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An Efficient Approach of Extracting Maximum Power from PV Cell under Partial Shading Condition

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Abstract: The Perturb & Observe (P&O) algorithms are widely used in control of MPPT due to their simple structure and reduced number of necessary measured parameters. This algorithm has the drawback that after reaching the maximum power point its starts deviating continuously all the time resulting in substantial amount of power loss at maximum power point. Although this algorithm is quite simple to implement and requires only one voltage sensor, the cost of implementation of this algorithm is low. On the other hand the Incremental Conductance (IC) method has the advantage over the Perturb & Observe as it does not oscillate around the maximum power point under rapidly varying environmental conditions. The disadvantage of the Perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by INC method. The INC can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V Increment size determines how fast maximum power point is tracked. Fast tracking can be achieved with bigger increments but the system might not operate exactly at the maximum power point and oscillate about instead. This method has complex circuitry, accuracy of the method depends on the iteration size, which is usually fixed for the conventional incremental conductance method

In this paper the proposed scanning MPPT adjusts the duty cycle corresponding to the global maxima. The power obtained from the proposed controller is higher and non-oscillatory around the MPP compared to P&O and INC controllers which fails under partial shading condition when multiple peaks come into play. The scanning technique algorithm determines the maximum power delivering capacity of the panel at a given operating condition and controls the PCU to extract the same from the PV panel.

Keywords: PV Panel, MPP, Boost converter, VSI & SPWM

I. INTRODUCTION

The highest efficiency of a commercially available solar panel is about 14–19%. So, the utilization efficiency of a panel should be improved by extracting the maximum power available under all operational conditions dynamically. This can be done by using a maximum power point tracking (MPPT) controller. There are many MPPT algorithms that have been proposed and compared with the known methods. The most widely used are perturb and observe (P&O) and incremental conductance (INC) algorithms. These algorithms provide good results for stable and slow varying irradiation and temperature changes. A major drawback of these algorithms is that the system oscillates about the MPP and fails under partial shading condition, when multiple peaks come into play. The INC method is a bit more sophisticated and gives a stable MPPT compared to P&O but holds well as long as dP/dV provides the accurate measure of the distance from the maximum power point for slow changes in irradiation. There is always a trade-off between accuracy and speed. PV installation in urban regions led to a new problem called shading. Shading effects are detrimental to efficiency since it diminishes the output power drastically.

The shading problem arises due to the presence of clouds, dust, trees or any other obstacle in the path of the sun's irradiation. These obstacles give rise to non-uniform irradiation incidence on the PV panel. Many algorithms were proposed to find the MPPT under shading condition in order to avoid the local maxima of the power while tracking the global maxima corresponding to the irradiation condition. The power delivered by a non-uniformly shaded PV array at the global maximum is always lower than the sum of individual PV modules maximum power delivering capacity at that particular incidental irradiation. Generally, the solar cells in a PV module are arranged in series and their different series and parallel configuration give rise to the PV system. The connection of PV cells in parallel to overcome the effects of shading proposed in is only suitable for low power systems

The output characteristics of PV module depends on the solar irradiance, cell temperature and output voltage of PV module. Since PV module has nonlinear characteristics, it is necessary to model it and simulate for Maximum

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Power Point Tracking (MPPT) of PV system applications. A PV module generates small power, so the task of a MPPT in a PV energy conversion system is to continuously tune the system so that it draws maximum power from the solar array regardless of weather and load conditions. The limitation of PI controller is observed in tracking maximum power point during variable environmental conditions. The PI controller increase complexity of system. In this work direct control of duty cycle using MPPT technique is explored.

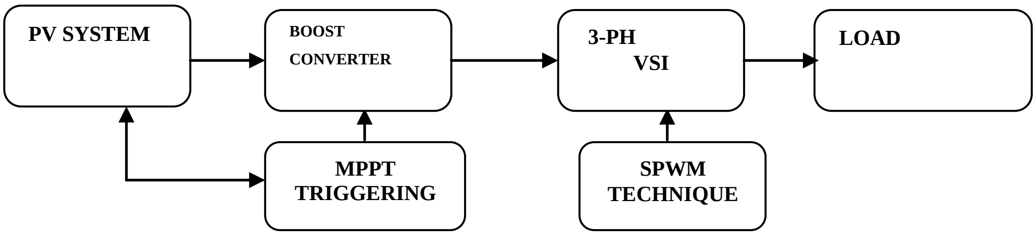
II. METHODOLOGY

The scanning process is implemented under any given operating condition ($V_{pv} > 0$), by closing the switch S of the boost converter and setting the duty cycle (D1) to 1. This results in short circuiting of the PV panel current path I_{pv} through the boost inductor L_{boost} and switch S. Due to this, the panel voltage V_{pv} tends to 0 V and current I_{pv} increases to the short circuit value I_{sc} A. But this does not happen immediately because the inductor L_{boost} does not allow the sudden change in current and the capacitor C_{pv} does not allow the sudden change in voltage. The time taken for the voltage to drop and current to rise will be in the order of milliseconds (ms) for any PV panel.

During this scanning time the voltage V_{pv} and current I_{pv} are measured and the corresponding power P_{pv} is obtained by taking the product of these two values. The maximum value of the power $P_{\mathbf{MAX}}$ during the scanning is obtained by applying a peak detector for the P_{pv} signal and the voltage V_{MP} corresponding to $P_{\mathbf{MAX}}$ is obtained by triggering a sample and hold circuit. The PV panel is scanned, means the switch S remains in the closed state till the voltage of the panel V_{pv} reaches the V_{sc} limit indicating the scanning of the PV curve and extracting the global MPP in case of shading where multiple peaks come into play.

III. HARDWARE APPROACH

3.1 Block Diagram:



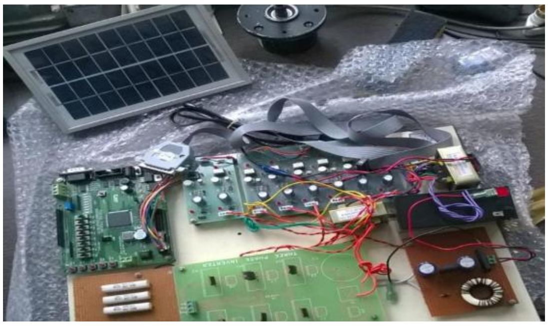


Fig: Total hardware kit

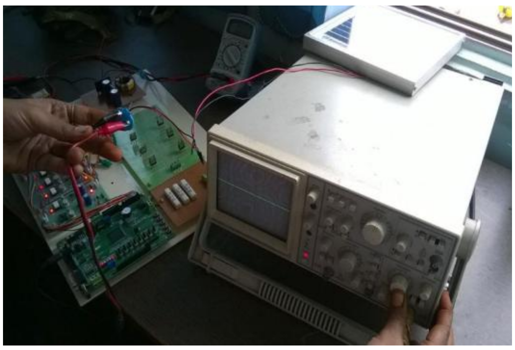


Fig:PV panel output waveform

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- *3.1.1* Current, voltage and power curve *:*

A Current (I) versus Voltage (V) Curve of a PV / Solar Module shows the possible combinations of its current and voltage outputs.

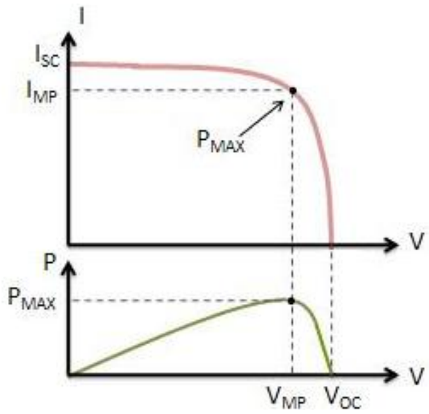

Fig: Location of MPP on curves

A typical I-V curve for a 12 V Module is shown in Fig above. The power in a DC electrical circuit is the product of the voltage and the current. Mathematically, Power (P) in Watts (W) = The Current (I) in Amperes (A) X the Voltage (V) in Volts (V) i.e. W=VXA

A Solar Panel / (PV) Cell or Module produces its maximum current when there is no resistance in the circuit, i.e. when there is a short circuit between its Positive and Negative terminals. This maximum current is known as the Short Circuit Current and is I_{sc}. When the Cell / Panel (Module) is shorted, the voltage in the circuit is zero.

Conversely, the maximum voltage occurs when there is a break in the circuit. This is called the Open Circuit Voltage (V_{oc}). Under this condition, the resistance is infinitely high and there is no current, since the circuit is incomplete. Typical value of the open-circuit voltage is located about 0.5 - 0.6 V for Crystalline Cells and 0.6 - 0.9 V for Amorphous Cells**.** These two extremes in load resistance are depicted on the I-V Curve.

- *3.1.2 Maximum power point and rated power point*

There is a point on the knee of the I-V Curve where the maximum power output is located and this point is called the Maximum Power Point (MPP). The voltage and current at this Maximum Power Point are designated as V_{mp} and I_{mp}. The values of V_{mp} and I_{mp} can be estimated from V_{oc} and I_{sc} as follows:

V_{mp} = (0.75-0.9) Voc

I_{mp}=(0.8-0.95)Isc

The rated power of the PV / Solar Module in Watts (P_{max}) is derived from the above values of voltage V_{mp} and current I_{mp}. The Maximum Power Point (MPP) is rated power in Watts given by

$P_{max} = V_{mp} \times I_{mp}$

- *3.1.3 Power and Efficiency calculation of PV Module*

Input radiation= 1000watt/m2
PV area=0.22m2
Total power present in this radiation= 0.22*1000 Watt = 220Watt
This is the available power in the solar radiation at this location at this instant
Number of PV arrays=2
Number of series connected cells in each array
(Ns)= 10*5= 50cells
Each cell voltage rating, Voc=0.6volt
Each cell current rating, Isc=7.31A
Net voltage form each array=50*0.6=30volt
These two arrays are connected in parallel , so voltage will be same and currents are added(KCL)
Net current form entire module= 7.31+7.31= 14.6A
PV under loading condition:
Vpv=14.67V
Ipv=14.3A
Pmax=215.6watt

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Fig: Multimeter connected to PV panel

3.2 Boost converter:

- *3.2.1 Inductor Selection:*

The inductor value is chosen from the range of recommended values. The higher the inductor value, the higher is the maximum output current because of the reduced ripple current. The lower the inductor value, the smaller is the solution size. Note that the inductor must always have a higher current rating than the maximum current because the current increases with decreasing inductance. For parts where no inductor range is given, the following equation is a good estimation for the right inductor:

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_S \times V_{OUT}}$$

V_{IN} = typical input voltage
V_{OUT} = desired output voltage
f_S = minimum switching frequency of the converter
ΔI_L = estimated inductor ripple current,
The inductor ripple current cannot be calculated because the inductor is not known. A good estimation for the inductor ripple current is 20% to 40% of the output current

$$\Delta I_L = (0.2 \text{ to } 0.4) \times I_{OUT(max)} \times \frac{V_{OUT}}{V_{IN}}$$

ΔI_L = estimated inductor ripple current
I_{OUT} (max) = maximum output current necessary in the application

- *3.2.2 Rectifier Diode Selection:*

To reduce losses, schottky diodes are used. The forward current rating needed is equal to the maximum output current:

$$I_F = I_{OUT(max)}$$

I_F = average forward current of the rectifier diode
$I_{OUT(max)}$ = maximum output current necessary in the application

$$P_D = I_F \times V_F$$

schottky diodes have a much higher peak current rating than average rating. I_F = average forward current of the rectifier diode
V_F = forward voltage of the rectifier diode

- *3.2.3 Input Output Capacitor Selection*

The minimum value for the input capacitor is necessary to stabilize the input voltage due to the peak current requirement of a switching power supply and the minimum value for output capacitor is to minimize the ripple on the output voltage. The best practice is to use low equivalent series resistance (ESR) ceramic capacitors. If the converter has external compensation, any capacitor value above the recommended minimum can be used, but the compensation has to be adjusted for the used output capacitance. With internally compensated converters, the recommended inductor and capacitor values should be used for adjusting the output capacitors to the application. With external compensation, the following equations can be used to adjust the output capacitor values for a desired output voltage ripple:

$$C_{OUT(min)} = \frac{I_{OUT(max)} \times D}{f_S \times \Delta V_{OUT}}$$

$C_{OUT\ (min)}$ = minimum output capacitance
$I_{OUT\ (max)}$ = maximum output current of the application
D = duty cycle
f_S = minimum switching frequency of the converter
ΔV_{OUT} = desired output voltage ripple
The ESR of the output capacitor adds some more ripple, given with the equation:

$$\Delta V_{OUT(ESR)} = ESR \times \left(\frac{I_{OUT(max)}}{1-D} + \frac{\Delta I_L}{2} \right)$$

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$\Delta V_{OUT\,(ESR)}$ = additional output voltage ripple due to capacitors
ESR = equivalent series resistance of the used output capacitor
$I_{OUT(max)}$ = maximum output current of the application
D = duty cycle calculated , ΔI_L = inductor ripple current

- *3.2.4 Design steps:*

The following four parameters are necessary to calculate the power stage:
1. Input Voltage Range: $V_{IN\,(min)}$ and $V_{IN\,(max)}$
2. Nominal Output Voltage: V_{OUT}
3. Maximum Output Current: $I_{OUT\,(max)}$
4. Integrated Circuit used to build the boost converter.

If these parameters are known the calculation of the power stage can be done.
3.2.5 Calculate the Maximum Switch Current:
The first step to calculate the switch current is to determine the duty cycle D, for the minimum input voltage. The minimum input voltage is used because this leads to the maximum switch current.

$$D = 1 - \frac{V_{IN(min)} \times \eta}{V_{OUT}}$$

$V_{IN\,(min)}$ = minimum input voltage
V_{OUT} = desired output voltage
η = efficiency of the converter, e.g. estimated 80%

The next step to calculate the maximum switch current is to determine the inductor ripple current. In the converters data sheet normally a specific inductor or a range of inductors is named to use with the IC. The one calculated in the Inductor Selection section

$$\Delta I_L = \frac{V_{IN(min)} \times D}{f_S \times L}$$

$V_{IN\,(min)}$ = minimum input voltage
D = duty cycle,
f_S = minimum switching frequency of the converter ,
L = selected inductor value
Now it has to be determined if the selected IC can deliver the maximum output current.

$$I_{MAXOUT} = \left(I_{LIM(min)} - \frac{\Delta I_L}{2}\right) \times (1-D)$$

I_{LIM} (min) = minimum value of the current limit of the integrated switch
ΔI_L = inductor ripple current,
D = duty cycle

- 3.2.6 *Power and Efficiency calculation of Boost Converter*

Input voltage, Vin=14.67V
Ideal passive elements, only MOSFET losses are considered
Output voltage, Vout=250V
(1-D)=Vin/Vout
D= 1-(14.6/250)
=0.9(duty ratio)
Iout=0.849A
Vout=250V
Pout=212.3watt
Pin=215W; Pout=212.3W
So P_{losses} in boost converter = Pin-Pout
=215-212.3W
= 3.7W
Efficiency of boost converter= Pout/Pin= 98.74%

3.3 Inverter and SPWM :

- *3.3.1 Inverter filter design:*

LC FILTER Output voltage wave is synchronized with the grid voltage. So the PWM inverter will inject ripple current into the grid. The LC filter is to remove high switching frequency components from output current of inverter. The filter is designed for the grid and inverter as shown in fig

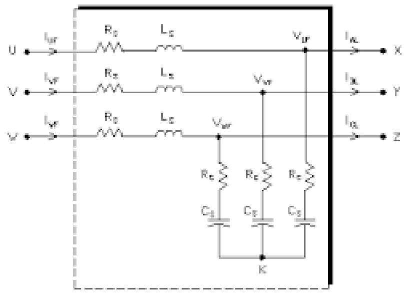

Fig. Inverter filter design

The value of L is designed based on current ripple as smaller ripple results in lower switching and conduction losses. Typically the ripple current can be chosen as 10% - 15% of rated current. Considering 10% ripple at the rated current the designed value of inductor (L) in the system
is given by

$$\Delta i_{L\ max} = 1/8 * V_{dc} / L * fs$$

The capacitor C is designed based on reactive power supplied by the capacitor at fundamental frequency. In this design reactive power can be chosen as 15% of the rated power is given by

$$C = 15\% * \text{Prated} / 3*2\pi f * V\ 2\ \text{rated}$$

- *3.3.2 Implementation of SPWM Technique:*

Digital implementation of SPWM technique is based on classical SPWM technique with carrier and reference sine waveforms with only one difference ie., in digital SPWM a sine table consisting of values of sine waveform sampled at certain frequency is used. As a result reference waveform in digital SPWM represents a sample and hold waveform of sine waveform. This sampling of sine waveform comes in two variants; a) Symmetrical sampling, b) Asymmetrical sampling. In symmetrical sampling, reference sine waveform is sampled at only positive peak of the carrier waveform and sample is held constant for the complete carrier period. This introduces the distortion in modulating signal and phase shift between modulating signal and fundamental component of output voltage. Here sampling frequency is equal to carrier frequency. The phase shift is given by m/ f π , where

$$m_f = \frac{f_c}{f_m}$$

f_c = Carrier frequency .
f_m = Reference Sine wave frequency

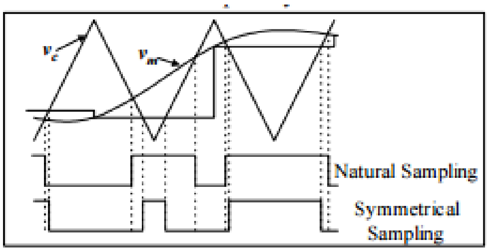

Fig: symmetrical sampling

In asymmetrical sampling, the reference signal is sampled at positive as well as negative peak of carrier frequency and held constant for half the carrier period. Here sampling frequency is twice the carrier frequency. Asymmetrical sampling is the preferred method, since each switching edge is the result of new sample and give better performance as shown in Fig. The phase shift is given by 2mf/ π.

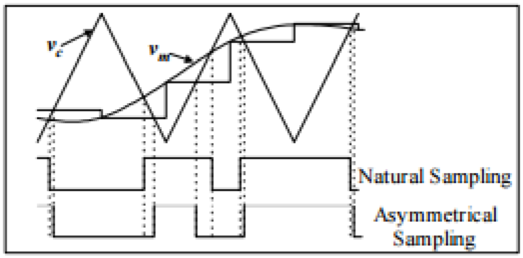

Fig : Asymmetrical sampling

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- 3.3.3 Comparison of natural SPWM and digital SPWM

The digital SPWM has following disadvantages: Digital SPWM method samples the input signal at the beginning of the switch cycle, before the actual switching edge reflects this value later in the cycle. This introduces a delay in out-put waveform. A delay of mf π is introduced in symmetrical sampling method and 2mf π in asymmetrical sampling method, where mf is frequency modulation ratio. This delay in response is significant when the ratio of switch frequency to reference frequency (the pulse number) is small. It leads to a frequency response roll-off which obeys a Bessel function, similar to the familiar sine function roll-off for Pulse Amplitude Modulation (PAM). Another unwanted effect of digital SPWM is odd harmonic distortion of the synthesized waveform. The severity of these effects is a function of the ratio of the modulating and carrier frequencies, f_1/fc.

- 3.3.4 *Procedure of calculating time delay Δt_k*

The time delay Δt_k is calculated as follows:
Considering reference signal

$$V_r(t) = M_a V_m \sin(\omega_m t)$$

Where M_a = Modulation index.
V_m = Peak value of Reference signal.
$\omega_m = 2\pi$ fm .
f_m = fundamental frequency of reference signal
t_k= Time instant at which sine wave form is sampled.

Carrier signal equation for positive slope and negative slope,

$$V_{c(P\_S)} = 2V_c f_c t - \frac{V_c}{2}$$

$$V_{c(N\_S)} = -2V_c f_c t + \frac{V_c}{2}$$

- 3.3.5 *Power and Efficiency calculation of Inverter,load and overall efficiency*
- 3.3.5.1 Inverter

Input power to inverter= 212.3 W
V_{dc}input DC voltage= 250V
Output AC voltage from inverter= $\frac{\sqrt{3}}{2}$ *m* V_{dc}
Vout(AC) =*m* Vdc
= 200V(L-N)
Under loading condition Iout=1Amp
Power factor calculation:
PF= cos(Ǿ)= $\frac{P}{S}$
S= $\sqrt{P^2 + Q^2}$
PF= $\frac{210}{\sqrt{210^2+10^2}}$ = 0.998
Power output from this inverter= V* I* Cos (phi)
= 200 * 1 * 0.99
= 210W
Losses in inverter stage= Pin- Pout
= 212.3-210
=2.7W

- 3.3.5.2 *Load &Power Transformer*

Three Phase Resistive load
Rated voltage=415V (L-L)
Rated frequency=50Hz
Before transformer voltage= 210V
Current= 0.6734A
Power input= 210W
After transformer voltage= 415V
Current= 0.2951
Power output= √3 *V*I*cos(Ǿ)
= √3 *415*0.2951*0.99

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= 207W

- 3.3.5.*3 Overall conversion efficiency*

Total power input form PV=215.4W
Total power output to load= 205W

$$\%\text{Efficiency}=\frac{205}{215}*100$$
$$= 93.8\%$$

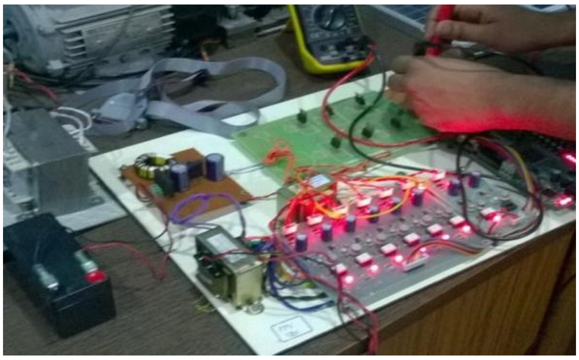
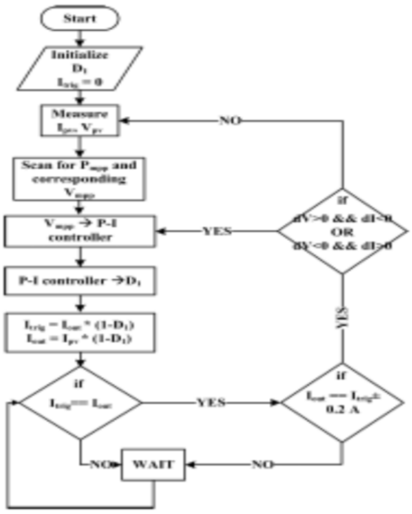


Fig: Measurement at the load

IV. FLOW CHART FOR SCANNING PROCESS



V. SIMULATION AND HARDWARE RESULTS

The various blocks of the block diagram are simulated seperately and then integrated

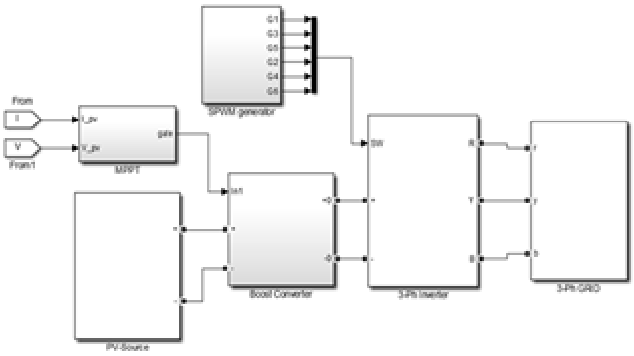


Fig: Total Simulation Circuit

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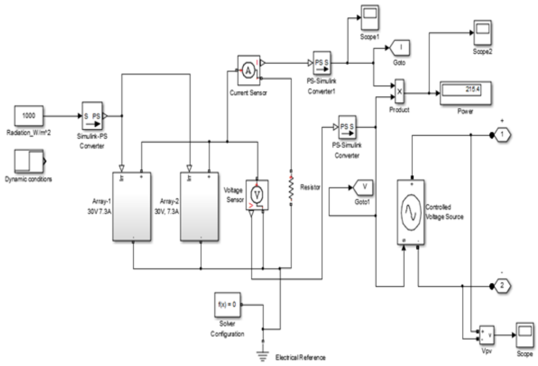

Fig: Simulated PV System Sub module

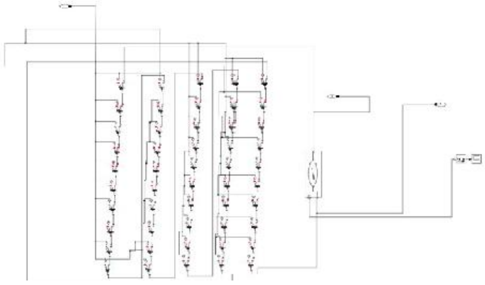

Fig: Array1

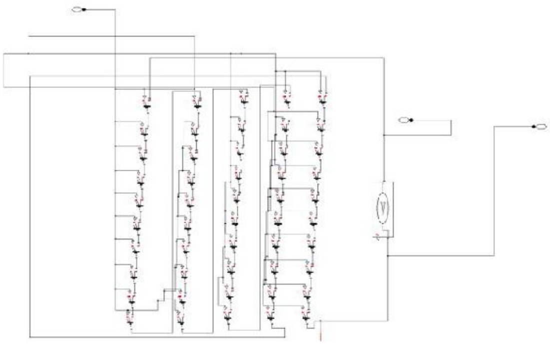

Fig: Array2

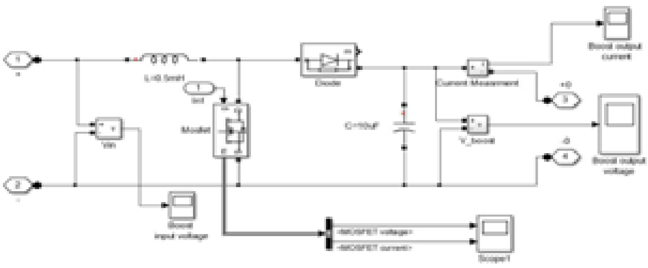

Fig: Boost Converter

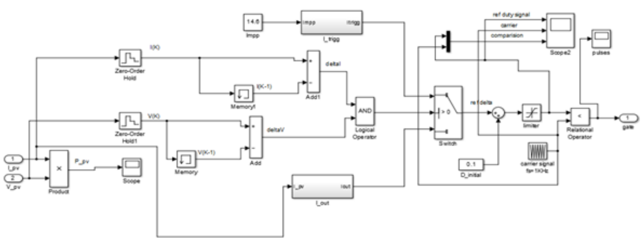

Fig: MPPT

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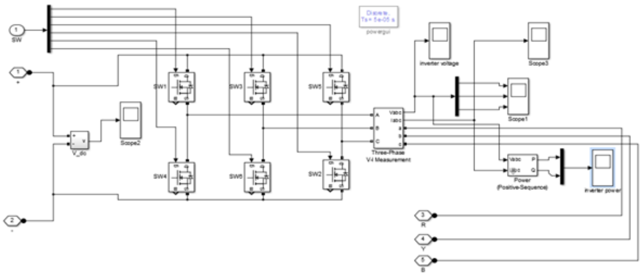

Fig: Three Phase VSI

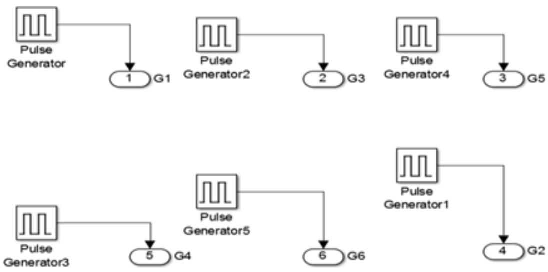

Fig: SPWM

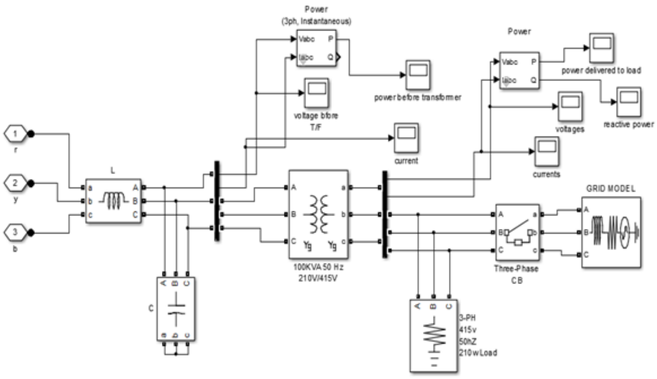

Fig: Three Phase Load and Grid interconnection

VI. Output waveforms:

- *PV characteristics*

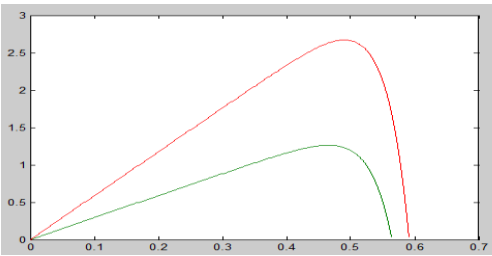

Fig: PV curve

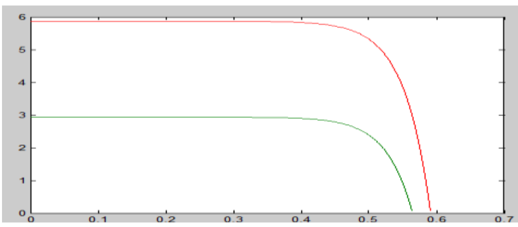

Fig: IV curve

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Fig: PV output voltage

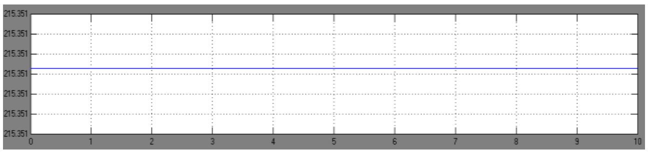

Fig: PV output power

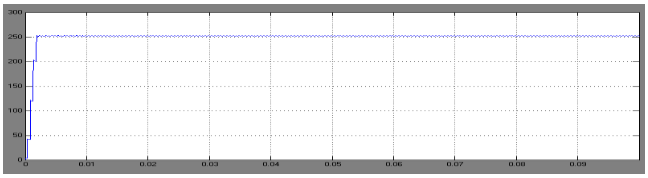

Fig: Boost converter output voltage

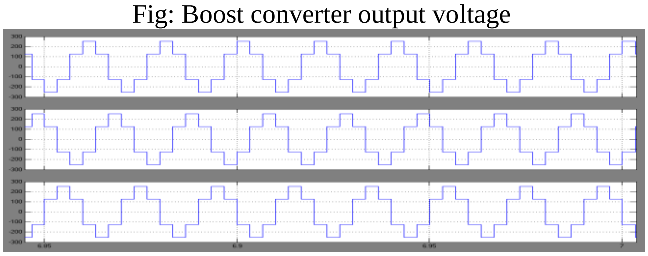

Fig: Three Phase inverter output voltage

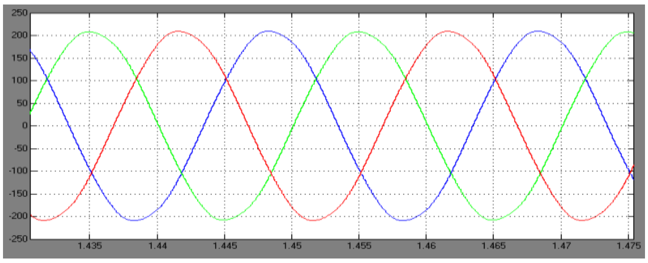

Fig: Voltages after filtering

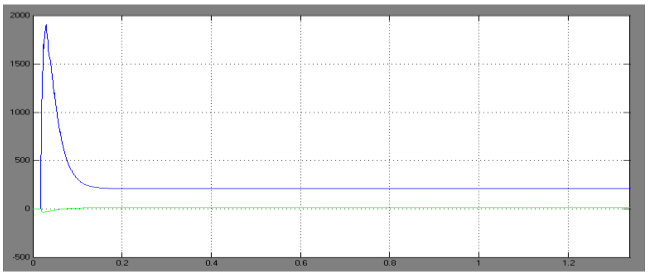

Fig: Three Phase inverter output powers

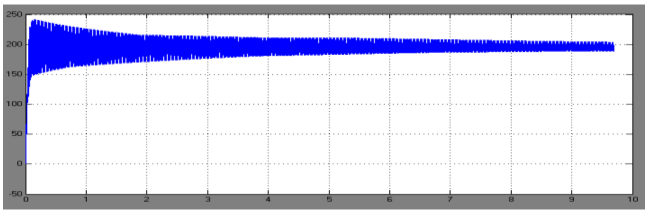

Fig: Power through transformer

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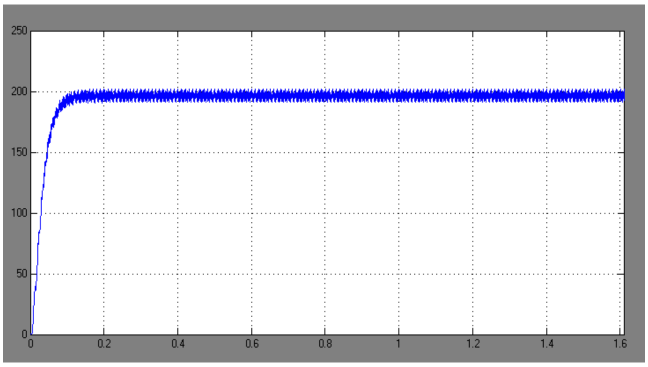

Fig: Final Power delivered to load

VI. CONCLUSION

In this paper a high performance controller to track the maximum power point (MPP) of a photovoltaic (PV) module has been proposed. The proposed scanning technique determines the maximum power delivering capacity of the panel at a given operating condition. Simulation and Hardware circuits are designed and developed to verify the proposed system. Combined deployment of solar with MPPT and EV technologies can address the individual challenges of both. EVs can assist with the integration of higher levels of solar generation on the utility grid by smoothing the solar supply curve, reducing the need for curtailment, and increasing the efficient use of transmission and distribution resources. Installing solar in proximity to EV charging infrastructure can reduce or eliminate demand spikes and increases in peak load caused by daytime charging. In all cases, the use of controlled charging, which synchronizes the timing of EV charging to match the production of the solar system, increases the benefits for both technologies. Controlled charging technology can be employed in the absence of solar, as well as when EV charging stations are combined with distributed solar technology. Finally, combining solar PV with controlled EV charging can be expected to result in a smoother net demand profile than can exist through the implementation of either technology alone for future automobile industry.

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