Comparison of P&O and Improved IC MPPT Controller Boost Converter for Solar PV Standalone and grid Connected Mode Operation

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Abstract:

Maximum Power Point Tracking (MPPT) algorithms is important in PV systems because it reduces the PV array cost by reducing the number of PV panels required to achieve the desired output power. This paper presents a comparative simulation study of two important MPPT algorithms specifically perturb and observe and incremental conductance with integrator controller. These algorithms are widely used because of its low-cost and ease of realization. Some important parameters such as voltage, current and power output for each different combination has been traced for both algorithms. Matlab simulink tool box has been used for performance evaluation by a 70W photovoltaic (PV) array. In both cases system performances are also analysed with connected micro grid.

Keywords: *- Photovoltaic (PV), Maximum Power Point Tracking (MPPT), Perturb and Observe (P&O), Incremental Conductance (InC). Micro grid*

I.INTRODUCTION

Photovoltaic (PV) generation represents currently one of the most promising sources of renewable green energy. Due to the environmental and economic benefits, PV generation is preferred over other renewable energy sources, since they are clean, inexhaustible and require little maintenance. PV cells generate electric power by directly converting solar energy to electrical energy. PV panels and arrays, generate DC power that has to be converted to AC at standard power frequency in order to feed the loads. Therefore PV systems require interfacing power converters between the PV arrays and the grid. Photovoltaic-generated energy can be delivered to power system networks through grid-connected inverters. One significant problem in PV systems is the probable mismatch between the operating characteristics of the load and the PV array.

The system's operating point is at the intersection of the I-V curves of the PV array and load, when a PV array is directly connected to a load.the maximum power point of any PV varies with the variation of the atmospheric conditions (solar irradiance and temperature). This means that there is always one optimum terminal voltage for the PV array to operate at with each condition as shown in Figure 1, to obtain the maximum power out of it i.e. increase the array's efficiency.

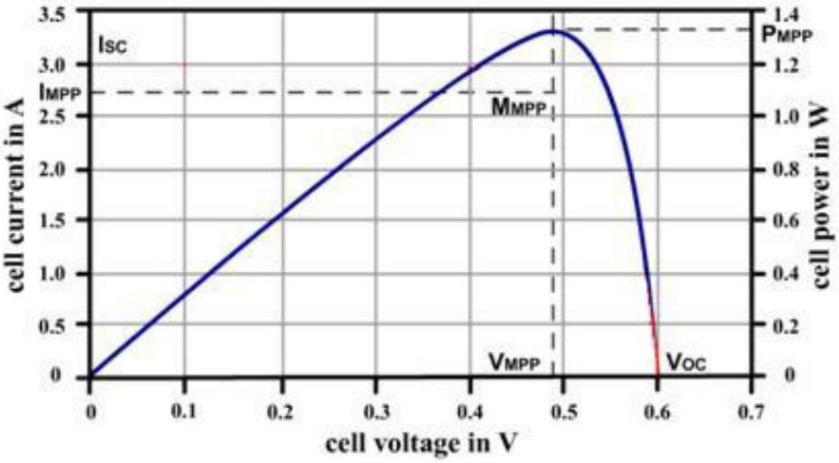


Fig. 1: PV curve showing Maximum Power Point

DC-DC converters play an important role in the maximum power point tracking process. As by connecting the array's output terminals with the DC-DC converter's input terminals, the array voltage can be controlled by varying the duty cycle of the converter and the voltage at which maximum power is obtained can be maintained.

DC-AC inverter's main task is to convert the DC electricity to AC and hence it could be tied to the grid. The inverter has also a very important role in the MPPT process which is fixing the DC-link voltage at certain value. As varying the duty cycle of the DC-DC converter will change the array terminal voltage (the DC-DC converter's input voltage) only in case of fixing the output voltage of the DC-DC converter at a certain value, a control scheme for the DC-AC inverter is proposed to keep the DC link voltage constant (which is the DC-DC output voltage also) and thus, varying the duty cycle of the DC-DC converter varies the array terminal voltage. The complete system discussed in this thesis is shown in Figure 2.

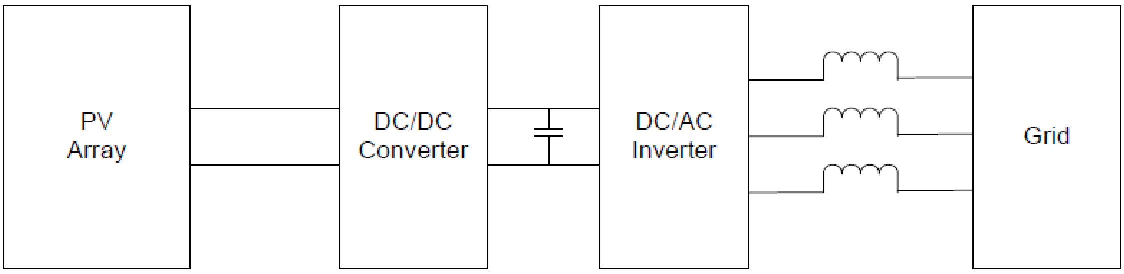


Fig. 2: A complete Grid-Connected PV system

a) **DC-DC CONVERTERS:** The maximum power point tracking is basically a load matching problem. In order to change the input resistance of the panel to match the load resistance, a DC to DC converter is required.

The main equation of the boost converter is

$$\frac{V_o}{V_i} = \frac{1}{1-D} \qquad (1)$$

Where, Vi is the input voltage to the boost converter V0 is its output voltage, and D is the duty cycle. In the case of this thesis, V0 is fixed using the inverter control scheme. And Vi is at the same time the array terminal voltage which is controlled by varying the duty cycle D.

b) MPPT ALGORITHMS

Two methods are concentrated in this paper, those are 1) Perturb and Observe (P&O) Algorithm 2) Incremental Conductance (IC) Algorithm with integrator. To improve performance of InC MPP an integrator is proposed in before the PWM controller implemented in DC-DC controller. A slight perturbation is introduced in this algorithm. The perturbation causes the power of the solar module to change continuously. If the power increases due to the perturbation then the perturbation is continued in the same direction. The power at the next instant decreases after the peak power is reached, and after that the perturbation reverses. The algorithm oscillates around the peak point when the steady state is reached. The perturbation size is kept very small in order to keep the power variation small [4]. The algorithm can be easily understood by the following flow chart which is shown in figure 3a.

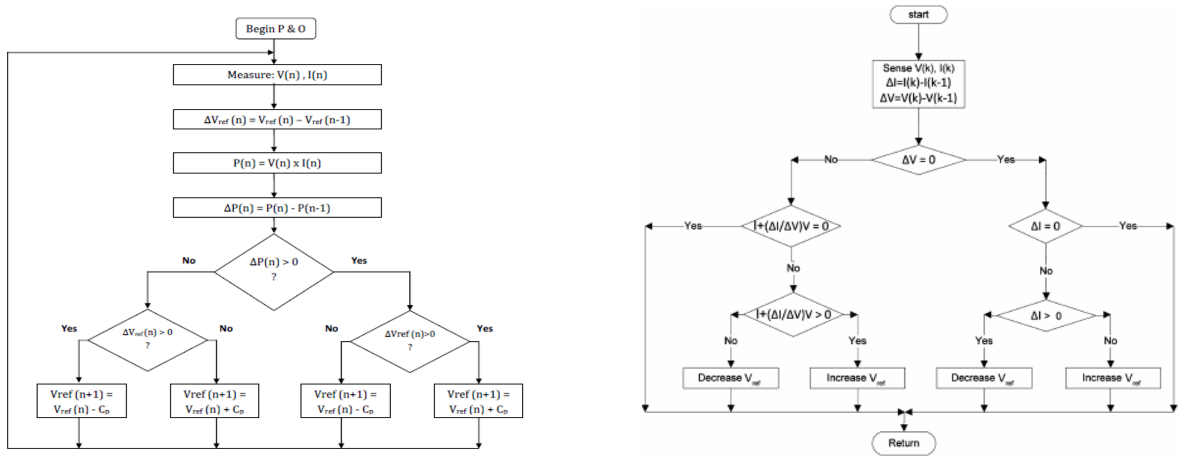


Figure 3 a) Perturb and Observe algorithm flow chart b) Flowchart of the IC method

The algorithm is developed in such a manner that it sets a reference voltage of the module corresponding to the peak voltage of the module. A PI controller is used to move the operating point of the module to that particular voltage level. It is observed that there is some power loss due to this perturbation and it also fails to track the power under fast varying atmospheric conditions. But still this algorithm is very popular because of its simplicity.

c) Incremental Conductance (IC) Algorithm

Incremental Conductance (IC) method overcomes the disadvantage of the perturb and observe method in tracking the peak power under fast varying atmospheric condition. This method can determine whether the MPPT has reached the MPP and also stops 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. This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm determines when the MPPT has reached the MPP, whereas P&O oscillates around the MPP. This is clearly an advantage over P&O. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe method [4]. The disadvantage of this algorithm is that it is more complex when compared to P&O. The algorithm can be easily understood by the following flow chart which is shown in figure 3b.

II. Grid-connected systems with mathematical equations and PV characterisers

In this chapter, an overview of the importance of renewable energy and its various types and resources is made. The Photovoltaic energy in particular is reviewed with its global growth, advantages, cell types and mathematical model along with the equivalent circuit. The two main PV system types are also discussed and their components are mentioned.

Unlike stand-alone systems, utility-interactive systems are connected to the power line, as shown in Figure 4. This system has PV solar modules which supply electrical power to the equipment though a high quality inverter. This inverter converts PV-generated DC to high quality AC normally available from the power company [11]. Also Electric Power stations based on PV modules are considered grid-connected systems as they generate huge amount of power and adds it to the grid power.

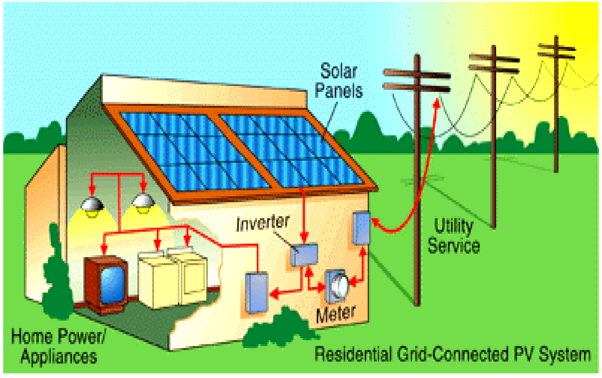


Figure 4 Example of Grid-connected PV system

Grid-connected systems show recently very good potential compared to stand-alone ones, as grid-connected users can sell their unused extra electricity to the utility with high prices and still supply their needs at nights from the utility if they have shortage.

a) Equivalent circuit and mathematical model

A current source type PV model is discussed in this section [8]. The equivalent circuit is shown in Figure 5

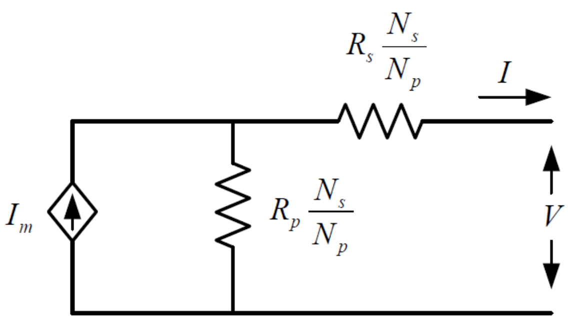


Fig. 5 PV module equivalent circuit

Where Rs is the array series resistance, Rp is the array parallel resistance, Ns and Np are the number of series and parallel modules respectively, I and V are the output current and voltage of the array and Im is the module current and can be obtained from the following equation

$$I_m = I_{pv} N_p - I_o N_p \left[\exp\left(\frac{V + R_s \left(\frac{N_s}{N_p} \right) I}{V_t a N_s} \right) - 1 \right] \text{-----------------------------------(2)}$$

Where, a is the diode ideality constant, Vt is the thermal voltage of the array and can be obtained from the equation

$$V_t = \frac{N_{cs} k T}{q} \quad \text{...(3)}$$

Ncs is the number of cells connected in series, q is the electron charge, k is Boltzmann's constant and T is the temperature of the P-N junction in Kelvin's. Ipv is the photovoltaic current and can be expressed by

$$I_{pv} = \left(I_{pvn} + K_i \Delta T \right) \frac{G}{G_n} \quad \text{.................................(4)}$$

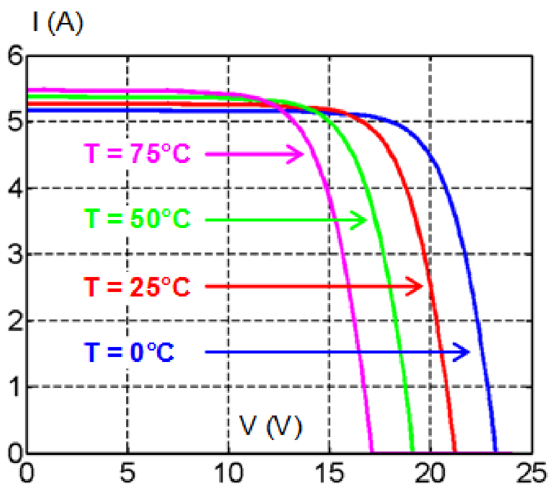
And Io is the reverse leakage current of the diode and can be calculated from

$$I_0 = \frac{I_{scn} + K_i \Delta T}{\exp\left(\frac{V_{ocn} + K_v \Delta T}{a V_t} \right) - 1} \quad \text{..................................(5)}$$

Where: Ipvn is the generated current at 25oC and 1000W/m2(nominal conditions), Ki, Kv the current and voltage temperature confidents respectively, G is the irradiance and Gn is the irradiance at nominal conditions, Iscn ,Vocn are the short circuit current and open circuit voltage respectively at nominal conditions and T is the difference between the actual and the nominal temperatures in Kelvin's

b) Characteristics of PV Modules

Photovoltaic have nonlinear characteristics, where the performance and output power are directly affected with the change of the operating conditions (temperature and solar irradiance. Figures 6, 7, 8 and 9 show the effect of changing the temperature and solar irradiance on PV's output current, voltage and power



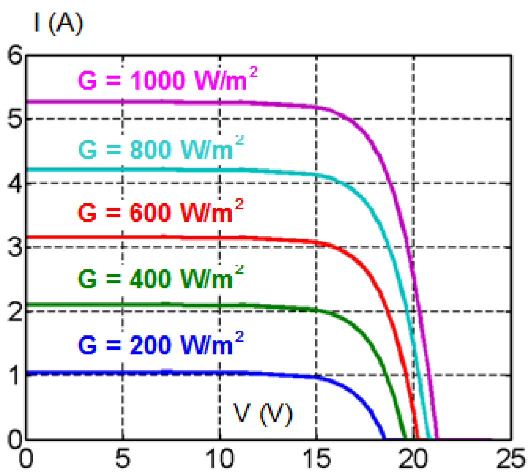


Fig. 6 Effect of temperature changes on I-V curves Fig. 7 Effect of solar irradiance changes on I-V curves.

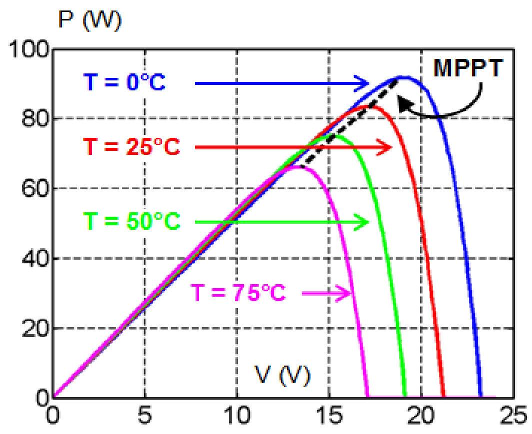


Fig. 8: Effect of temperature changes on P-V curves

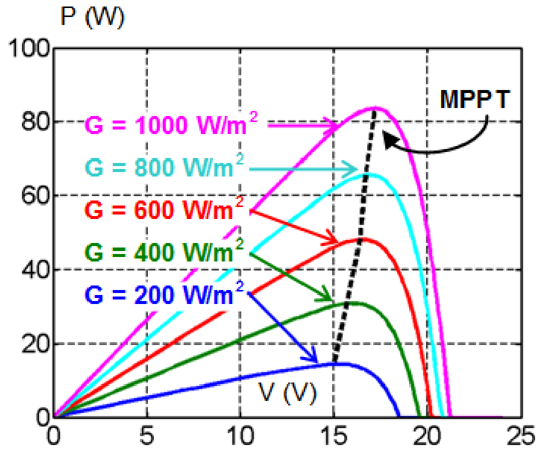


Fig. 9: Effect of solar irradiance changes on P-V curves

It is clear from the previous figures that the output power of PV's is directly proportional with the amount of solar irradiance falling on it, and inversely proportional with its temperature. Figures 8 and 9 show that with the change of the temperature and the solar irradiance the point at which maximum power can be obtained also changes, this means that the array terminal voltage must be varied using DC-DC converters in order to track the maximum power point.

III. Simulation Results and discussion

a) PV module operated in standalone

Simulation diagram of PV module operated in standalone condition shown in figure 10.PV is connected to R load through DC-DC Boost converter with MPPT-PWM controller.

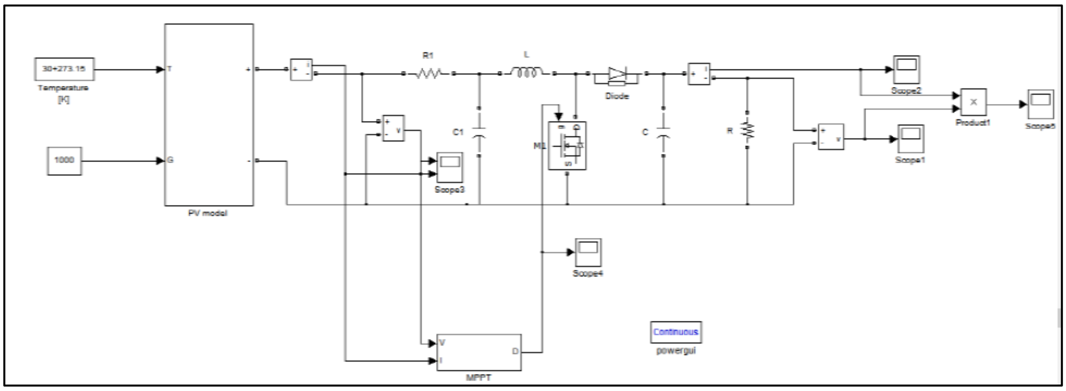
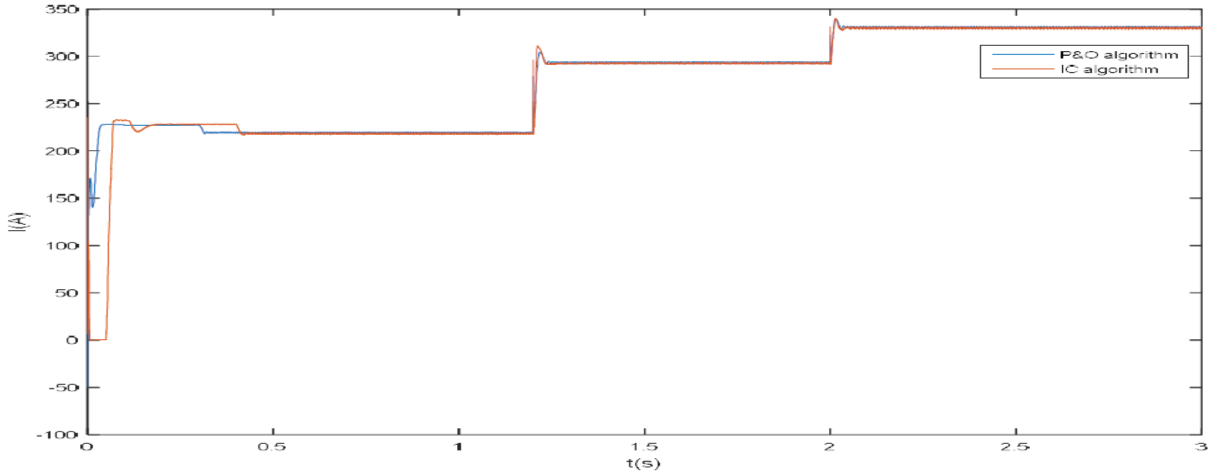
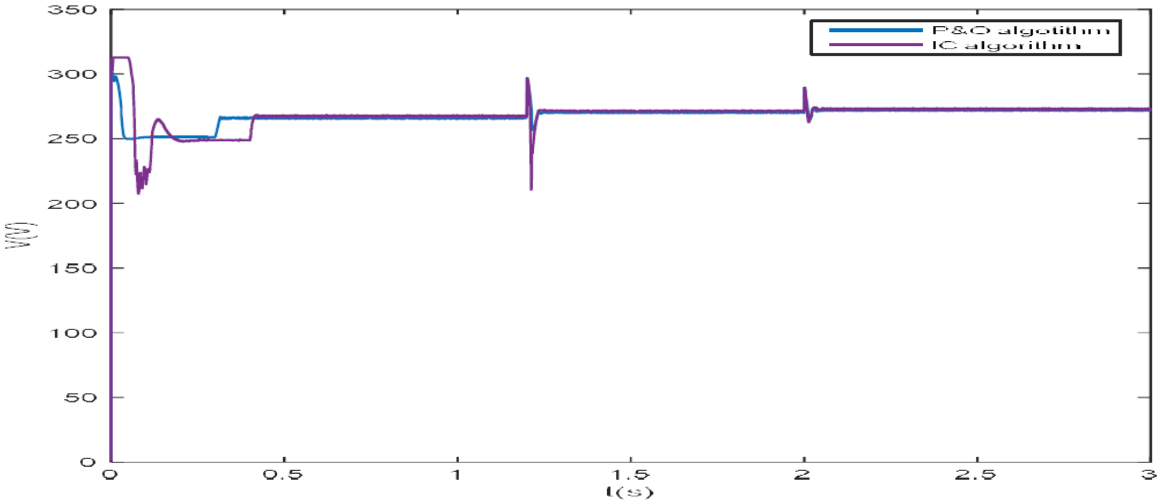


Fig. 10 Simulink Model of P&O MPPT with dc-dc converter

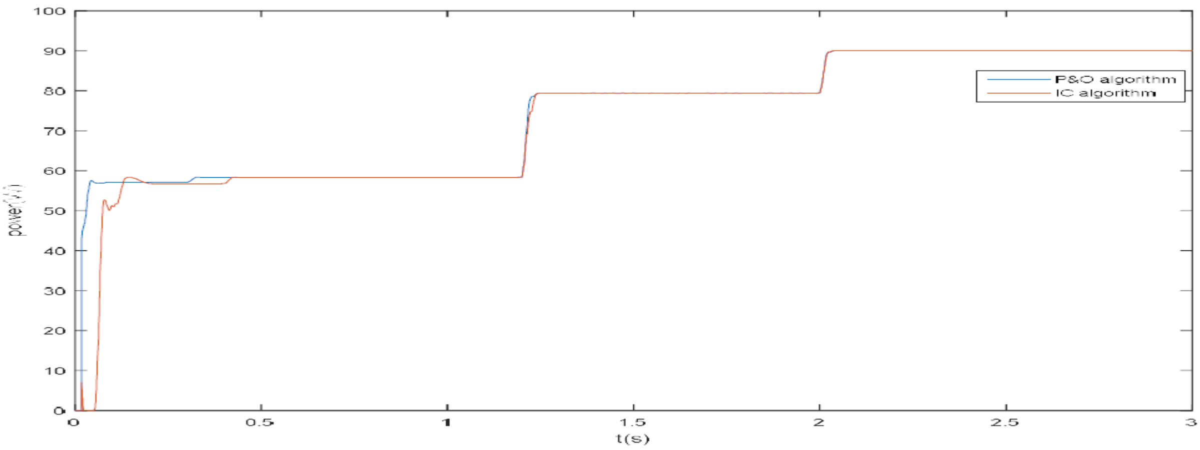
The various equations describing the PV array characteristics are modelled using suitable blocks from the simulink library. The Simulink model of PV array with dc-dc boost converter and P & O MPPT algorithm is implemented, it is also simulated under the same conditions with InC MPPT algorithm. The test results are shown below. The G value changed with respect to time from 0 to 1000 w/m2 with constant temperature, at this condition from the test results load voltage and current having less ripples in InC MPPT method compare to P&O MPPT method. See below figures. Fig. 11c, shows the simulation results of IC and P&O based controller with changing irradiation from low to high level, Simulation starts with constant temperature of 25 °C and 600 W/m. power extraction from PV is more in case of improved InC MPPT compare to P&O.



(a)



(b)



(c)

Figure 11 Simulation results of P&O and IC MPPT algorithm a) Current output b)Voltage output c)Power output

b) PV model -Grid Connected Mode operation

See figure 12 solar PV array connected to grid through improved incremental conductance MPPT controller with DC-DC boost converter. The simulation results are also shown in figure 13,14. Grid power and PV input and output quantities.

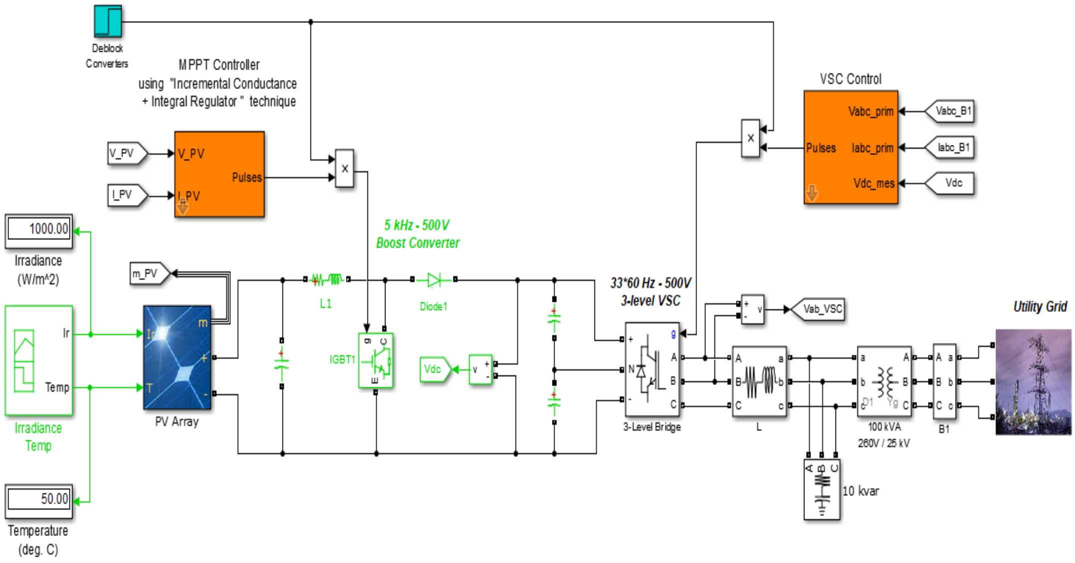
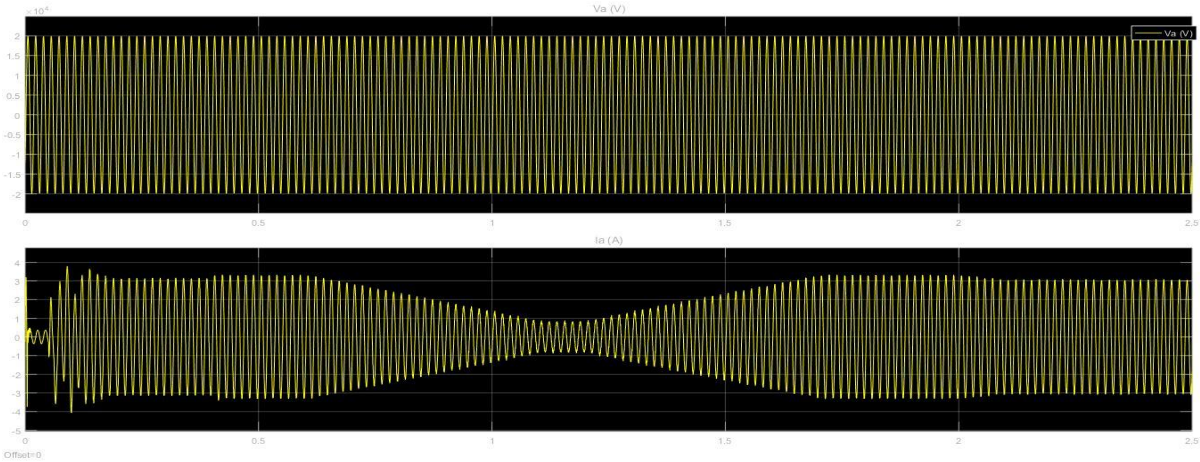
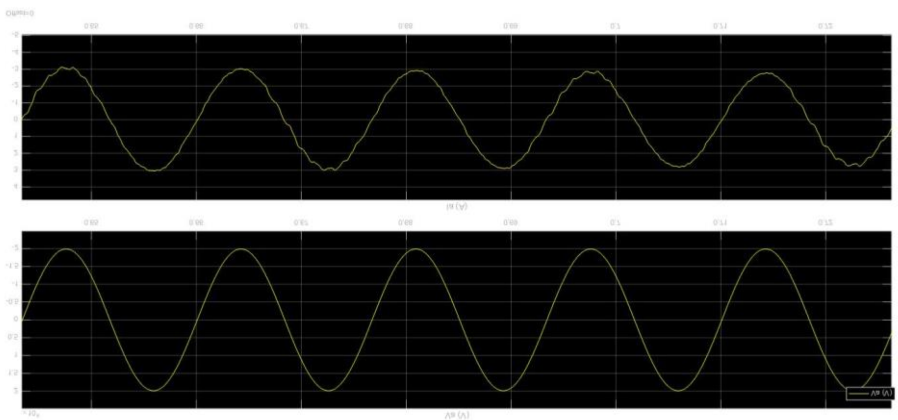


Figure 12 Simulation circuit of 100KW PV grid connected system with InC MPPT



Grid voltage and current total wave form in run time



a) Grid voltage and current zoomed at 6.8 see.

Fig. 13 Grid voltage and current with improved InC MPPT Boost converter

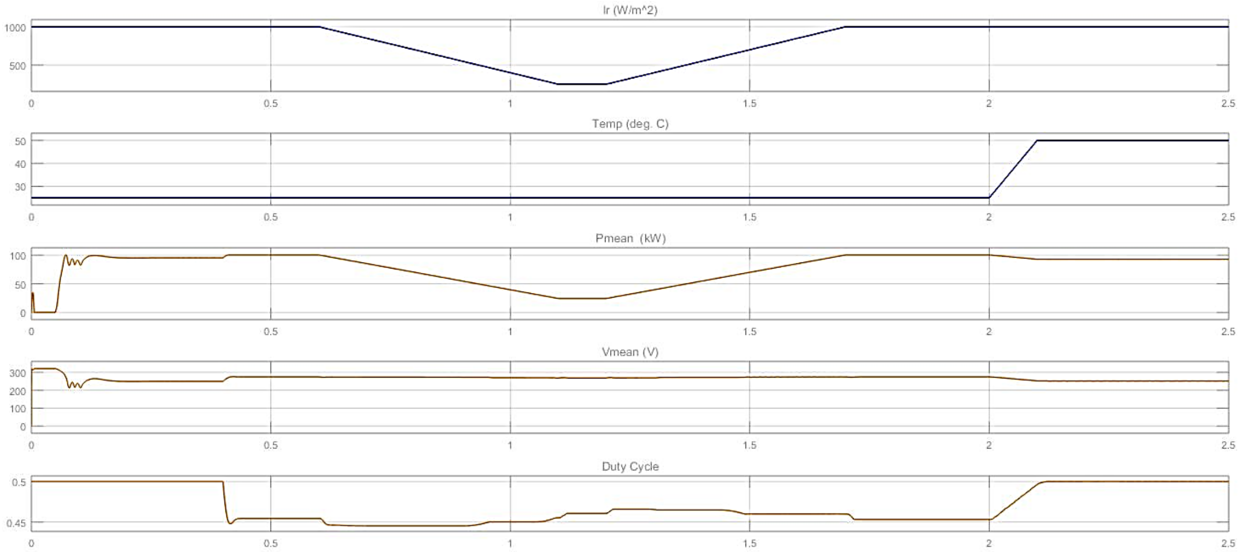


Fig. 14PV output and inputs wave forms a) irradiation b) temperature c) dc PV power (Pmean) d) PV voltage e) Duty cycle

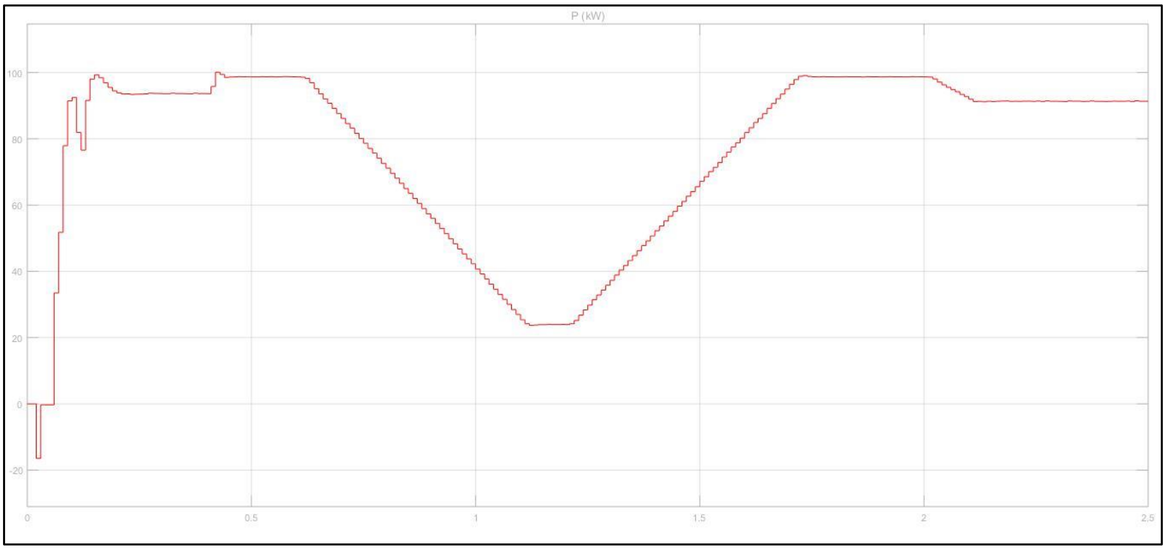


Fig. 15 PV- Grid connected output power at grid side

Simulation circuit of 100KW PV grid connected system with IC MPPT

IV. Discussion:

The simulation results are shown in (Figures 12). These figures represent the performance and effectiveness of both P&O and IC algorithms. From Fig.12 (a), (b), (c), it is noticed that both P&O MPPT and IC MPPT can track the maximum power operating voltage point. For practical implementation, the P&O must be selected for its higher performance compared to the IC controller. Hence the P&O has better performance and closed to the IC and this is shown in Fig.12. P&O has better response time, less oscillation and much more accurate tracking at each step.

TABLE I. MPPT SYSTEM PARAMETERS.

Solar panel model	Sun Power SPR-305
Solar panel wattage	305.266Watt (Wp)
Open circuit voltage for panel	64.2 Volt
Voltage at MPP for panel	54.7 Volt
Short circuit current for panel	5.96 A
Current at MPP for panel	5.57 A
No. of panels in series	5
No. of panels in parallel	66
Total power of system at MPP	305 * 66*5 = 100.65 kW
Boost converter output voltage	500 Volt
Grid voltage (Through X'mer)	50 kVA, 500 V/25 kV
Boost converter inductance	5 mH
Boost converter switching frequency	5 kHZ 5 kHZ
Filter inductance	250 µ H
Inverter	3 Level VSC
Grid length	25 km. (pi section)
Grid load	32 MW, 2 MVar

V. CONCLUSION

The maximum power point tracking algorithm has applied using different control strategies (P&O, Incremental Conductance). In addition to that a controller has to be used in order to achieve the synchronization to the grid and to perform the power management between the system and the electrical grid.This paper presents P-V and I-V characteristics of SunPower (SPR- 305) solar array, the comparison of P&O MPPT and conventional IC MPPT have been developed to examine the performance of both controllers. In order to construct a PV grid connected system, a number of parameters have to be taking into account and to be optimized in order to achieve maximum power generation.

In this work, the aim was to control the duty cycle of the boost converter in order to obtain the maximum power possible from a PV generator, whatever the solar insulation and temperature conditions. Based on the simulation it can be concluded that with the both controllers the PV panel can deliver the maximum power. However, the performance of P&O MPPT is better than the traditional controllers for the nonlinear systems, it has the capability of reducing perturbed voltage when MPP has been recognized. This action directly preserves a more stable output power compared to the conventional IC MPPT where the output power fluctuates around MPP.

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