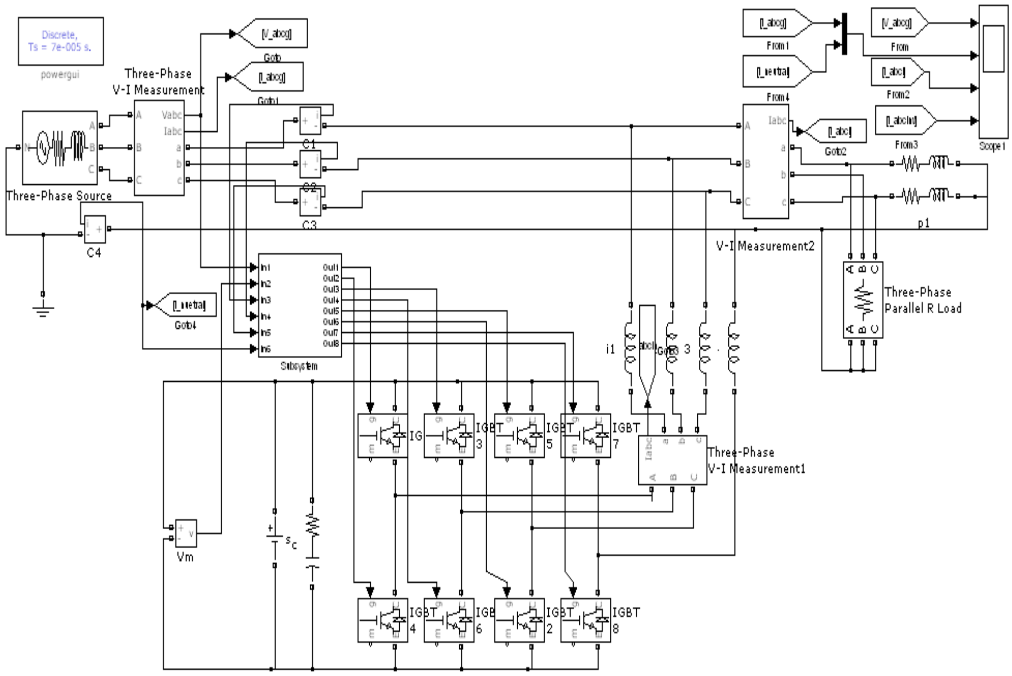

Figure 8. simulink model when unbalanced load connected to grid with grid interfacing inverter control

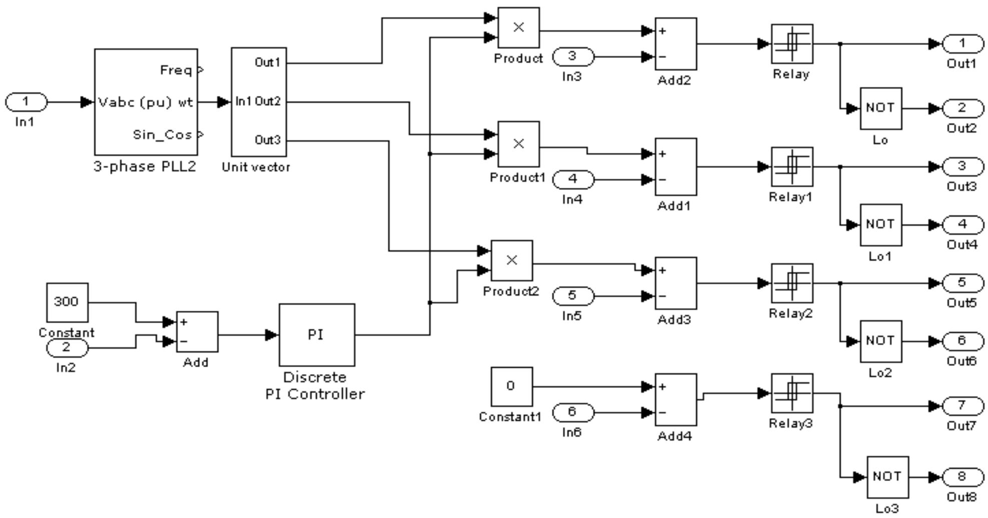

Figure.9 simulink control model when unbalanced load connected to grid with grid interfacing inverter control

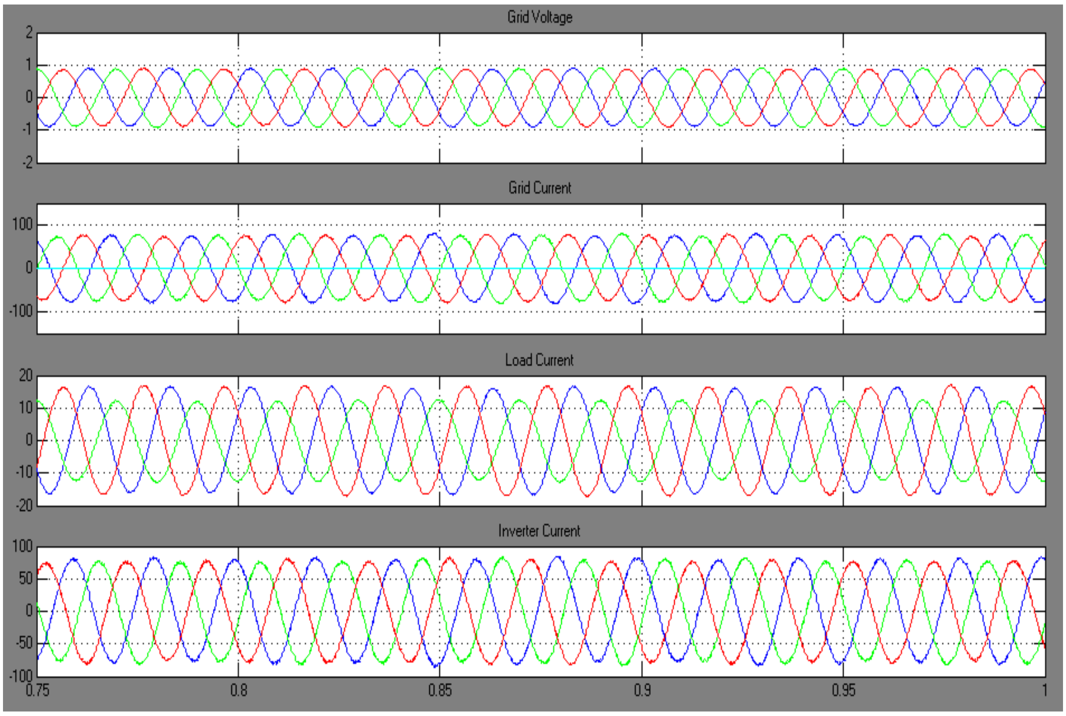

Figure.10 Simulation results: (a) Grid voltages, (b) Grid Currents (c) load currents and d)Inverter current when unbalanced load directly connected to grid with inverter control

The waveforms of grid voltage , grid currents and load current when Unbalanced load directly connected to grid with inverter control are shown in figure 10. It shows that the Grid voltage and grid currents are get balanced when a set of 3phase balanced linear and 1 phase unbalanced nonlinear loads are connected to the grid with grid interfacing inverter control method.. The dc-link voltage across the grid- interfacing inverter during different operating condition is maintained at constant level. Thus from the simulation results, it is evident that the grid-interfacing inverter can be effectively used to compensate the current unbalance and current harmonics.

V. CONCLUSION

This thesis has presented a novel control of an existing grid interfacing inverter to improve the quality of power at PCC for a 3-phase 4-wire DG system. 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 this approach can be utilized to:1)inject real power to the grid, and/or,2)Operate as a shunt Active Power Filter (APF).This approach thus eliminates the need for additional power conditioning equipment to improve the quality of power at PCC. Extensive MATLAB/Simulink simulation results have validated this approach and have shown that the grid-interfacing inverter can be utilized as a multi-function device.

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