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# SIMULATION AND ANALYSIS OF PV ARRAY BY PERTURB AND OBSERVE MPPT ALGORITHMS USING FLYBACK CONVERTER

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***Abstract: In this paper, PV module is designed. The different characteristics curve of solar cell is obtained and it's dependency is observed on temperature and irradiation. The flyback converter is used as interface between PV panel and the load. A detailed analysis and operation of converter has been discussed. Perturb and Observe (P&O) MPPT algorithm has been employed for operate the PV panel voltage at the Maximum power point (MPP). Initially, the PV panel peak voltage is obtained directly by varying the duty cycle of the flyback converter. Due to direct duty Ratio control method causes stress on the converter switch. That's why converter besides a significant amount of power loss. The second MPPT algorithm is also implemented with PI controller and P & O algorithm where algorithm is used to calculate the reference PV voltage. The performance of both method is compared in this paper. The DC voltage is converted into AC voltage by use of single phase voltage source inverter (VSI).***
***Keywords: Maximum Power Point Tracking, Fly back converter, Solar Voltaic cell, Voltage source inverter.***

## I. INTRODUCTION

Among the renewable energy resources, the energy through the solar photovoltaic effect can be considered the most necessary and prerequisite sustainable resource because of the ubiquity, large quantity, and sustainability of solar energy. 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 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 or load conditions. Previously buck, boost and buck-boost converters are used to transfer the power generated by PVA to load . In literature it is reported that direct control of Flyback converter minimizes power loss and avoids the discontinuous conduction. The PI controller increase complexity of system. In this work direct control of duty cycle using MPPT technique is explore.

## II. BLOCK DIAGRAM OF TRACKING SYSTEM

A block diagram of the solar PV energy conversion system with a dc-dc converter, a VSI, an output filter and the feedback control loop is shown in figure 1.1.

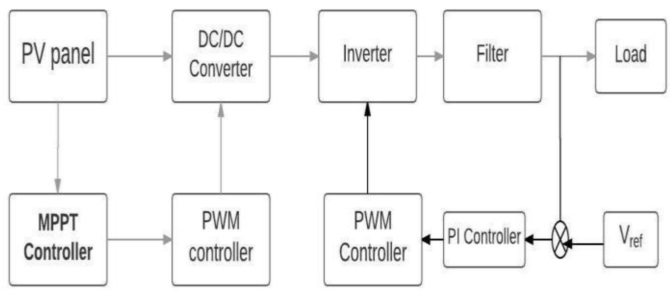



Fig. 1 Block diagram of system configuration

This is two stage stand-alone PV system in which low PV voltage is stepped up using converter and then is converted to AC. Flyback converter is used as DC-DC converter. Here P & O algorithm is used to track the maximum power point. The P & O algorithm is implemented in two ways, one by direct duty control and other by reference voltage control with PI controller. The duty ratio of flyback converter is controlled by MPPT control. The output voltage of converter is fed to voltage source inverter whose pulse is generated by sinusoidal pulse width modulation. The circuit configuration is shown in Fig2.

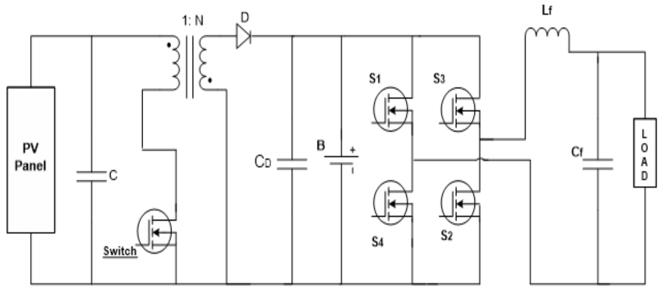



Fig 2. Proposed configuration of PV system

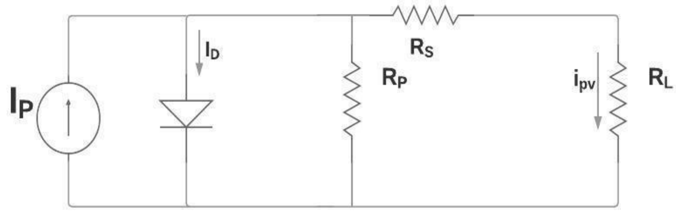
## III. PHOTOVOLTAIC SYSTEM

Photovoltaic (PV) cell is a semiconductor device which directly converts the light energy into electrical energy. A PV system consists of a multiple component, including the modules, mechanical connection, electrical interconnections, and mounting for other components. Photovoltaic cells are made of several types of semiconductors using different manufacturing process . Typically, photo voltaic (PV) cell generates a voltage around 0.5 to 0.8 volts depending upon semiconductor and the built-up technology. The numbers of PV cells are connected in series and parallel to get more amounts of voltage and current known as PV module and if many such modules are connected for any application to get desired amount of current and voltage then it is called as PV array .

## IV. MATHEMATICAL MODEL OF PV MODULE

PV device present a non-linear I-V characteristics with several parameters that need to be adjusted for experimental data of particular devices, the mathematical model of PV device may be convenient in the study of dynamic analysis of converters, in the study of PV systems and its components using circuit simulator. The equivalent circuit model of the solar cell is given in figure .




$$i_{pv} = I_{pv} - I_0[e^{(\frac{V_{PV}+i_{PV}R_S}{V_t*n})} - 1] - \frac{(V_{pv}+i_{pv}R_s)}{R_p} \quad \text{…(3.1)}$$

$$V_t = \frac{N_s kT}{q} \quad \text{………………….(3.2)}$$

Where,
$I_P$ is photon current which is directly proportional to solar insolation $I_0$ is diode reverse saturation current q is charge of electron
$V_{pv}$ is voltage across load
$V_t$ is thermal voltage
$R_S$ is series resistance $R_P$ is parallel resistance
k is Boltzmann constant (1.3806503e-23 J/K)
n is ideality factor of diode
T is p-n junction temperature in kelvin
Different parameters used in modeling of solar PV array are tabulated below at ambient temperature $25^0$ C and irradiation 1000 $W/m^2$.

| | |
|---|---|
| Peak power | 200 watt |
| Voltage at MPP | 26.3V |
| Current at MPP | 7.61A |
| Short circuit current | 8.21A |
| Open circuit voltage | 32.9V |
| Number of cell connected in series | 54 |
| Number of cell connected in parallel | 1 |

Table 3.1 Electrical parameters of photovoltaic module

The PV voltage and current vary when there is change in temperature and irradiance. So the PV power also varies. The different characteristics of PV module at different temperature and irradiation is shown. in the following figures [3.2], [3.3], [3.4] and [3.5].

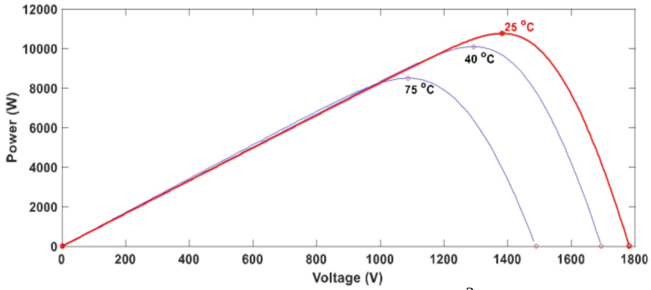



Fig. 4 P-V characteristics at 1000 $W/m^2$ for different temperature

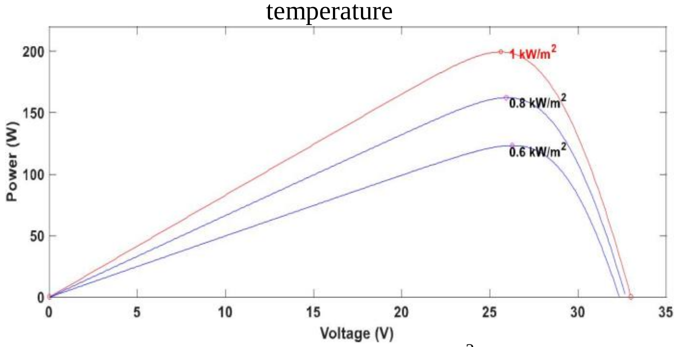



Fig. 5 P-V characteristics at 1000 $W/m^2$ for different temperature

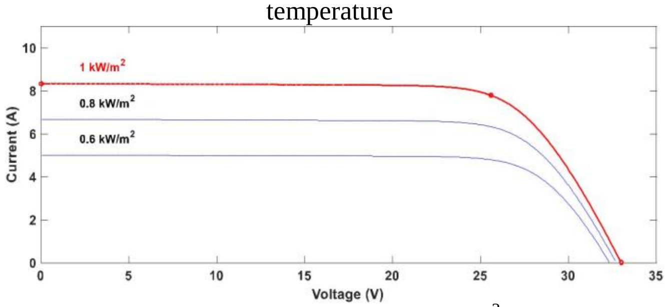



Fig. 6 V-I characteristics for G=1000 $W/m^2$ at different temperature

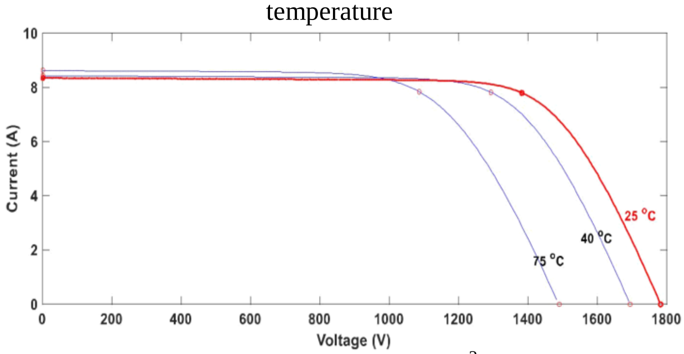



Fig. 7 P-V characteristics at 1000 $W/m^2$ for different temperature

## V. EQUIVALENT CIRCUIT OF PV ARRAY

To analyse the PV array with flyback converter, first we need to linearize the ($i_{pv}$, $V_{pv}$) curve at maximum operating point. The slope of tangent to ($i_{pv}$, $V_{pv}$) curve at maximum power point (V, I) is given by

$$m(V,I) = \frac{\partial i_{PV}}{\partial V_{PV}} = \frac{-I_0}{V_t N_S n} * e^{\frac{(V+R_S I)}{V_t N_S}} - \frac{1}{R_P} \quad (3.3)$$

The linear model of ($i_{pv}$, $V_{pv}$) becomes

$$i_{pv} = I + m(V,I)*(V_{PV} - V) \quad (3.4)$$

The equivalent circuit of PV array at MPP is shown in Fig. 3.6.

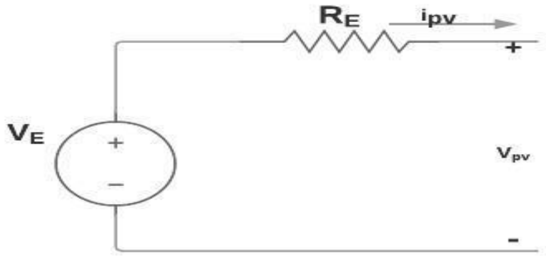



Fig.9 Linearized equivalent circuit of PV module

From Fig 3.2, $i_{pv}$ can be written as

$$i_{pv} = \frac{V_E}{R_E} - \frac{V_{pv}}{R_E} \quad (3.5)$$

By comparing Eq. (3.4) and Eq. (3.5) we can find $R_E = -1/m$ and $V_E = V - I/m$. Using the PV module data $R_E$ = 2.2323 and $V_E$ = 50.90.

## VI. FLYBACK CONVERTER TOPOLOGY

In industrial or home application, those power supplies are preferred which has more efficiency, which can isolate the source and load and has high power density. Switch mode power supplies are becoming more famous because of having more efficiency. The flyback converter based topology in PV system is more reliable and less expensive topology as it needs less number of switches and other component. It is the simplest topology which provide galvanic separation between source and load. This converter can boost or step down the input voltage depending on the turn ratio of transformer. It does not need additional inductor to store the energy because transformer magnetizing inductance store the energy. In half of switching period, energy is stored in transformer and other half period it transfer the energy to load.

*A. Analysis of flyback converter*

The equivalent circuit of flyback converter is given in Fig. 3.7. It has a DC voltage source (in our case PV panel is source), MOSFET switch, a transformer, a diode D, a filter capacitor $C_O$ and load R. As switch is operating at very high frequency, unregulated input voltage can be taken as constant. It also provides fast control on duty cycle to achieve required output. Flyback transformer is different from normal transformer as current does not flow in primary and secondary at same time. It may operates in continuous conduction mode (CCM) or discontinuous mode (DCM). Here continuous mode operation is used.

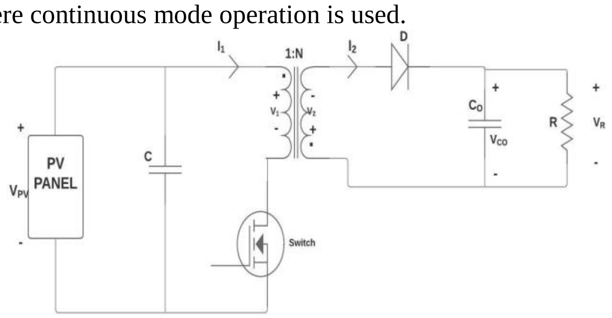



Fig.10 Circuit of flyback converter

## VII. PERTURB & OBSERVE ALGORITHM

P&O method is mostly used because it is simple and less expensive. This algorithm is mainly based on the sign of slope of PV curve of solar module. In this algorithm, voltage is perturbed and slope (dP / dV) is checked weather it is positive, negative or zero. If the slope is zero then that point is MPP and if slope is negative then voltage is perturbed in reverse direction else voltage perturbation is continued in same direction until we reach peak point.

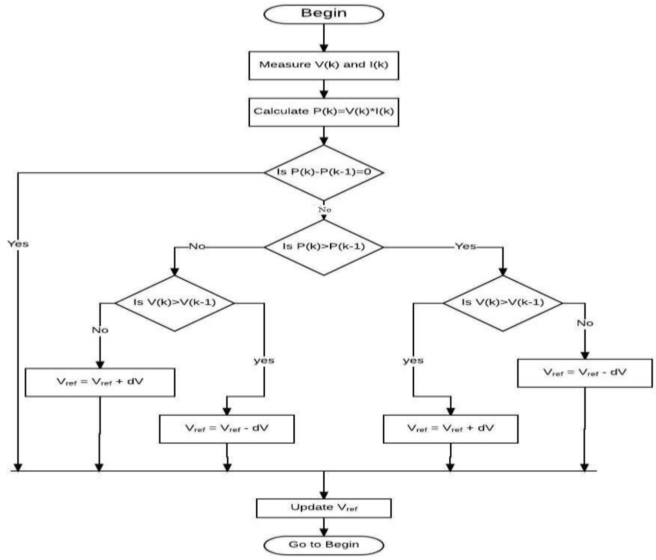



Fig.11 Algorithm for P&O

A. Direct Duty cycle control

we can write the output power with load R

$$P_O = \frac{N^2 D^2 V^2_{PV}}{(1-D)^2 R} \quad (3.37)$$

Assuming lossless system output power should be equal to input power supplied by PV panel. Panel output power is

$$P_{PV} = V_{PV} I_{PV} \quad (3.38)$$

Equating Eq.(4.1) and (4.2) we will get,

$$\frac{V_{PV}}{I_{PV}} = \frac{(1-D)^2 R}{N^2 D^2} \quad (3.39)$$

Thus by varying duty ratio we can vary the impedance of converter seen by PV panel. The algorithm will track mpp by matching impedance of PV panel and impedance of converter seen from PV. The general block of duty ratio control i

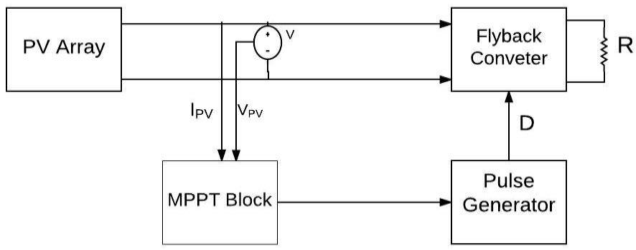



Fig.12 Block diagram of duty cycle control

The direction of perturbation of duty cycle depends on the slope of PV curve. If the slope is positive then perturbation direction is reversed, in other word D becomes $D - \Delta D$.

*B. Reference voltage control with PI controller*

In Voltage reference control, $V_{ref}$ is given by P&O algorithm. The voltage is perturbed in opposite fashion of the direct duty ratio control. If the dP/dV is positive then voltage is perturbed in same direction. In both method proper selection of perturbation time and perturbation step size are more important. The system should be allowed to settle in each perturbation period. In this view perturbation time should be more than settling time. Similarly if perturbation step size is high then oscillation in steady state will be more. The $V_{ref}$ generated by MPPT block is compared with converter input voltage $V_{PV}$. The generated error signal is fed to the PI controller which control the duty cycle of DC-DC converter.

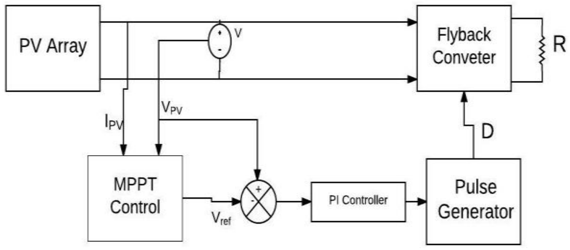



Fig.13 Block diagram of Reference voltage control with PI controller

The open loop transfer function is derived in chapter 3 taking d as input and $V_{PV}$ as input. The controller constant can be calculated by pid tool or siso tool auto tuning control toolbox in Simulink. The function of MPPT control box is to find the $V_{ref}$ and controller is trying to reduce the error generated by $V_{PV}$ and $V_{ref}$ .This control mechanism track the MPP faster than direct duty ratio control.

## VIII. INVERTER OPERATION

A full-bridge voltage source inverter (VSI) is used here which consists of four switches. Two complimentary PWM pulses are generated by the sinusoidal PWM controller. The basic principle in generating pulses with sinusoidal PWM is to divide the period of the desired sine wave output into number of intervals. In each interval, the control signal remains on for part of the time and off for the other part of the time. The ratio of the ON time and OFF time at any given instant determines the amplitude of the desired output signal commonly known as duty cycle, which is fed to switches of the VSI. One signal is sent in pair to S1 and S2. The other signal is sent to S3 and S4. The basic circuit of full bridge inverter is shown in Fig. (4.1)

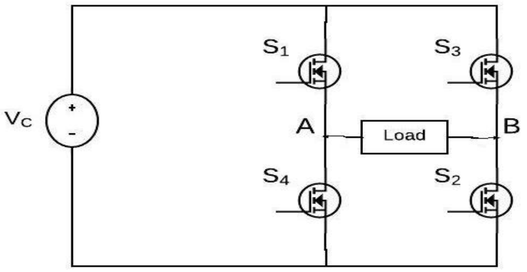



Fig.14 Full Bridge Voltage source inverter

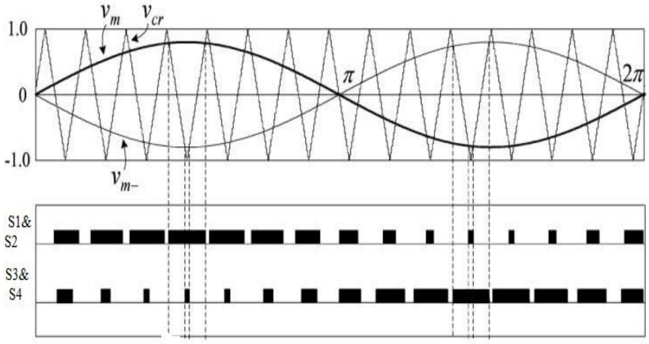



Fig.15 Gate signal pattern for switches

## IX. PROPORTIONAL INTEGRAL VOLTAGE CONTROLLER

In order to get a good quality of voltage at output side of inverter, the input voltage to inverter should be constant. But it is not always possible. To solve this problem PI voltage controller is used. The block diagram of PI controller is shown in Figure14. Here the output voltage of inverter is compared with reference voltage which will generate instantaneous error signal. Then the error signal is fed through PI controller. Integral controller mainly reduces the instantaneous error thus improves the tracking of desired value.

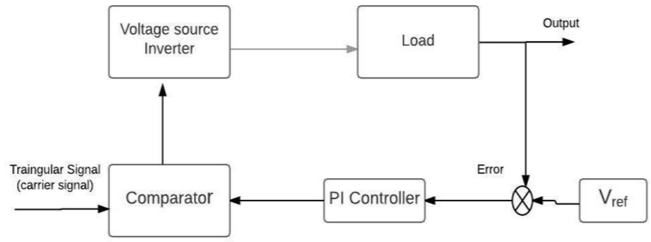



Fig.16 Structure of PI controller

By using that transfer function, controller constant can be calculated from Simulink control toolbox or Ziegler-Nichols method. Here $K_p$ = 2.430 and $K_i$ = 2303.6.

## X. LC FILTER

The output of VSI is not fully sinusoidal .It is basically low pass filter which filter out the component having high frequency than cut off frequency LC filter are mainly designed for eliminating lower order harmonics. The cut-off frequency is given by

$$f_c = \frac{1}{2\pi\sqrt{L_f C_f}}$$

## XI. RESULT

A. Direct ratio control

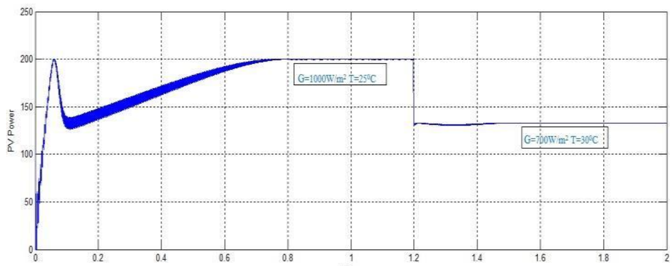



Fig.17. PV power of converter using duty ratio control

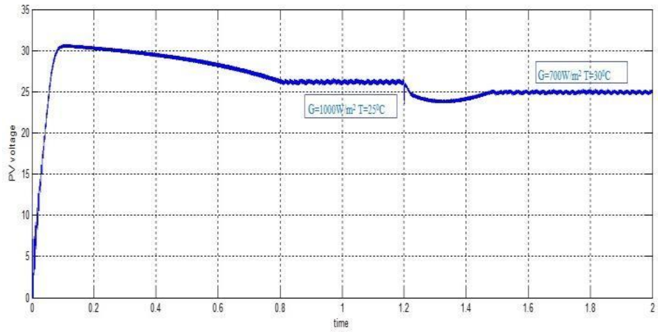



Fig.18 PV voltage of converter using duty ratio control

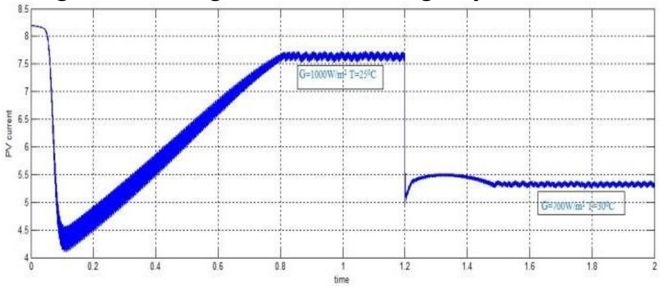



Fig 19. PV current of converter using duty ratio control

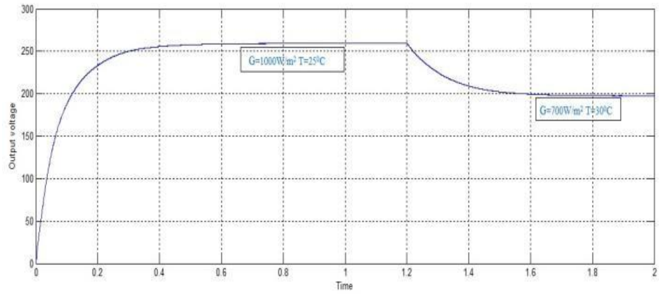



Fig 20. converter output voltage at D=0.54 using duty ratio control MPPT algorithm

*B. Reference voltage control using PI controller*

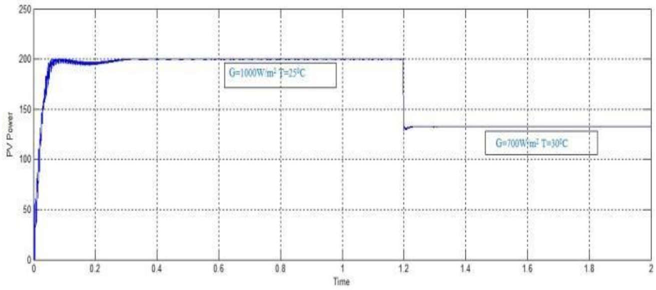



Fig.21. PV power of converter using PI controller

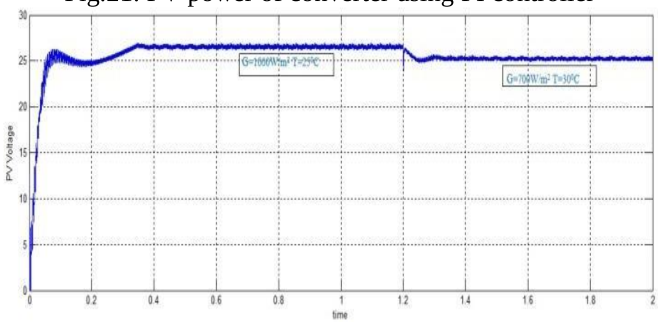



Fig.22. PV voltage of converter using PI controller

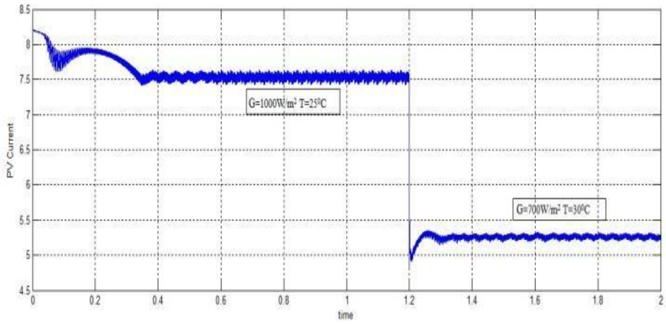



Fig 23.PV current of converter using PI controller

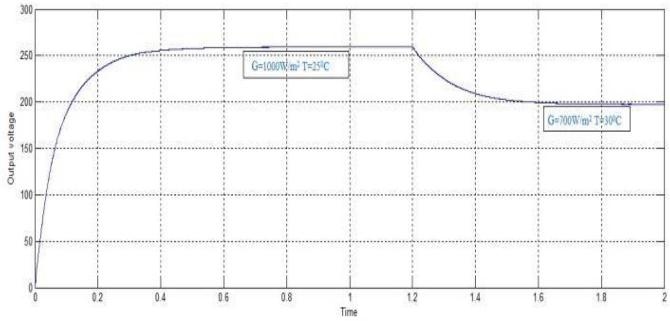



Fig 24. converter output at duty cycle D=0.54 voltage using PI controller

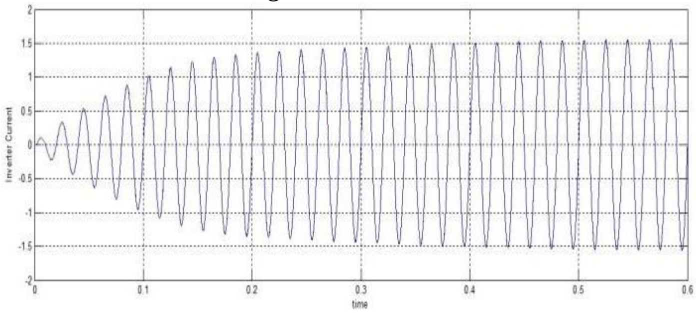



Fig25. Inverter current using direct ratio control with R=100 ohm at duty cycle 0.46

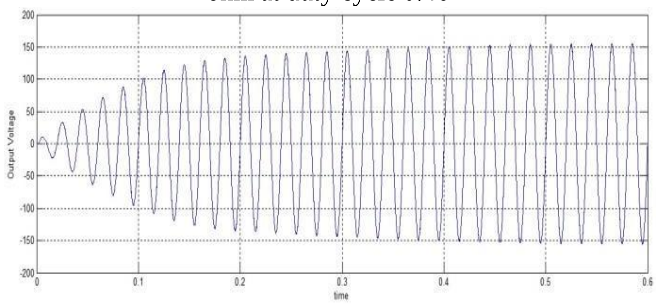



Fig 26. Inverter voltage using direct ratio control with R=100 ohm at duty cycle 0.46

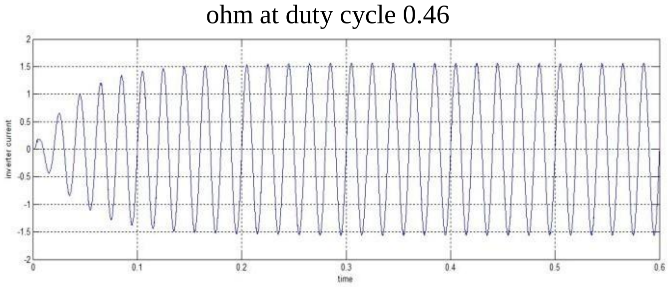



Fig 27. Inverter current using reference voltage control with R=100 ohm

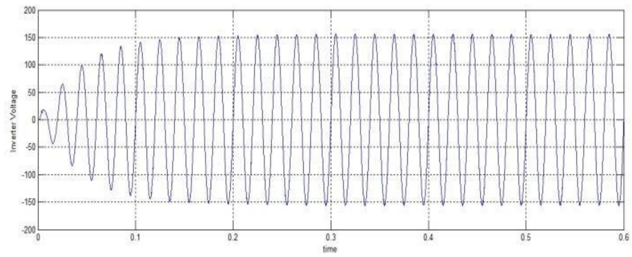


Fig 28. Inverter voltage using reference voltage control with R=100 ohm

## XII. CANCLUSION

This paper presents a comparative analysis of the reference voltage perturbation and direct duty ratio perturbation method. The response of the system is faster with reference voltage method. Energy utilization is poor with reference voltage method but direct duty ratio method offers better utilization of energy and better stability. The P-V and V-I curve is plotted for different temperature and irradiation. We observe that with the increase in temperature PV power decreases and with the increase insolation PV power increases. Perturb and Observe (P&O) MPPT algorithm has been also implemented in the Simulink to extract maximum power form solar PV array. The curves of the PV power, current, voltage are plotted using both direct duty ratio control and reference voltage control with PI on MATLAB/Simulink platform. We observed that tracking time is less in latter method.

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