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REVIEW OF GRID CONNECTED PV ARRAY USING P&O MPPT ALGORITHM

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ABSTRACT
The renewable energy is becoming more mainstream and accessible. This has been made possible due to an increase in environmental awareness coupled with the popular demand to cut back on the greenhouse emissions. We in this project propose a grid connected PV system. The aim of the project is to implement a complete distributed energy resource system (DER). The project will feature a PV module, which will be controlled and optimized by means of a maximum power point tracking (MPPT) algorithm. A boost converter along with a single phase grid tie inverter will be used to increase the output voltage and to convert it to AC. A phase locked loop circuit will be used to integrate the single phase inverter with the grid. A control methodology consisting of PI controllers is employed for operating the PV at the MPPT point by controlling the switching of the boost converter and also for the operation of the single phase inverter and its integration with the grid. The parameters of these controllers are tuned to give the best results. This will be followed by a detailed mathematical and engineering analysis for the simulated results. The validity of the proposed scheme will be verified by simulation using the PSIMsoftware.

Index Terms - Boost converter; Maximum power point tracking system (MPPT); Perturb and Observe algorithm (P&O); Phase Locked Loop (PLL); Photovoltaic (PV) system;PSIM.

INTRODUCTION
Several countries have vowed to reduce their carbon footprint for which the necessary legislation is already underway amongst several developed and developing countries. The use of renewable resources to power load and the integration of such resources with the conventional grid infrastructure is becoming an increasingly popular alternative to the conventional employed power plants which primarily run on fossil fuels and thus leave a major carbon footprint which is harmful to the ecology of the environment. As the countries have already started to take an action toward addressing the threats to overcome the climate change and energy crisis, the share of clean energy has seen an upward surge in recent years. Many of the countries have come up with a strategic plan suitable to their needs to cut down their carbon footprint and to overcome their energy needs by innovative, creative and sustainable solutions. One of the ways to increase the share of renewable energy is to invest in solar energy. Solar energy is considered as the most popular source of renewable energy because of its round the clock availability during the day, easy commissioning, decreasing costs and increasing efficiency. The output power produced by the photovoltaic modules is intermittent in nature and depends on the intensity of solar radiation and temperature of solar cells [1]. As the efficiency of the commercially available solar cells is low, it is important to track the maximum power point. For this purpose different algorithms employing MPPT are used. Using MPPT not only ensures that the output voltage of the PV is regulated, but also ensures that the PV is operated at the maximum power point. Different MPPT methods have been presented in literature [2], [3], [4], [5]. In this paper we implement the Perturb & Observe (P&O) algorithm for the MPPT in which the voltage is slightly perturbed in the direction of the increasing power to find the MPPT point. A Dc-Dc boost converter

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not only increases the input voltage, but also ensures that the PV is operated at the MPPT point which is achieved by controlling the switching of the boost converter afterwards a singlephase grid tied inverter is used to convert the DC input into AC. We also employ a low pass filter in order to remove the high frequency harmonics which are an impediment to our grid integration. The Grid integration with the PV module is achieved by implementing a Phase Locked Loop circuit. All of these converters and circuits require a significant degreeof control and tuning to serve their intended purpose for these case PI controllers are used and are accordingly properly tuned to give the bestresults.

I. SYSTEMCONFIGURATION

The configuration of the grid connected PV is shown in Fig. 1 in which the PV is connected to the DC-DC converter which will work to control dc output from unregulated dc input by adjusting duty cycle. The DC-DC boost converter is controlled using PWM which is done by varying the duty cycle for the boost converting this duty cycle is generated by the P&O MPPT algorithm. A single phase inverter will then be used to convert photovoltaic DC voltage into line frequency AC voltage. A Sinusoidal Pulse Width Modulation (SPWM) switching control is designed to control the inverter [6]. The switching frequency of the boost converter and the grid tie single phase PWM converter is chosen to be 30 kHz. The employed scheme also ensures that the DC-link voltage remains stable without varying rapidly thus ensuring a smooth system operation. A Phase Locked Loop (PLL) was also designed to synchronize the inverter with the grid voltage. Finally L filter was connected between the inverter and the grid to fulfill the standard specifications of current harmonics injected to the grid [7]. The inductor offers high impedance to high frequency signals and low impedance to low frequency signals, therefore its series connection suppresses the AC ripples making it act as a low pass filter.

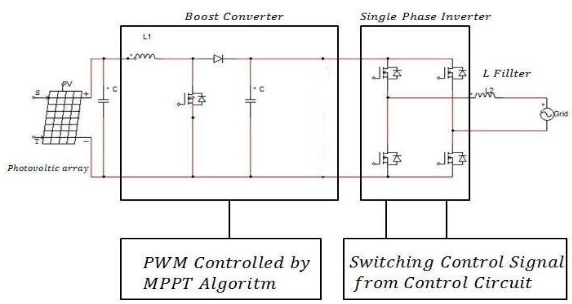

Fig.1. Block diagram of grid-connected PV farm.

II. SYSTEMMODELING

A. PV

The PV array was modeled in PSIM using six identical solar Solarex MSX-60 PV panels which were connected in series to form a solar array. The parameters used for modeling the array are shown in Table 1. The characteristics of PV module are shown in Fig. 2, in which the relationship between the electrical power, voltage and current is illustrated by constructing the PV and IV curves of the solar array. The simulations were performed at a constant temperatureof25°Cattwodifferentirradiationvaluesof 25 °C at two different irradiation values of 800 W/m2 and 1000W/m2 to observe the MPPT response of the system when responding to a change in the irradiation which has a direct impact on the power generated by the solar module.

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Table 1: Solar Module Parameters

Specification	Value
Number of Cell (N_s)	216
Maximum Power (P_{max})	360 W
Voltage at P_{max}	102.6 V
Current at P_{max}	3.5 A
Open-Circuit Voltage (V_{OC})	126.6 V
Short-Circuit Current (I_{SC})	3.8 A
Temperature coeff. of V_{OC}	-0.38 %
Temperature coeff. of I_{SC}	0.065 %

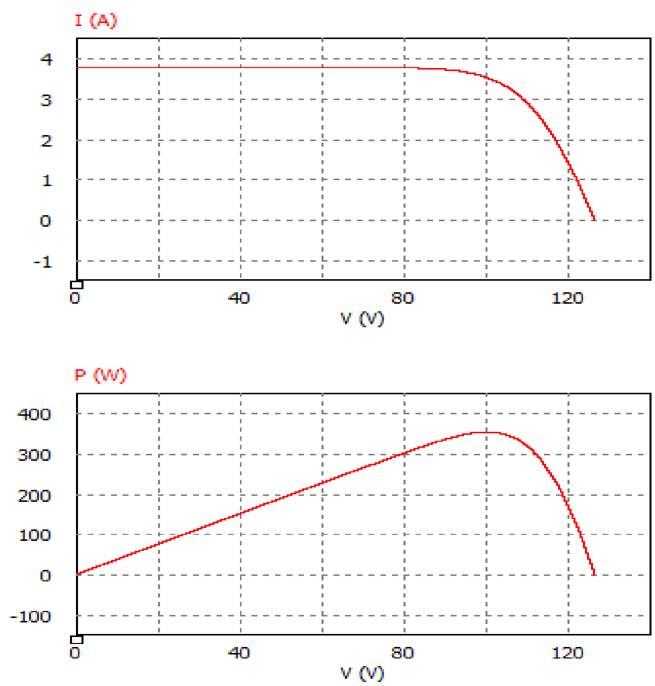

Fig. 2. PV & IV Characteristics of the PVpanel

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B. DC-DC BoostConverter

The boost converter as shown in Fig. 3 is one of the most essential component of the system as it controls the dc output from the unregulated dc input by adjusting its duty cycle.The converter ensures that our system`s output voltage will be higher than Dc-Dc converter`s input voltage. The structure of boost converter consists of a combination of an inductor and a capacitor, when converter`s switch is open the voltage sum across these elements gives the converter`s boost voltage [8]. The duty cycle of the converter is given by equation 1 [1]. Using this expression the desired output voltage can be obtained by adjusting the converter`s dutycycle

$$D = 1 - \frac{Vin}{Vout} \qquad (1)$$

where D is the duty cycle; Vin is the input voltage; and Vout is the output voltage.

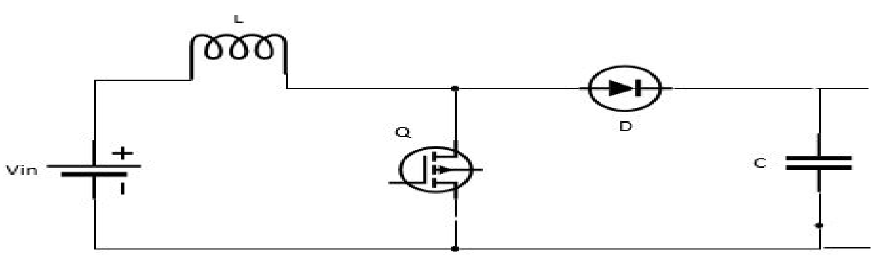

Fig. 3. BoostConverter

C. Single PhaseInverter

The single phase DC-AC inverter is a power electronics device which converts low voltage direct current (DC) into the standard alternating current (AC) forAC loads i.e. 120/240 V AC, 50/ 60 Hz. For system stability it is essentialthat the inverter produces power of a similar quality to that of the main electricity grid. Inverters can be widely classified, one of these classifications is based on the arrangement of the power electronic switches i.e. – Half Bridge Inverter and Full bridge inverter. In this paper the full H-bridge single phase inverter will be used. This topology consists of power electronic switches which are fed with constant amplitude pulses of varying duty cycle for each period. The SPWM pulses are generated by comparison of two waves- a carrier wave, which is a triangular wave and a modulating reference sinusoidal wave. Single phase inverter is characterized by a simple circuitry and a rugged control scheme which employs the conventional SPWM technique in order to obtain inverter output voltage control as well as to reduce its harmonic content [9].

Fig.4showsthe structure of the single phase inverter, in which it will operate asfollow:

- When S1 and S2 are turned on +VAB is obtained at the output
- When S3 and S4 are turned on –V AB is obtained at theoutput
- When S1 and S3 or S2 and S4 are turned on together, zero voltage is obtained at the output

D. Phase Locked Loop (PLL)

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A conventional phase locked loop as shown in Fig. 5 consists of three primary units namely phase (error) detection unit (PD), a loop filter and a voltage controlled oscillator (VCO) [10]. The phase detector measures the phase difference between the input and the output signal. The obtained phase error then passes through the loop filterwhich extracts the DC component from the phase error. This obtained DC component is then amplified and passed onto the VCO which consists of a PI controller which generates the frequency of the output signal, which is onwards passed through the integrator resulting in the phase angle of the output signal, this phase angle is afterwards extracted from the PLL loop and is used for the generation of the grid current reference signal[12].

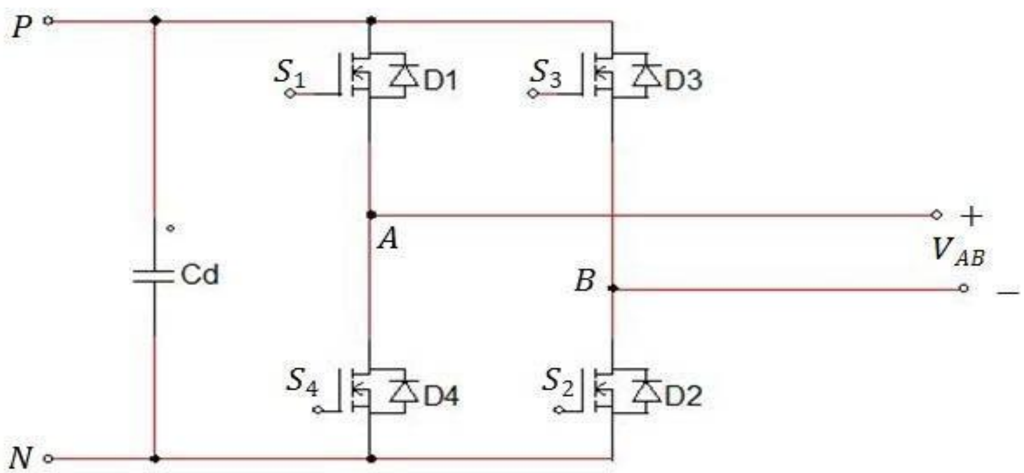

Fig. 4. Single Phase Inverter

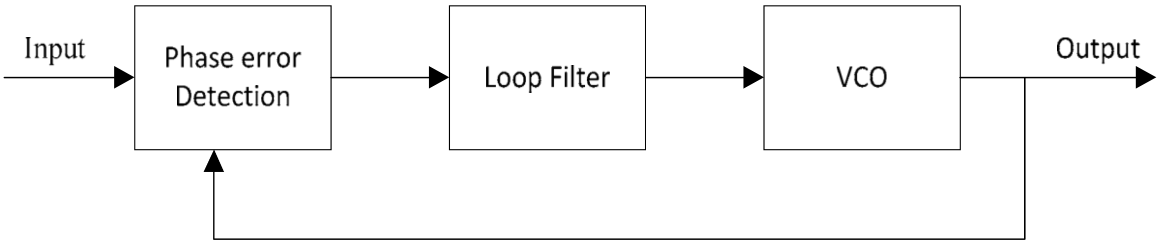

Fig. 5. Phase Locked Loop Conventional Structure

III. SYSTEMCONTROL

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A. MPPT control of boostconverter

Current–voltage (I–V) characteristic of a PV depends on the intensity of the irradiation & the temperature. Temperature influences the PV output voltage while solar irradiance affects PV output current. There is a maximum power point (MPP), at which the array operates with the highest efficiency. Based on the impedance matching principle the power output of a circuit is maximum when the source impedance matches with the load impedance. The MPPT algorithm does this impedance matching byadjusting the duty factor D of the DC-DC converter. The input and output impedances are related by the followingexpression

$$R_{in} = (1- D^2)\ R_{load} (2)$$

Where *D is* the duty cycle; *Rin is* the PV impedance; and *Rload* is the load impedance

In this paper we use the P&O algorithm for MPPT. The principle of this approach is that it will perturb the reference voltage by observing the system response to determine the direction of the next perturbation. The reference voltage perturbations are performed in the direction in which the power should increase. Fig. 6 shows the P&O principle.

The control circuitry consists of two PI controllers which have an integral gain of 100 and a time constant of 0.1 tuned by trial and error, the reference voltage is being fed into the first PI controller, which is being employed for the voltage control and drives the PV system voltage towards the MPPT voltage. This is followed by another PI controller which acts as a current controller and drives the system current towards the MPPT current. The output of the control loops is fed to the comparator which generates the PWM to drive the boost converter ensuring that the system operates at the desired maximum power point. Fig. 7 shows the control block diagram for the boost converter.

B. Phase Locked Loop for single phasesystem

The Phase Locked Loop (PLL) control subsystem is oneof the essential component of grid connected inverters as it plays a key role in synchronizing the inverter with the grid`s voltage, frequency and phaseangle.

ThestructureofthePLLusedinthispaperisshowninFig.8. The input signalto the PLL is a unit sinusoidal voltagewaveform denoted as Asin (0_i) where A denotes a unit value.
The voltage error, V_{err} is written as

$$v_{err} \square A\sin(\square_i)\cos(\square_e) \square \sin(\square_e)\cos(\square_e) \qquad (3)$$

Here 0_i is the input phase angle & 0_e is the estimated phase angle. It can be noticed from (3) that when the estimated phase angle tracks the actual one ($0_e \div 0_i$) at unity amplitude in per unit the V_{err} approaches zero, this is known as the frequency/phase locked condition. Moreover, the PLLsystem canstillworkwelleveniftheamplitudeisnotequalto1[11]. The PI controller employed for the PLL has been tuned using trial & error for an integral gain of 80 and a time constant of 0.1.

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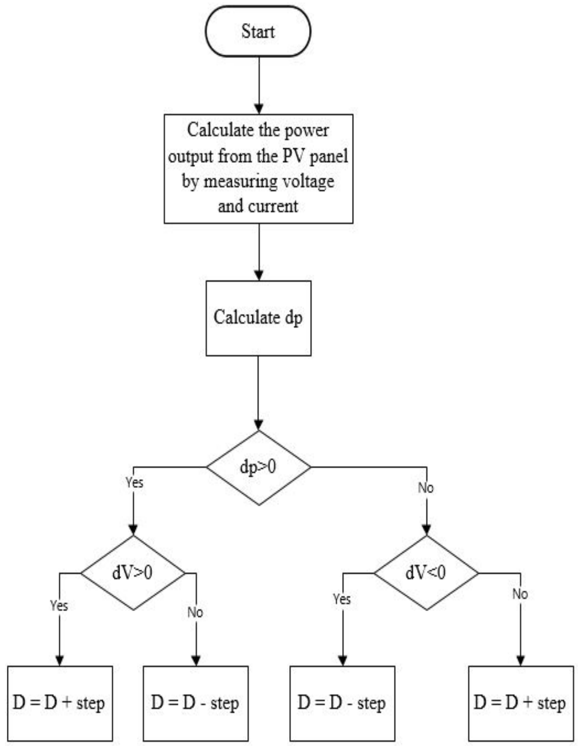

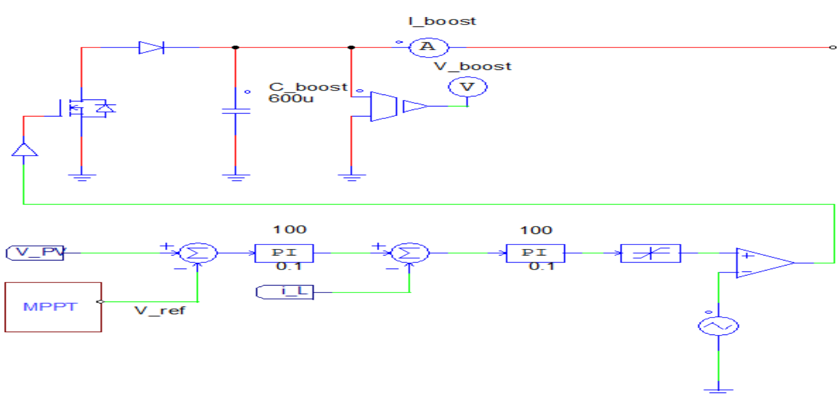

Fig. 7. Control block diagram boost converter

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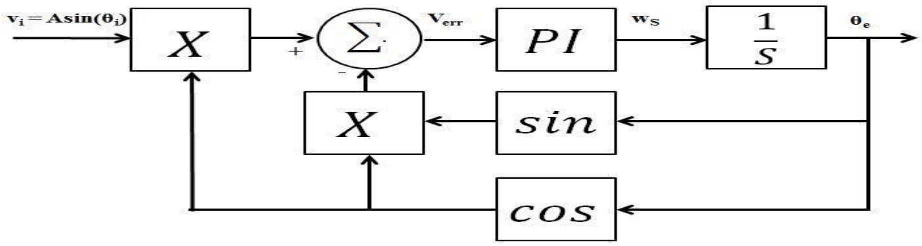

Fig. 8. Modified PLL Structure

C. Control scheme of single-phase grid-tieinverter

A grid-tie inverter is a power inverter which converts direct current (DC) electricity into alternating current (AC) and has the ability to synchronize and interface with the utility grid. Its primary application involves convertingDC sources such as solar panels and integrating AC sources such as small wind turbines with utilitylines.

The inverter used in our application delivers the power from the PV to the grid via the boost converter, where the dc link voltage ensures that there are no power losses. The process involves extracting the fundamental component of the line voltage and feeding it to the phase locked loop, which detects and outputs the phase angle 0_e. The sine of the angle 0_e is multiplied with the amplitude of the grid current I^* this gives us the reference grid current I^*. The amplitude of the grid current depends on the reference power P^* which corresponds to the power which we get from the employed P&O MPPT control scheme. This grid current amplitude is calculated by

$$I^*_{amp} = \frac{2\,p^*_t}{E_{mag}} \qquad (4)$$

E_{mag} here is the fundamental component of the grid voltage, which in our case is rated to be 110 V. Now that we have 0_e and grid current amplitude $I^*$the grid current reference is givenby

$$I^*_g = I^*_{amp}\sin(\theta_e) \qquad (5)$$

A PI regulator is employed for the grid current control, with Ig^* providing the reference current and the gridcurrent being fed into the PI controller by means of the feedback loop. The output of the controller acts as the reference signal. This reference signal is compared with the triangular wave rated at 1V peak to peak and 30,000 Hz to generate the PWM which drives the grid tied single phase inverter. The control diagram for the single phase inverter is shown inFig.9.

The PI controller employed for the single-phase grid-tie inverter has been tuned using trial & error for an integral gain of

120 and a time constant of 0.1.

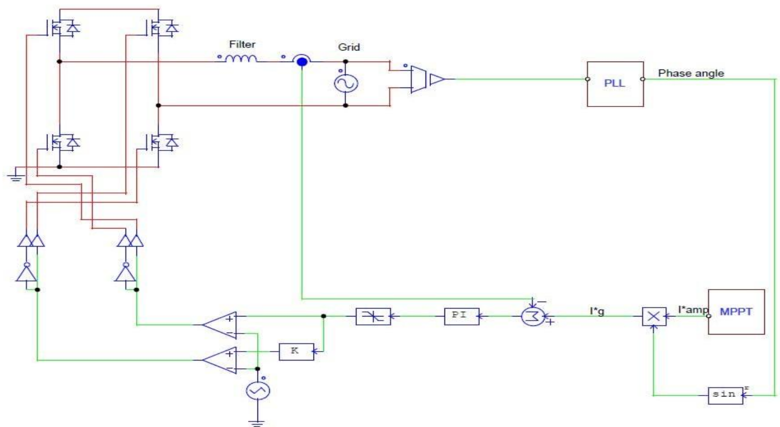

Fig. 9. Control diagram of single-phase PWM converter

SIMULATIONRESULT

The PSIM simulation for the 360 W solar PV systems was carried out in order to verify the validity of the system and the employed control schemes. The system parameters used for performing the simulations are listed in Table 2. The system control was optimized by configuring the controller parameters and by employing the P&O MPPT scheme.

Table 2. SYSTEM PARAMETERS (SIMULATION)

No.	Parameters	Value
1	Power of PV system (including 6 solar panels 60Wp)	360 Wp
2	PV array Output Voltage	100 V Dc
3	Output voltage of Boost converter	150 V Dc
4	Output Voltage of Single Phase Inverter	150 V Ac
5	Switching frequency of the converters fs	30,000 Hz
6	PV array Capacitor C in	60 uF
7	Boost Inductor L boost	3.5m
8	DC Link Capacitor	600 uF
9	L filter	5m
10	Grid rating	110 V, 60 Hz

Fig. 10 shows the transient and steady state response of the voltage and current output of the PV array, from the results we can see that the output voltage of the PV panel settles down at 100 V while the current value changes depending on the irradiation. Fig. 11 corresponds to the irradiation values usedinthesimulationsi.e.800W/m^2 and1000W/m^2.Fig.12 shows maximum output of the PV array in blue and corresponding MPPT response of our system in red which shows that MPPT

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algorithm has been successfully implemented and precisely follows the maximum output powerofthePVarrayforthegivenirradiationvalues& temperature. Fig. 13 shows the output of the boost converter and we can see that the boost circuit successfully increased the input voltage from 100 V that is the output of the PV array to 155 V. Fig. 14 (a) presents the rated grid voltage which is rated at 110V and 60 Hz, Fig. 14 (b) corresponds to the 2nf output of the PI controller in the phase locked loop and Fig. 14 (c) shows the frequency output which after an initial transient settles down at a steady state value of 60 Hz. Fig. 15 shows the output of the phase locked loop angle 0e in blue which is the phase angle and will be used for the computation of the reference grid current. From the figurewe can see that the phase angle perfectly tracks the unit sinusoidal input which is shown in red. Fig. 16 (a) shows the outputvoltageofsingle-phasegrid-tieinverterandFig.16

(b) shows the corresponding grid current which gives a perfect sinusoid, this shows that the PV system has been successfully integrated with the grid which is rated at 110 V & 60 Hz. Fig. 17 shows the circuit diagram for the full system which has been implemented in PSIM showing the PV module, Dc-Dc boost converter, P&O MPTT algorithm, single phase grid tie inverter and the employed control schemes for the MPPT control via Dc-Dc boost converter, single phase inverter & the phase locked loop (PLL) for synchronizing the single phase inverter with the Gird.

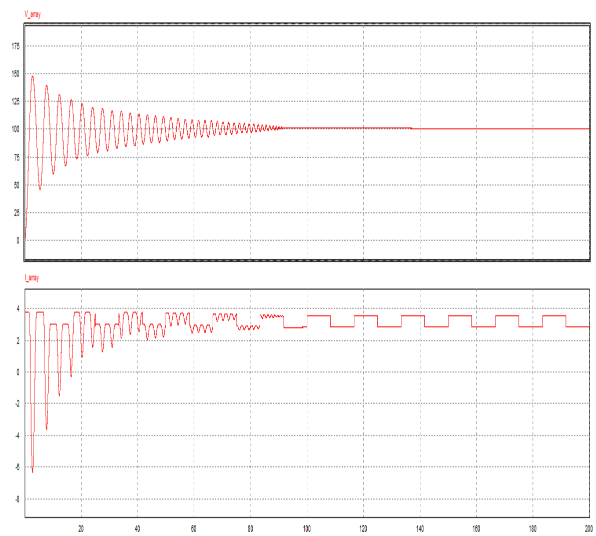

Fig. 10. (a) PV array voltage (b) PV array current

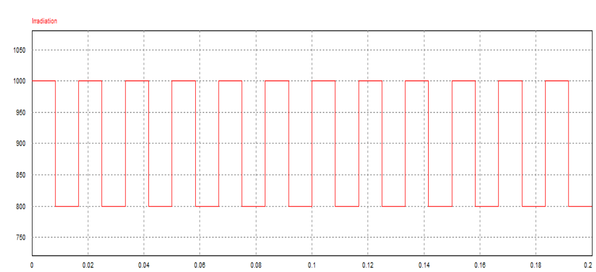

Fig. 11. Irradiation (W/m2)

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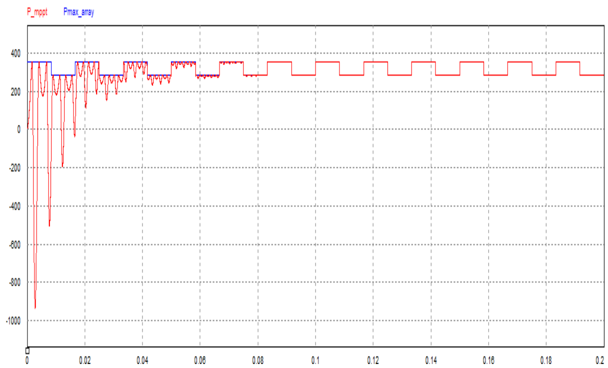

Fig. 12. Maximum PV array power (blue) & the MPPT response (red)

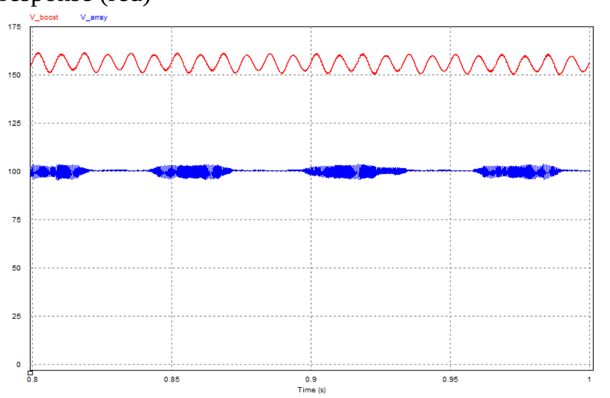

Fig. 13. Boost converter Output Voltage (red) (b) Boost converter Input Voltage (blue)

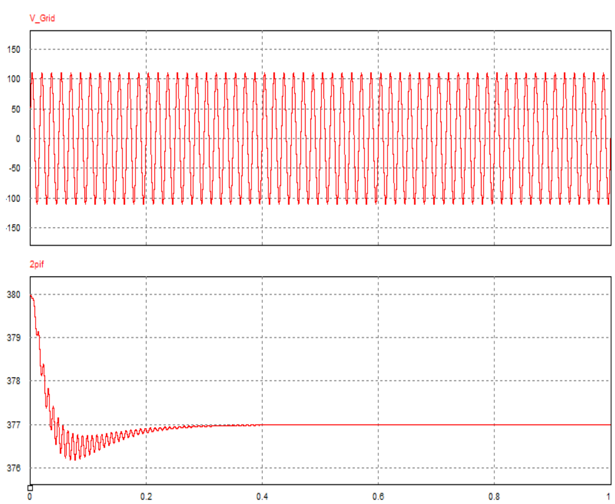

Fig. 14. (a) Grid Voltage, (b) 2nf Frequency (Hz) of output signal in PLL

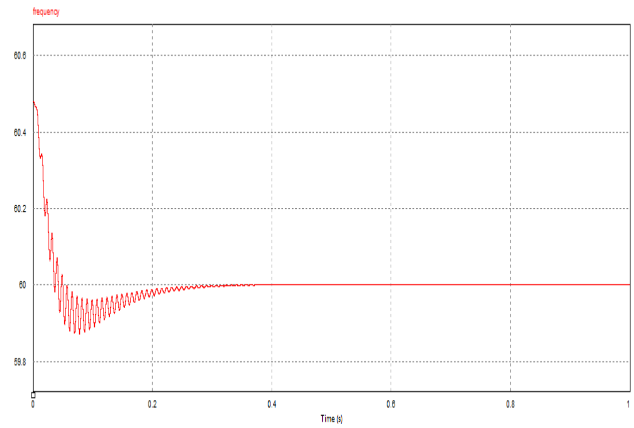

Fig. 14. (c) Desired Frequency

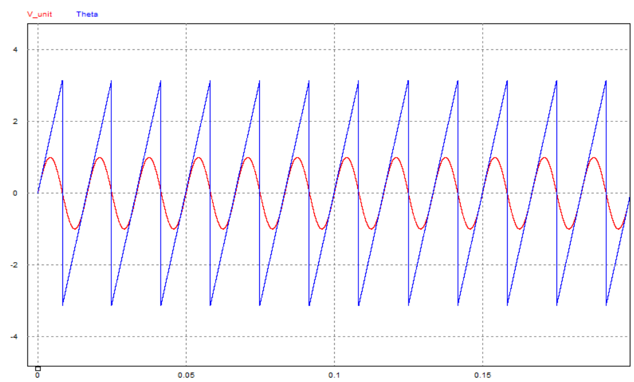

Fig. 15. Phase angle (blue) successfully tracking the Sinusoidal unit input

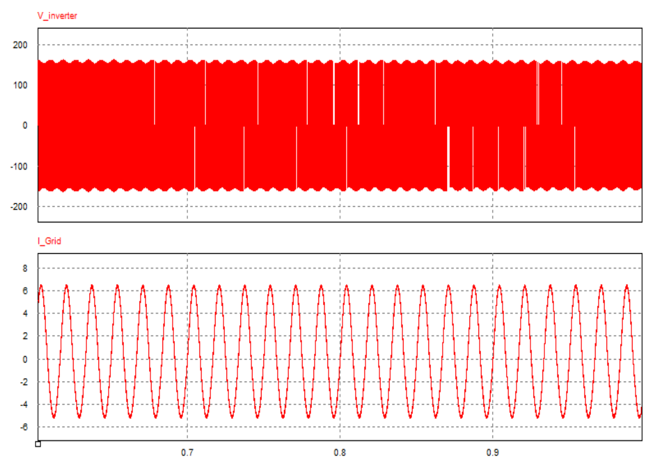

Fig. 16. (a) Inverter Output Voltage (b) Grid Current

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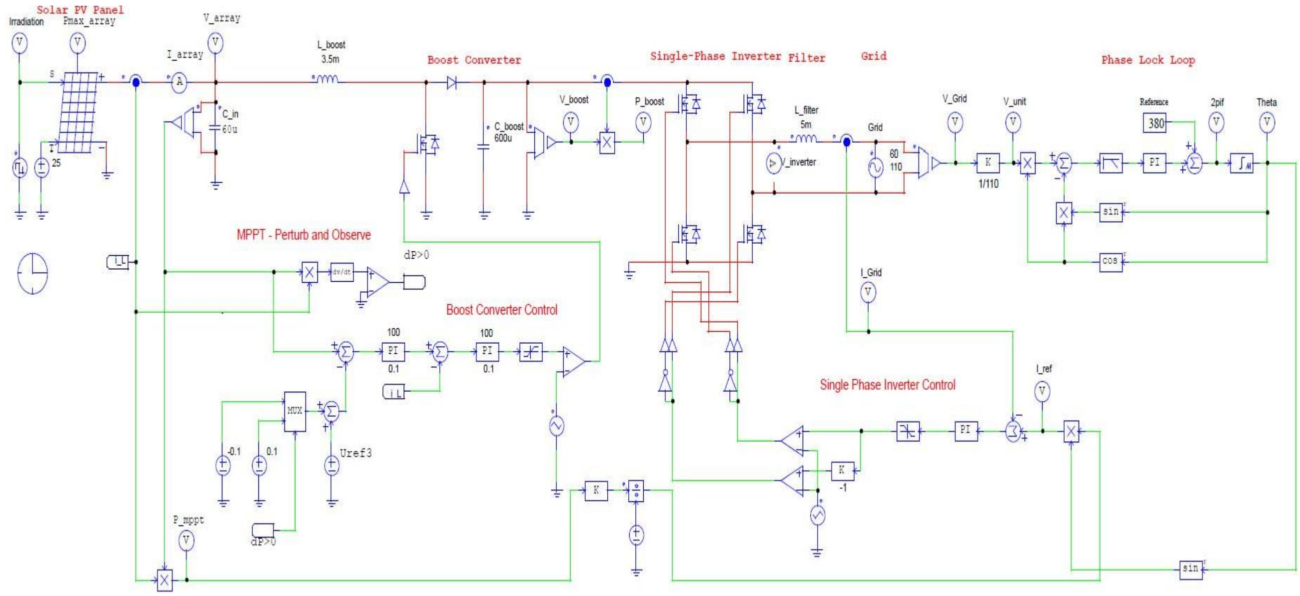

Fig. 17. PSIM Simulation Grid connected PV system

CONCLUSION

A grid connected PV system was successfully implemented; the effectiveness of the system was confirmed by the simulation results in PSIM which gave a perfect sinusoid for the grid current. The system was also successfully operated at the MPPT point by applying the P&O based MPPT algorithm. Control schemes were applied for the single phase inverter, boost converter and the PLL. Control scheme for the MPPT was applied by controlling the duty cycle for the boost converter. The single phase inverter was also successfully synchronized with the grid by using the phase locked loop.

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