Single Phase Grid Synchronization by Load Compensation Using Photovoltaic Generation System

Roopa Nayak H.[1], Ashwini A.[2]

[1]M. Tech scholar, BNM Institute of Technology Bengaluru, India
[2]Assistant Professor, Department of EEE, BNM Institute of Technology Bengaluru-560070, KARNATAKA INDIA

Abstract: **The synchronization with the grid uses Phase Locked Loop (PLL) for finding the angle at which the wave is travelling. Synchronization would help in both the power factor correction and the harmonic reduction due to the load. The load compensation is the way these harmonics are compensated by use of the PLL techniques. The PI controller would be involved with the PLL in the grid synchronization. The dynamic performance of the grid interfacing depends on the PI controller. This paper targets an attempt to develop a PLL less grid interfacing technique, which would be used for the power factor correction and the harmonic elimination. The notch filter algorithm is used to remove a particular amount of frequency from the signal during the signal detection mode before giving it to the current controller, which is used for the power factor correction using the harmonic elimination algorithms. This implementation is carried out with the solar panel as the input with the boost converter supplying the inverter. The Maximum Power Point Tracking (MPPT) controller is used in the boost converter for tracing the maximum power from the solar panel. Perturb and observe method for the MPPT algorithm is used in this implementation. The notch filter output is given as the reference to the PWM generation in order develop a PWM that would reduce the harmonic current effect to the load side, A synchronized wave is generated in the output of the inverter that would be used to be connect to the single phase grid. The Mat lab based simulation of the whole closed loop implementation would be carried and the results are discussed and tabulated.**

Keywords: **MPPT, P&O, Single phase PLL-less, Harmonic Elimination, Boost converter, PCC, PWM, and Notch filter.**

I. INTRODUCTION

The converter based power plants like the Photovoltaic and the Wind based supply are in demand in the near future. And in the single-phase grid, which is used for the domestic purpose, are in the rise in many of the western countries. In order to develop the synchronization of the non-sinusoidal outputs to the sinusoidal grid PLL based methods are used. These PLL based methods generate the angular movement of the wave and get the angle from the actual sinusoidal wave and would try to generate the wave in phase with the grid sinusoidal waves. For this purpose the inverters are used. The solar power will not be always constant, as the irradiation of the sunlight on the solar panel will be varying in terms of the instance in the day and the year. Thus the solar power must be regulated in such a way that the solar power's maximum possible power at that irradiation level must be tapped out by the use of the MPPT controller [1].

The PV grid interfaced systems feeding only active power into the grid are introduced earlier [2]. However, in this project work a multifunctional grid tied VSC is presented. The VSC in this system not only feeds the extracted solar power in to the grid but also works for reactive power compensation and harmonics mitigation for the selected loads. Some of the researchers have proposed solar PV system with active filtering capacity [3]. Two wire and three wire single phase single stages PV system with harmonic filtering capacity uses the control algorithm which is based on load power estimation [6].

The estimated load power consists of second harmonic ripple which are inherent in single phase systems. The estimated load power is then passed through low pass filters for estimation of average value. The cut off frequency of low pass filter is kept low to estimate the dc part however that makes the response sluggish in case of load variation. If second harmonic oscillations are not properly removed, then this cause distortion in reference grid currents. As compared to that the proposed algorithm employs a simple notch filter based strategy and low pass filter is avoided for estimation of load active power component.

II. PROBLEM IDENTIFICATION AND PROPOSED METHODOLOGY

The PLL methods usually used in the grid interfacing methods have always depended on the PI controller that would indirectly be affected by the Kp and Ki values that is the proportional and integral constants. But the fixed constants would be not much helping in the dynamic characteristics of the solar power. The main drawback to the PLL-based clock driver is cost, although some PLLs are priced very competitively with buffer solutions. Due to the complexity of the circuitry and speeds at which the VCO must run, PLLs are expensive. In general, a PLL-based clock driver costs two to five times as much as a gate-based clock driver. This price is based upon the value of the product.So in order to get rid of this a PLL less method has to be developed.

This paper attempts to develop the PLL less more dynamically efficient method that utilizes the concept of notch filter that would remove the harmonic current from the current waveform. These harmonics are to be eliminated by the single phase inverter that would develop a waveform that would eliminate the harmonic in the load side. Thus the pure sinusoidal voltage is generated in the output side. Simpler and more hardware efficient method of MPPT method is P and O method. The reference voltage is guessed in the first perturb stage and the output is observed for the power change and then the new reference voltage is created by the use of the Perturb and Observe (P and O) method in order to track the maximum power form the solar panel.

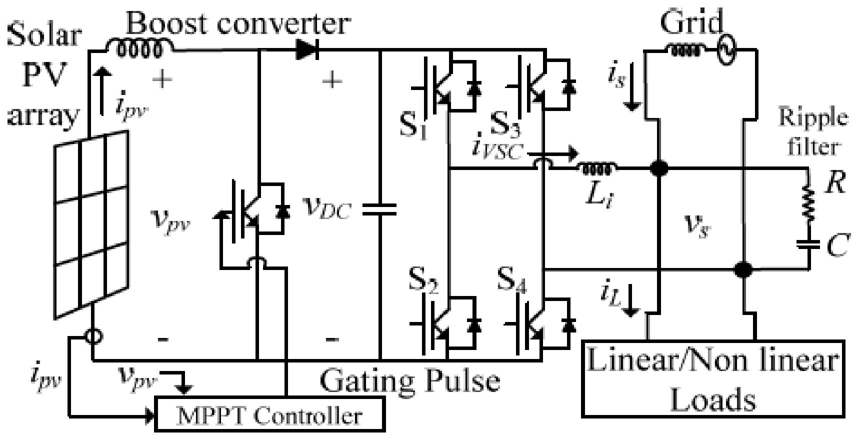

Fig. 1The circuit Topology of the proposed work.

The circuit diagram of the proposed system is shown in figure.1 which is a double stage single phase grid interfaced solar PV generating system having two power stages that utilize power electronic converters to extract the maximum power from the solar PV modules and transfer it to the grid. A series-parallel combination of PV modules is designed according to the rating requirement to form a PV array and this PV array is interfaced with a DC-DC boost converter, in which duty cycle is determined by the P&O MPPT algorithm, ensuring MPP operation. The DC-DC boost converter is interfaced to a voltage source converter (VSC) through a DC link capacitor. The VSC is in-turn interfaced with the power grid, local load and a ripple filter, through an AC inductor at the PCC.

The voltage and frequency of the power grid are considered to be constant. The varying local load can be of both linear and nonlinear type. The system configuration is used to extract the maximum power from the PV array and transfer it to the grid, while compensating the local reactive power demand and eliminating harmonics introduced by the nonlinear local load. The variables 'i_{pv}' and' v_{pv}' are the PV array current and voltage respectively. Current entering the PCC from the VSC is denoted by 'i_{vsc}', where as the grid and load currents are denoted by' i_s' and 'i_L' respectively. The PCC voltage is denoted by 'v_s' as shown in system configuration.

A. P&O Algorithm:

The P&O MPPT algorithm is based on the following criterion: if the operating voltage of the PV array is perturbed in a given direction and if the power drawn from the PV array increases, this means that operating point has moved towards the MPP, and therefore, the operating voltage must be further perturbed in the same direction. Otherwise if the power drawn from the PV array decreases, the operating point has moved away from the MPP and, therefore the direction of the operating voltage perturbation must be reversed.

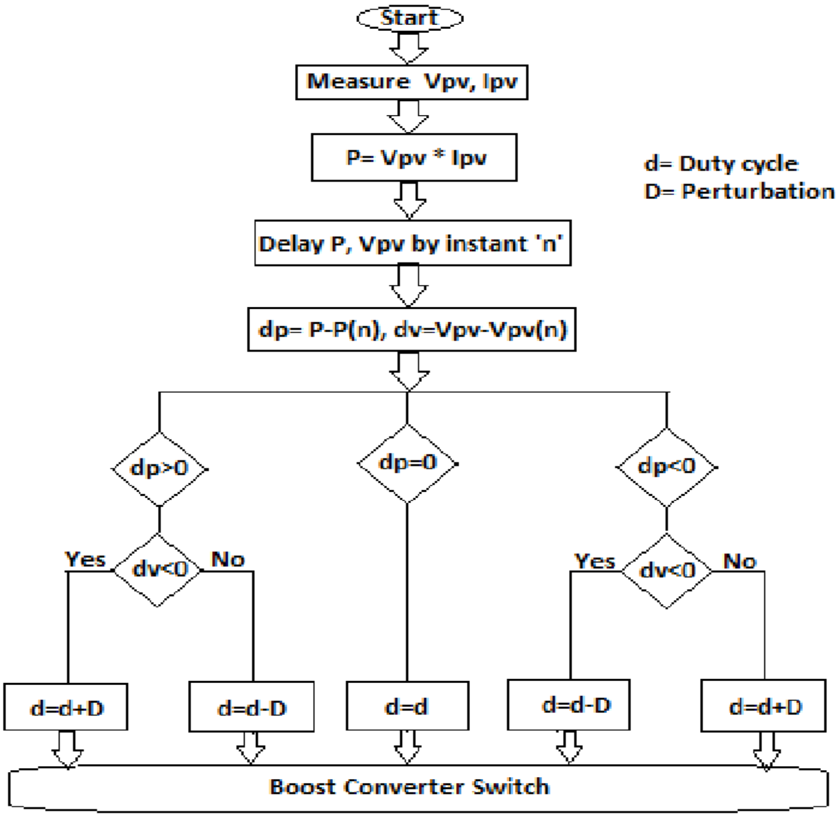

Fig. 2 Flowchart of P&O MPPT algorithm

The governing equations for the MPPT algorithm are as follows The P&O technique involves the deliberate perturbation of PV array output voltage and hence the power parameters before and after the perturbation and arrives at a MPP, which can be explained in detail as follows:

- This is the method where the reference voltage given for the closed loop is adjusted in order to attain the MPP.
- The voltage and current at different instant of time is measured.
- The difference in voltage and current is calculated.
- The difference in power is calculated.
- The change in power is checked for its sign change for current point in the PV curve.
- If difference in power is positive meaning power is increasing, then voltage has to be checked.
- There will be two combinations, one is power increases and voltage reduces another one is power increases and voltage increases.
- From the PV curve for power increases and voltage increases condition then Vref must be increased.
- If power increases and voltage decreases then Vref must be reduced.
- In case power is decreasing then again we have two combination, power decreases and voltage increases and power decreases and voltage decreases.

- If power decreases and voltage increases then Vref must be reduced.
- If power decreases and voltage decreases is occurring then Vref must be increased.

$$D(k)=D(k-1)-\Delta D \text{ if } dP_{pv}>0 \text{ and } dV_{pv}>0 \quad \text{.................................(1)}$$

$$\text{Or } dP_{pv}<0 \text{ and } dV_{pv}<0$$

$$D(k)=D(k-1)+ \Delta D \text{ if } dP_{pv}>0 \text{ and } dV_{pv}<0 \quad \text{.................................(2)}$$

$$\text{Or } dP_{pv}<0 \text{ and } dV_{pv}>0$$

Where ΔD is the perturbation in the duty ratio.

B. VSC control block:

The VSC control block generates the switching pulses for controlling the VSC using an indirect current control scheme. The magnitude of real component of load current is derived using a notch-filtering based scheme, zero crossing detector (ZCD) and a sample and hold (S&H) logic. While the loss component of the VSC is determined using a proportional-integral (PI) controller. The estimated reference current is synchronized with the grid voltage using the unit template of the PCC voltage, to ensure unity power factor operation of the system.

The following equations gives the values of in-phase component of load current and magnitude of the real component of load current as;

$$i_{La}=I_m \sin(\omega t-\phi) \quad \text{……………………………………..(3)}$$

$$i_{La}=I_m \sin(\omega t)\times\cos(\phi) - I_m\cos(\omega t) \times \sin(\phi) \quad \text{……………………………………..(4)}$$

$$[I_m \sin(\omega t-\phi)]_{\cos\omega t=0} = I_{Lp} = I_m \cos(\phi) \quad \text{……………………………………..(5)}$$

Where ωt is angle of PCC voltage measured from positive zero crossing and ϕ is the fundamental phase difference between PCC voltage and load current. Absolute value of ‘ i_{La}’ for all instances when‘$v_{s\beta}$’ is zero is calculated to find the magnitude of the real component of load current. The ‘$v_{s\beta}$’ and ‘$v_{s\alpha}$’ values are determined using a notch filtering scheme. To calculate a unit template, ‘u_v’ which is required for synchronization of reference current with the grid volage, the amplitude of PCC voltage is calculated according to following equation,

$$V_{sp}(k)=\sqrt{v_{s\alpha}^2(k)+v_{s\beta}^2(k)} \quad \text{……………………………………………..(6)}$$

$$u_v(k)= v_{s\alpha}(k)/V_{sp}(k) \quad \text{……………………………….................. (7)}$$

The DC link voltage of the VSC is maintained at a predetermined voltage level using a PI controller. This facilitates active power transfer from the PV array and also determines the losses of VSC. The PI controller generates compensating current signal as,

$$i_d(k)=i_d(k-1)+K_P[e_{dc}(k)-e_{dc}(k-1)]+K_I[e_{dc}(k) \quad \text{……………………………………..(8)}$$

$$e_{dc}(k)=v^*_{dc}(k)-v_{dc}(k) \quad \text{…………………………...................(9)}$$

where ‘K_P’ and ‘K_I’ are proportional and integral gains of the PI controller respectively, and v^*_{dc} is the reference voltage for PI controller.

C. Notch filter:

A tunable notch filtering system is designed to extract in-phase, harmonics free component of load current, and both the in phase and 90° out of phase components of the PCC voltage.The derrived transfer function pertaining to notch filtering scheme can be written as,

$$G(s,\theta) = h(t) / u_{in}(t) = s^2 + \theta^2/ s^2 + \zeta\theta s + \theta^2 \quad \text{…………………(10)}$$

Notch filtering system has a mechanism to vary the θ value corresponding to a change in the grid frequency but design of such system is highly complicated and has a greater calculation burden. Since the grid frequency for proposed system is almost constant, the simple tunable notch filtering system with a low calculation burden is chosen over the adaptive notch filter.

III. SIMULINK MODEL OF THE PROPOSED SYSTEM

A PV array with 50 cells in series and 40 such series in parallel is used at the input side which gives irradiation of 1000w/m^2. A MPPT technique is used to get maximum output voltage from PV array, for this a program code is written in MPPT block using P&O algorithm. Boost stage of the circuit is constructed by using a IGBT in parallel with the RLC branch and a diode according to the basic design of the boost converter. A PWM generator is used to generate pulses for the converter which is kept at a carrier frequency of 50Hz. This construction forms the converter which is used to amplify the amount of input voltage so that a higher value of voltage is obtained for further analysis.

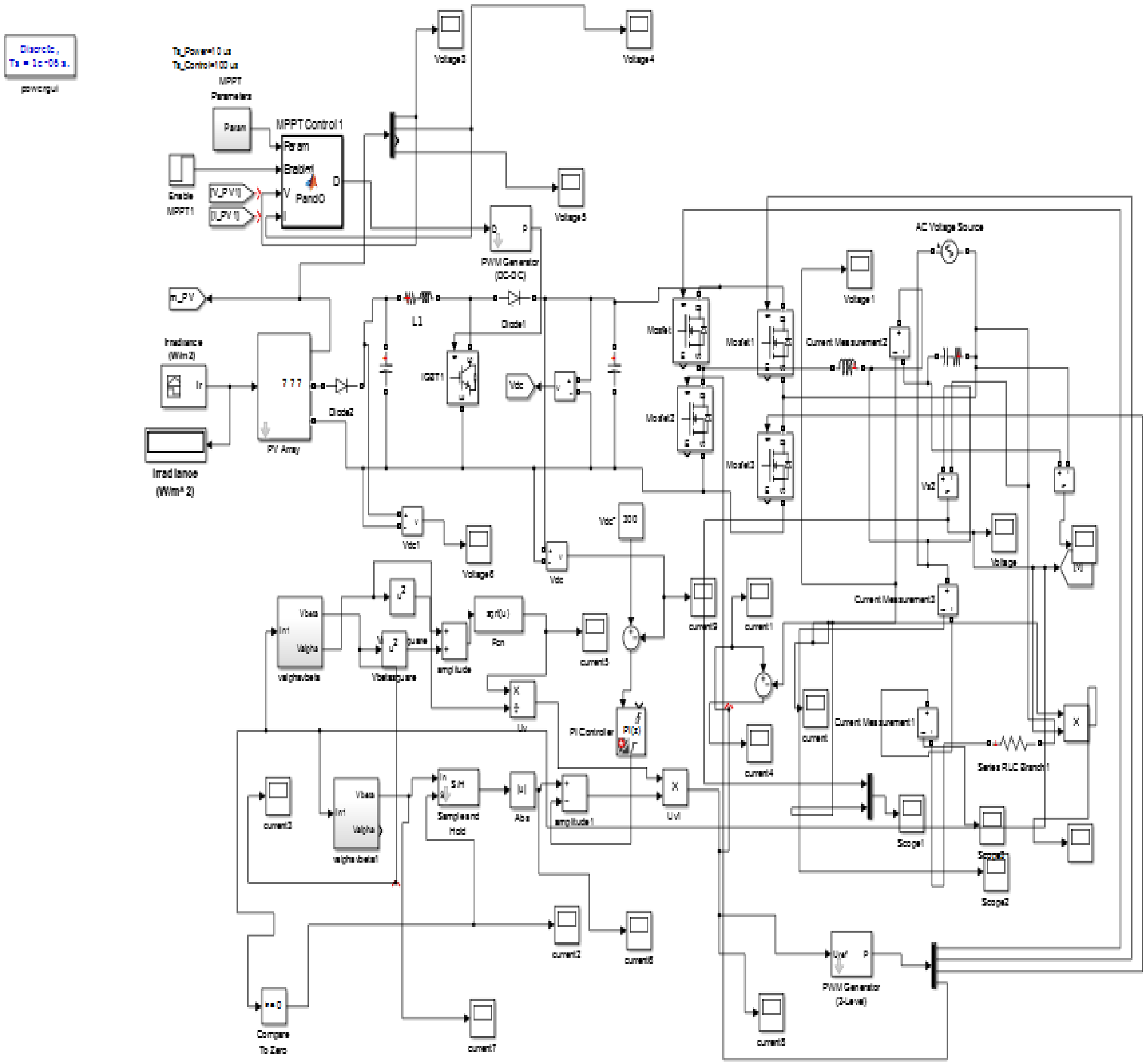

Fig. 3 Simulation model of the proposed system for linear load

An arm with capacitor is implemented parallel to boost converter construction to filter out any ripples in the circuit. Since design is closed loop system the measured quantity is compared with a reference value and fed to the PI controller which further triggers the MOSFET in case of negative signal. The single phase inverter is implemented which has two arms and use the MOSFETs and diode for internal construction of the bridge. A VSC control block generates switching pulses to trigger the MOSFETs of the inverter circuit.

The single phase measurement block is used to obtain the output voltage and current. AC voltage source is connected in place of a grid for the measurement of harmonics. In place of local loads a resistor and a bridge rectifier is used for linear and non-linear loads respectively. Current and voltage labels are used to find out the output and scopes are used at particular points to analyse the complete circuit. The voltage signal obtained is split up using a de-multiplexer. This forms the complete simulation model of the proposed work.

IV. SIMULATION RESULTS AND ANALYSIS

The proposed system is simulated using MATLAB software to verify the operation. The switching frequency is fixed at 10 kHz. Since we eliminate the use of line frequency transformer at the inverter output terminal and there by reduced additional power losses.

A. Linear load: The system has been tested under linear load and the values of various variables have been recorded. The PCC voltage (v_s), grid current (i_s) and THD of grid current 'i_S' values are obtained and are shown in figure 4.1, 4.2 and 4.3 respectively. The grid side power is negative with DPF of -1 which shows that power is being fed into the grid at unity power factor. It can be seen that the harmonics content in grid current 'i_s' is within the specified IEEE-519 standard (below 5%). The load current waveform and its THD content for linear load are shown in figure 4.4 and 4.5 respectively.

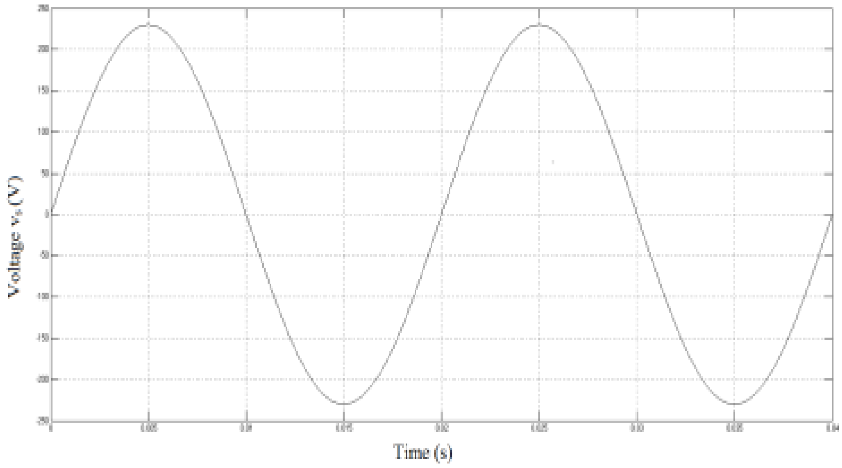

Fig. 4.1 PCC voltage (v_s) for linear load.

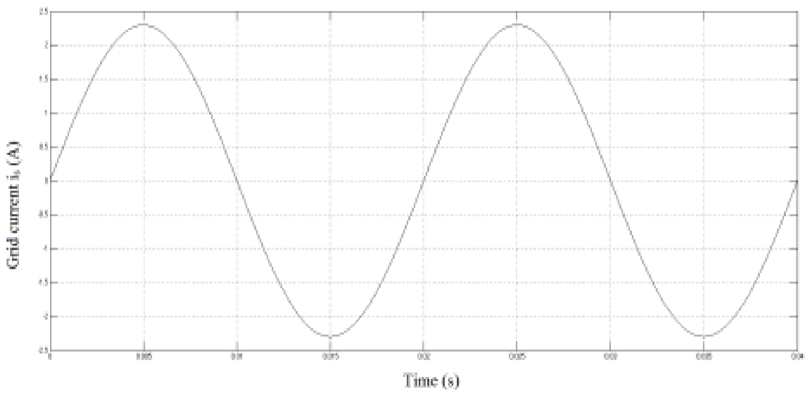

Fig. 4.2 waveform of grid current i_s for linear load.

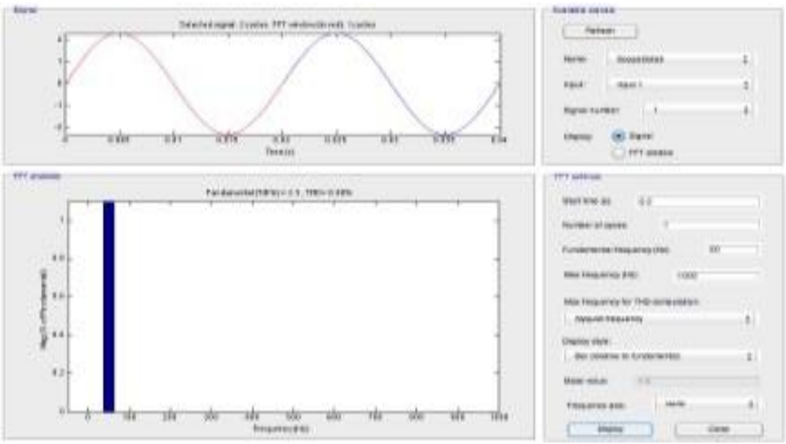

Fig. 4.3 Harmonic spectrum of grid current i_s for linear load.

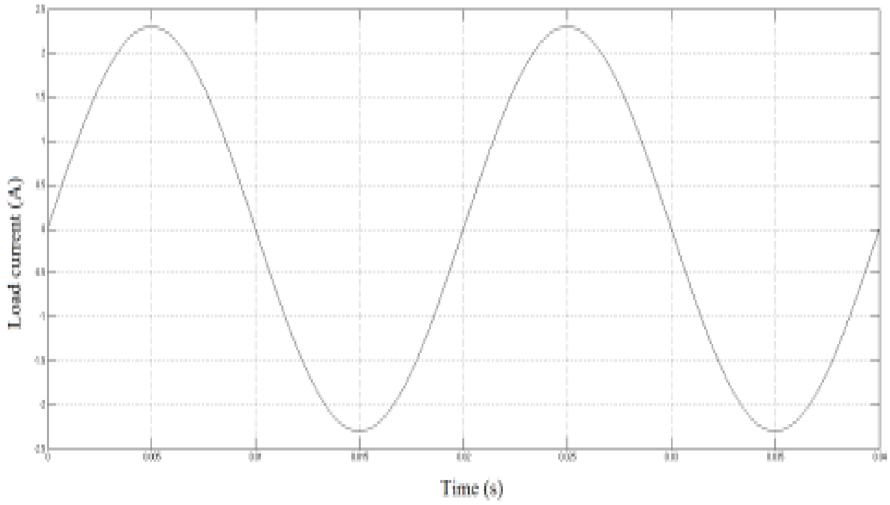

Fig. 4.4 waveform of load current i_L for linear load.

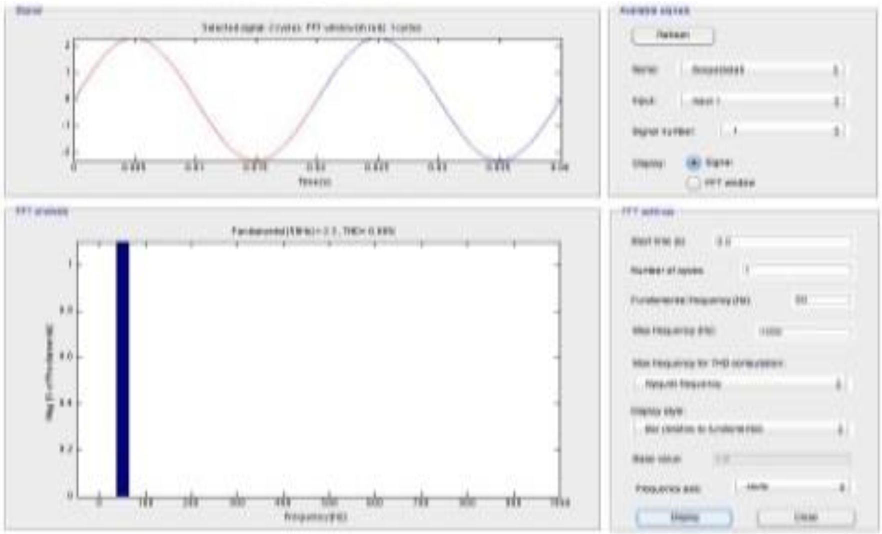

Fig. 4.5 Harmonic spectrum of load current i_L for linear load.

A. Non-linear load: The system has been tested under nonlinear load and the values of various variables have been recorded and presented. The simulink model for nonlinear load is shown in figure 5.8 with bridge rectifier as non-linear load. The grid current (i_s), PCC voltage (v_s) and THD content of grid current i_s are shown in figure 4.6, 4.7 and 4.8 respectively.

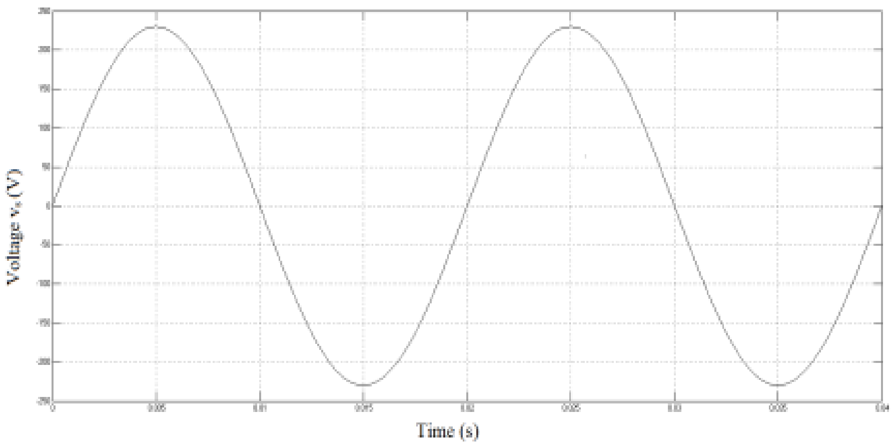

Fig. 4.6 PCC voltage for non-linear load

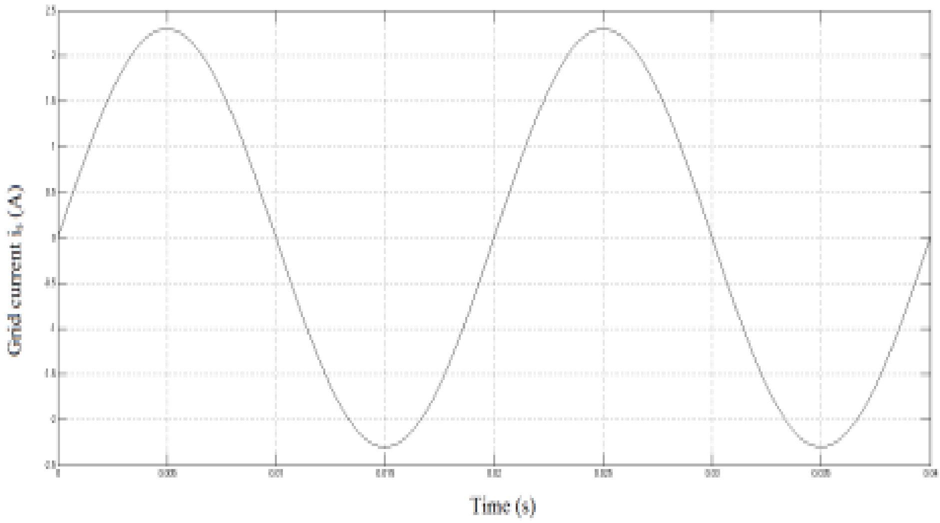

Fig. 4.7 waveform of grid current for non-linear load.

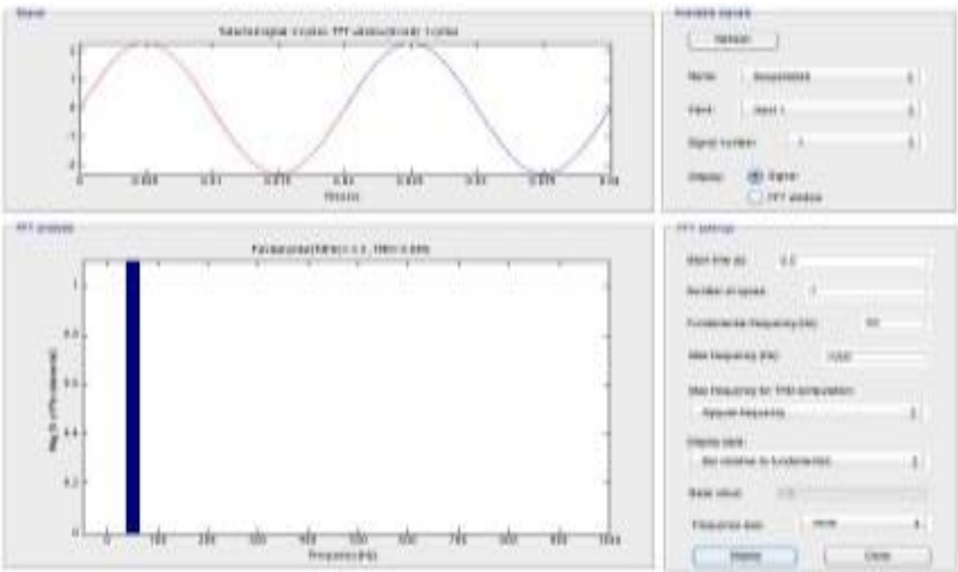

Fig. 4.8 Harmonic spectrum of grid current i_s for non-linear load.

The waveform of load current i_L and the THD content of load current for non-linear load are represented in figure 4.9 and 4.10 respectively

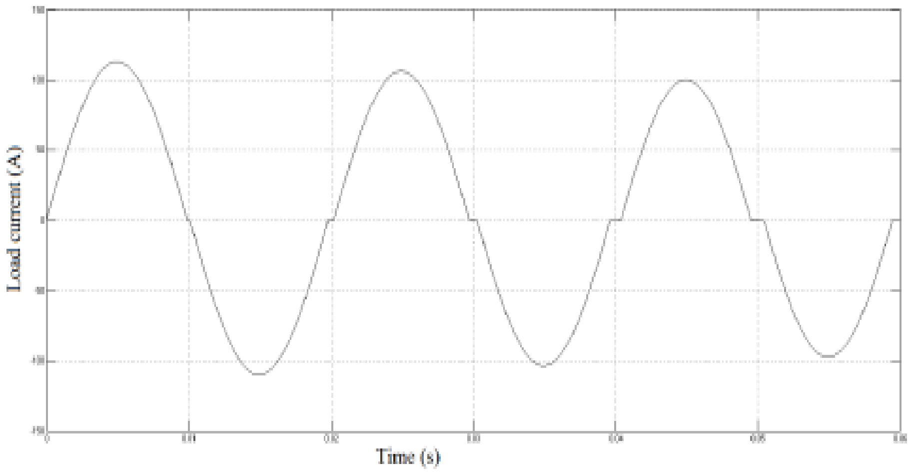

Fig. 4.9 Load current i_L of non-linear load

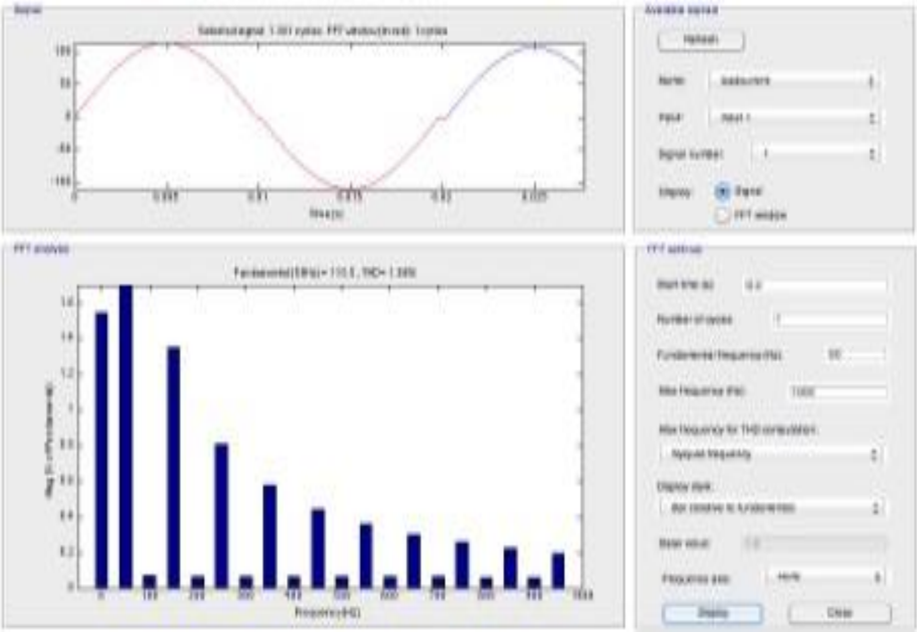

Fig. 4.10 Harmonic spectrum of load current i_L for non-linear load.

The PV output voltage and current values remains the same for linear and non-linear load which is represented in figure 4.11 and 4.12 respectively. The figure 4.13 represents irradiation level in W/m^2 for linear load and non-linear load connected at grid side.

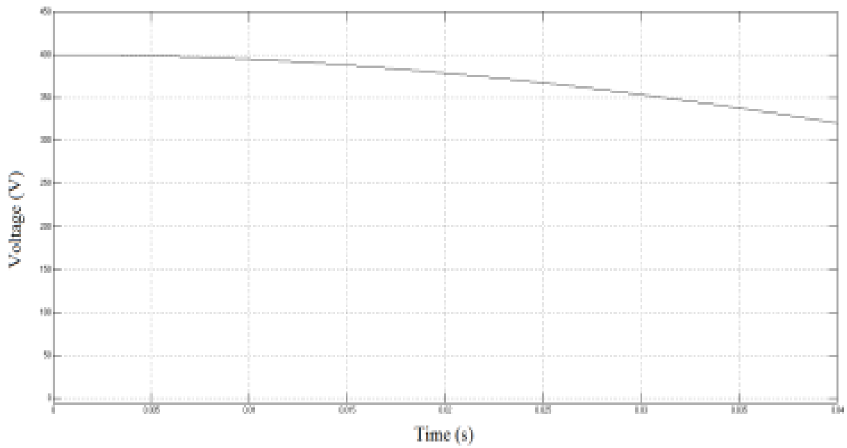

Fig. 4.11 PV output voltages.

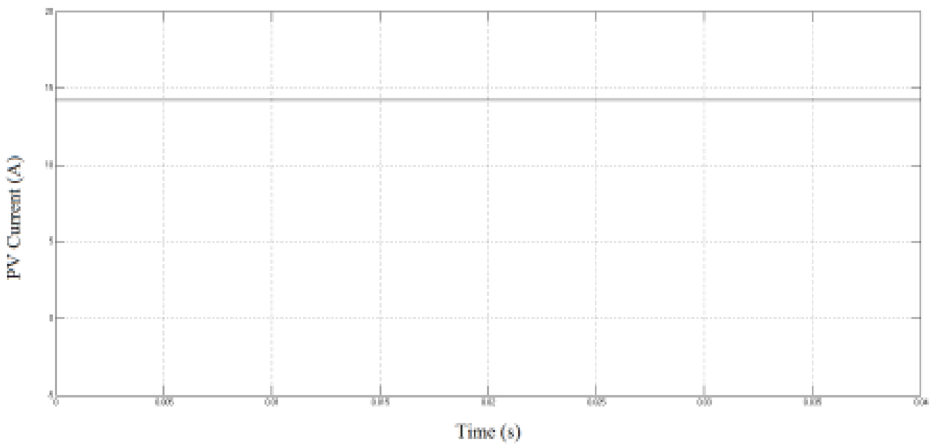

Fig. 4.12 PV output current for non-linear load.

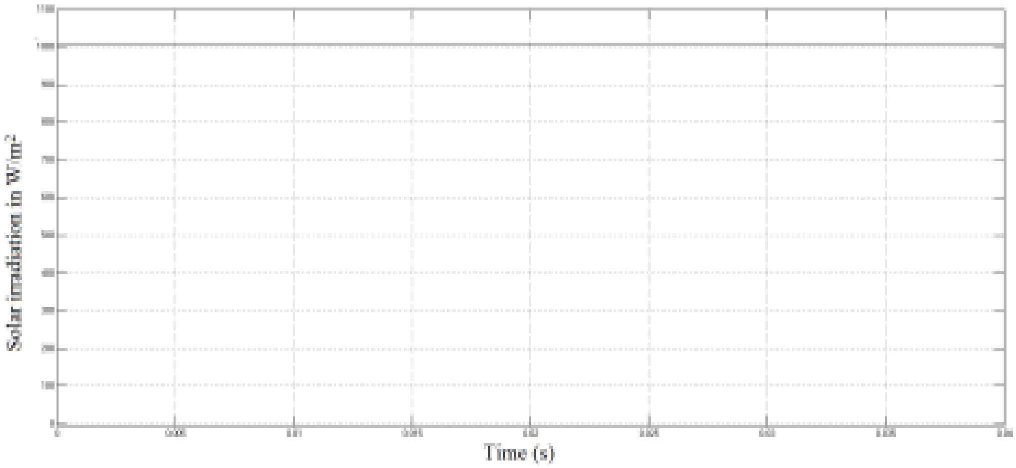

Fig. 4.13 Solar irradiation levels in W/m^2

V. CONCLUSION

The ability of this scheme has been validated to (a) generate correct duty cycle for control of DC-DC boost converter, (b) maintain a constant DC-link voltage, (c) extract the magnitude of real component of load current and (d) generate a reference current using the extracted unit template of PCC voltage. The scheme has performed these operations without dependence on PLL mechanism, and with a low calculation burden. As a result, the system has been found to extract the maximum power from solar PV array for varying solar radiation levels. It has also compensated reactive power demand of both linear and non-linear local loads, while bringing down harmonics content of grid current in accordance with IEEE-519 standard. The system has ability of active power filtering despite the absence of solar irradiance (cloudy day/ night time).

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