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Incremental Conductance MPPT Algorithm for PV System Implemented Using DC-DC Buck and Boost Converter

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ABSTRACT
The two basic topologies of switch mode DC-DC converters (Buck and Boost) are analyzed with a view of their use in PV (photovoltaic) systems, as the photovoltaic generator exhibits non-linear characteristics due to the change in environmental condition and load variation. As the efficiency of PV panels is low it becomes mandatory to extract maximum power from the PV panel at a given period of time. Several MPPT algorithms with different types of converters are being proposed for extracting maximum power from the PV panel. It is found that the nature of load plays an important role in the choice of topology. This paper investigates the implementation issues of Incremental Conductance method with Buck and Boost Converters. Mathematical analysis and desirable steady-state operating point of the converters are derived to give satisfactory maximum power point tracking operation.

Keywords - Buck converter, Boost converter, Continuous Conduction Mode (CCM), Incremental Conductance (IC), Maximum power point tracking (MPPT), Photovoltaic (PV) system.

I. INTRODUCTION

The global demand for electric energy has increased continuously over the last few decades. Energy and the environment have become serious concerns in the today’s world [1]. Alternative sources of energy generation have drawn increasing attention in recent years. Clean and renewable energy sources such as photovoltaic (PV) power generation can reply to that demand as the one of key technologies to mitigate global warning [2]. As one of distributed sources, photovoltaic (PV) power generation can be used for grid connected system or either stand alone system to reduce consumption of conventional energy [3].

However the PV system has low efficiency because of the power generated from PV system depends on the environmental condition i.e. variation in insolation and temperature may affect the output characteristics of the PV modules. A lot of research has been done to improve the efficiency of the PV modules. A number of methods to track the maximum power point of a PV module have been proposed to overcome the limitation of efficiency [4]. MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load. DC-DC converter (step up / step down) acts as an interface between the load and the PV module as it serve the purpose of transferring maximum power from the solar PV module to the load. By changing the duty cycle the load impedance is matched with the source impedance to attain the maximum power from the PV panel [5], [6]. Fig. 1 shows the DC-DC converter for operation at MPP.

In recent years, a large number of techniques have been proposed for tracking the maximum power point [5], [7]. Fractional open-circuit voltage and short-circuit current [8], stragies provide a simple and effective way to acquire the maximum power. Hill climbing and perturb and observe (P&O) methods are widely applied in the MPPT controllers due to their simplicity and easy implementation [9]-[11]. The P&O methods involves a perturbation in the operating voltage of the PV array, Incremental conductance (IC) method, which is based on the fact that the slope of the PV array power versus voltage curve is zero at the MPP has been proposed to improve the tracking accuracy and dynamic performance under rapidly varying conditions [12]. An improved MPPT algorithm for PV sources was proposed to reduce the tracking time where a dc-dc boost converter was used to track the MPP and was brought out that tracking performance depends upon the tracking algorithm used [13].

The overall performance of the PV system depends on the type of the DC-DC converter used and the algorithm used for tracking the MPPT both of this parameter plays an important role in increasing the performance of the PV array [13]. In this paper, comparative analysis of incremental conductance with buck as well as boost converter is presented by the help of Matlab & Simulink.

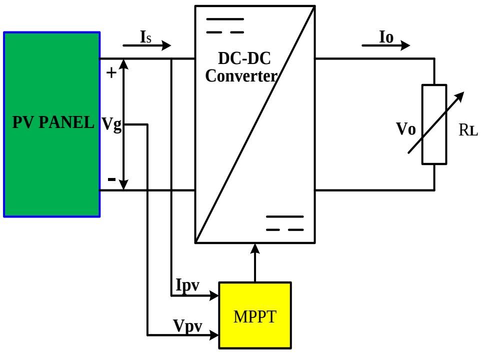


Fig. 1 DC-DC converter for operation at MPP

II. MODELING AND CHARACTERISTICS OF PV MODULE

The PV cell is a P-N semiconductor junction diode that converts solar energy in to electrical energy [14]. The equivalent circuit of a PV cell is shown in Fig.2

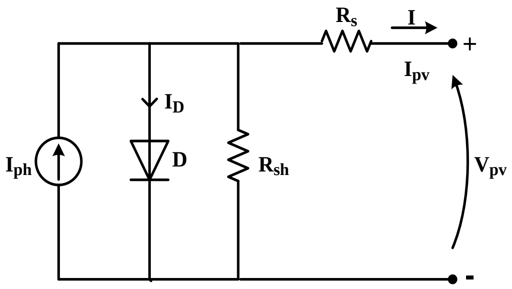


Fig. 2 Single diode model of PV cell

The basic equation from the theory of semi-conductor that mathematically describes the I-V characteristics of the ideal PV cell is given in eq (1-4), [14].

Module photo-current (I_{ph}) is given by eq (1), [15].

$$I_{ph} = \frac{[I_{scr} + K_i(T - 298)]S}{1000} \quad (1)$$

Module reverse saturation current (I_{rs}) is given by eq (2), [15].

$$I_{rs} = \frac{I_{sc}}{e^{(qVoc/NsKAT)} - 1} \quad (2)$$

Module saturation current (I_0) is given by eq (3), [15].

$$I_0 = I_{rs}\left[\frac{T}{Tr}\right]^3 e^{\frac{qE_{go}}{BK(1/Tr-1/T)}} \quad (3)$$

The current output of PV-module (I_{pv}) is given by eq (4), [15].

$$I_{pv} = N_p I_{ph} - NI_0\left[e^{\frac{q(V_{pv}+I_{ph}R_s)}{N_s AKT}} - 1\right] \quad (4)$$

Where,

V_{pv} is the output voltage of a PV module, T_r is the reference temperature =298K, T is module operating temperature in Kelvin, A is an ideality factor=1.6, K is the Boltzmann constant = 1.3805×10^{-23}J/K, q is the Electron charge =1.6×10^{-19}C, Rs is the series resistance of PV module , I_{sc} is the short circuit current of a PV module, K_i is the temperature co-efficient =0.0017, S is the reference insolation =1000W/m^2 , E_{go} is the band gap os silicon = 1.1eV, V_{oc} is the open circuit voltage [14].

The effect in the change of solar insolation level is illustrated from the output characteristics of PV module fig. 3 and 4 shows the typical I-V and P-V characteristics for different solar insolation keeping the ambient temperature constant at 25^{0}C. As the insolations increases the output current increases significantly which results in the increase of output power [14].

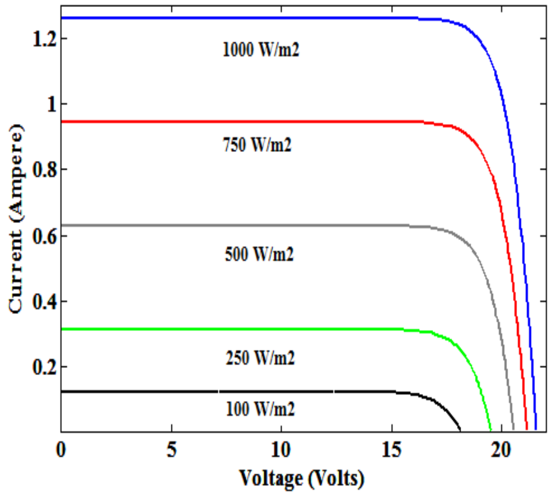


Fig. 3 Characteristic curve of (Ipv-Vpv) at different solar insolation

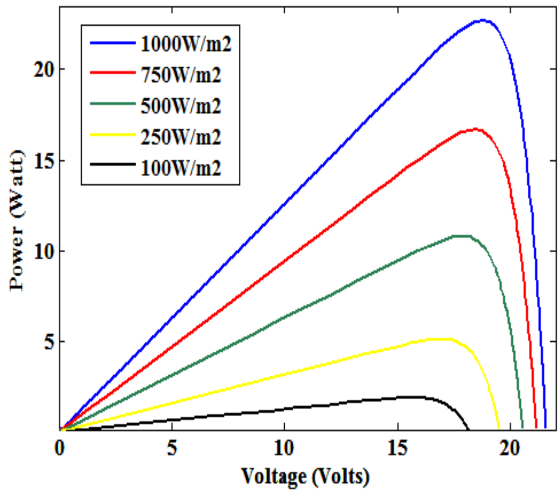


Fig. 4 Characteristics curve of (Ppv-Vpv) at different solar insolation

III. DC-DC CONVERTER FOR PV SYSTEM

The basic function of any switch mode dc-dc converter in any PV system is to work as intermediate power processor which changes the levels of voltage and current such that maximum power can be extracted from the PV array [16], [17]. For PV system with batteries the MPP of commercial PV module is set above the charging voltage of batteries for most combinations of insolation and temperature. A buck converter can operate at the MPP under most conditions, but it cannot do so when MPP goes below the battery charging voltage under a low insolation and high- temperature condition. Thus, the additional boost capability can slightly increase the overall efficiency [15].

3.1 DC-DC BUCK CONVERTER

The dc-dc buck converter converts a higher dc input voltage to lower dc output voltage. The basic dc-dc buck converter topology is shown in Fig. 5. It consists of a controlled switch S_W , an uncontrolled switch diode (D), an inductor L, an capacitance C and a load resistance R [16].

In the description of converter operation it is assumed that all the components are ideal and also the converter operates in Continuous conduction mode (CCM). In CCM operation the inductor current flows continuously over one switching period. The switch is either ON or OFF according to the switching position this results in two circuit states. The first sub-circuit state is when the switch is turned ON, the diode is reverse biased and inductor current flows through the switch [18],

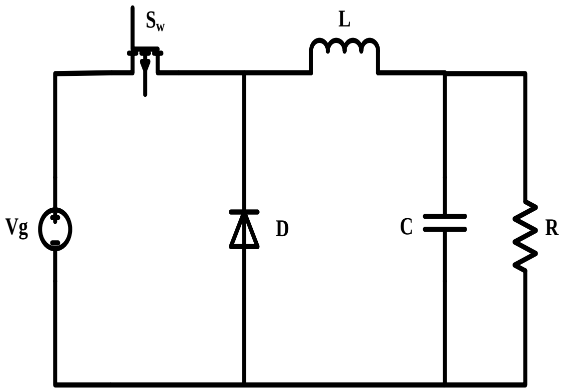
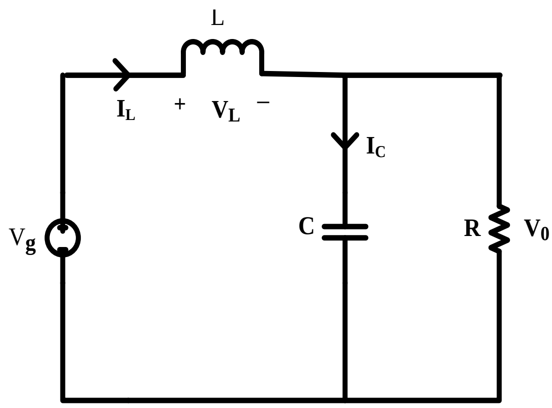
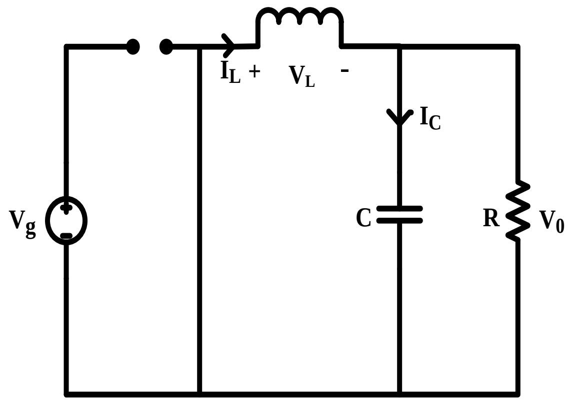


Fig. 5 DC-DC buck converter topology



(a)



(b)

Fig.6 .Buck Converter Circuit when switch:- (a) turns ON (b) turns OFF

which is shown in Fig. 6(a). The second sub-circuit state is when the switch is turned OFF and current freewheels through the diode [19] which is shown in Fig. 6(b).

When switch S_W is ON and D is reverse biased, then inductor current i_L and capacitor voltage V_C are given by eq. (5) and (6).

$$\frac{di_L}{dt} = \frac{1}{L} V_g - V_o \tag{5}$$

$$\frac{dv_0}{dt} = \frac{dv_c}{dt} = \frac{1}{C} i_c \tag{6}$$

When the switch is OFF and D is forward biased, i_L and capacitor voltage V_C are given by eq. (7) and (8).

$$\frac{di_L}{dt} = -\frac{1}{L} V_0 \tag{7}$$

$$\frac{dv_0}{dt} = \frac{dv_c}{dt} = \frac{1}{C} i_c \tag{8}$$

The state space representation for converter circuit configuration can be expressed as given in eq. (9)

$$\frac{dx}{dt} = \begin{Bmatrix} A_1 x + B_1 U \text{when Sw is closed} \\ A_2 x + B_2 U \text{when Sw is opened} \end{Bmatrix}$$

Where

$$\mathbf{X} = [\mathbf{x}_1 \mathbf{x}_2]^T = [\mathbf{V}_c \mathbf{i}_L]^T \tag{9}$$

The state transition matrix A, and B input matrix are system matrices as shown in eq. (10)

$$A_1 = A_2 = \begin{bmatrix} \frac{-1}{L}\left(r_L + \frac{ar_C}{R}\right) & \frac{-a}{RL} \\ \frac{1}{C}\left(1 - \frac{ar_C}{R}\right) & \frac{-a}{RC} \end{bmatrix}, B_1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}, B_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{10}$$

Where $a = \frac{R}{R + r_C}$

3.2 DC-DC BOOST CONVERTER

A boost converter can be also called as the step up converter because the DC voltage output is higher than its DC voltage input [20]. It is a sort of power converter, which is composed by two semi-conductor switches (Diode and Mosfet) and one energy storage element. The basic dc-dc boost topology is shown in Fig. 7. Boost converter operates in two modes.

During the mode-1 operation which is shown in Fig. 8 (a) when switch (S_w) is closed the inductor current get charged through the input source and stores the energy. In this mode inductor current rises (exponentially) but for simplicity we assume that the charging and discharging of the inductor are linear. The diode blocks the current flowing and so the load current remains constant which is being supplied due to discharging of the capacitor

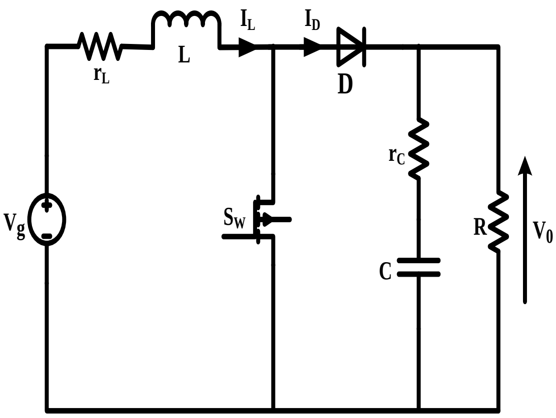
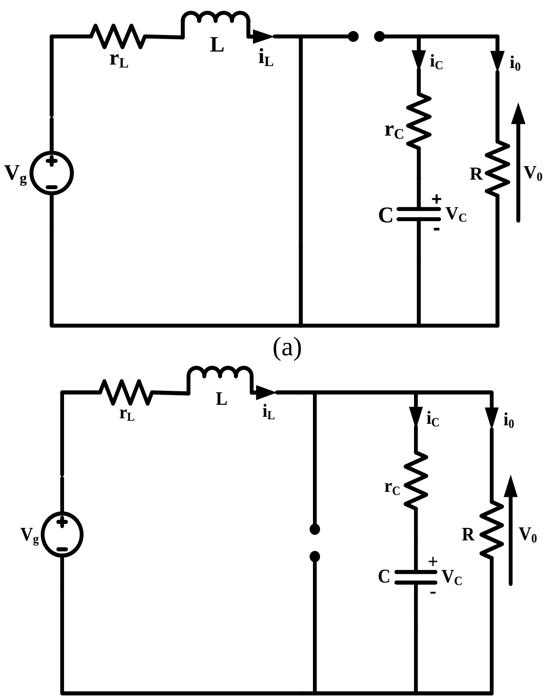


Fig. 7 DC-DC boost converter topology



(b)

Fig. 8 Boost converter circuit (a) when switch is ON (b) when switch is OFF

Inductor current and capacitor voltage equation for mode-1 are given by eq (11) and (12)

$$\frac{di_L}{dt} = \frac{1}{L}\left[V_g - i_L r_L\right] \tag{11}$$

$$\frac{dV_C}{dt} = \left[\frac{-1}{C\left(R + r_C\right)}\right]V_C \tag{12}$$

During the mode-2 operation which is shown in Fig. 8 (b) the switch (S_w) is open and so the diode become short circuited. The energy stored in the inductor get discharged through opposite polarities which charge the capacitor. The load current remains constant throughout the operation. Inductor current and capacitor voltage equation for mode-2 are given by eq (13) and (14)

$$\frac{di_L}{dt} = \frac{1}{L}\left[V_g - i_L(r_L + ar_C) - aV_C\right] \tag{13}$$

$$\frac{dV_C}{dt} = i_L\left[\frac{1}{C} - \frac{ar_C}{RC}\right] - \frac{a}{RC}V_C \tag{14}$$

The state space analysis, Input transition matrix, Output transition matrix are given by eq. (15)

$$A_1 = \begin{bmatrix} \frac{-r_L}{L} & 0 \\ 0 & \frac{-1}{C(R + r_C)} \end{bmatrix}, A_2 = \begin{bmatrix} \frac{-1}{L}(r_L + ar_C) & \frac{-aV_C}{L} \\ \frac{1}{C} - \frac{ar_C}{RC} & \frac{-a}{RC} \end{bmatrix}, B_1 = B_2 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix},$$

$$E_1 = \begin{bmatrix} 0 & a \end{bmatrix}, E_2 = \begin{bmatrix} ar_C & a \end{bmatrix}, F_1 = F_2 = \begin{bmatrix} 0 \end{bmatrix} \tag{15}$$

IV. INCREMENTAL CONDUCTANCE MPPT ALGORITHM

A typical solar panel converts about 30-40 % of the incident solar insolation in to electrical energy [20]. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to maximum power transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance [21], [22]. Hence the problem of tracking the maximum power point reduces to an impedance matching problem. There are several techniques to track the MPPT but this paper deal with Incremental conductance

4.1 INCREMENTAL CONDUCTANCE ALGORITHM

Incremental Conductance method uses the information of source voltage and current to find the desired operating point. From the P-V curve of a PV module shown in Fig. 4 it is clear that slope is zero at maximum point [23], so the formulas are as follows

$$\left(\frac{dP}{dV}\right)mpp = \frac{d\left(VI\right)}{dV} \tag{16}$$

$$0 = I + V\left(\frac{dI}{dV}\right)MPP \tag{17}$$

$$\left(\frac{dI}{dV}\right)MPP = -\frac{I}{V} \tag{18}$$

Equation (18) is the condition to achieve the maximum power point, when the variance of the output conductance is equal to the negative of the output conductance, the module will work at the maximum power point [21]. The flow chart of the incremental conductance is shown in Fig. 9.

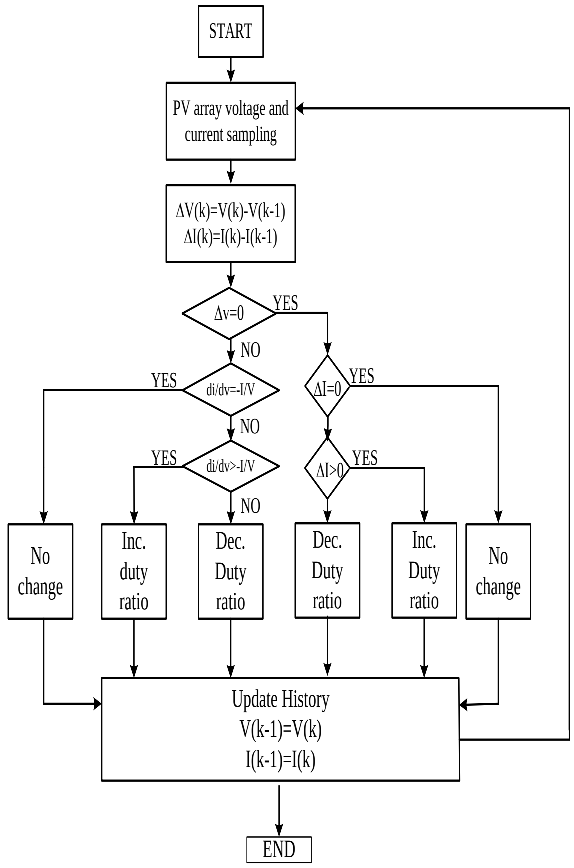


Fig. 9 Flow chart of the Incremental Conductance method

In this flow chart, V(k) is the new detection voltage and I(k) is the new detection current, V(k-1) and I(k-1) is previous detection values. When the new value is read in to the program, it calculates the previous value compare with the new one, and then determine the voltage differentials is zero or not, according the voltage differentials is zero, the current difference can be determined zero or not. If both of them are zero, it shows that they have the same value of impedance and the value of duty ratio will remain the same as before. If the voltage differential is zero, but the current differential is not zero, it shows that the insolation has changed. When the difference of the current values is greater than zero, duty ratio will increase, when the difference of the current value is less than zero the duty ratio will decrease. If the voltage differential is not zero determine it whether satisfy the eq. 18 or not, when eq. 18 is satisfied the slope of the power curve will be zero that means the system is operating at MPP, if the variance of conductance is greater than the negative conductance values, it means the slope of the power curve is positive and the duty ratio is to be increased, otherwise it should be decreased [22], [23].

The intersection of current-voltage (I-V) curve and the load line gives the operating point of directly coupled PV module to the load [5] which is shown in the fig.10

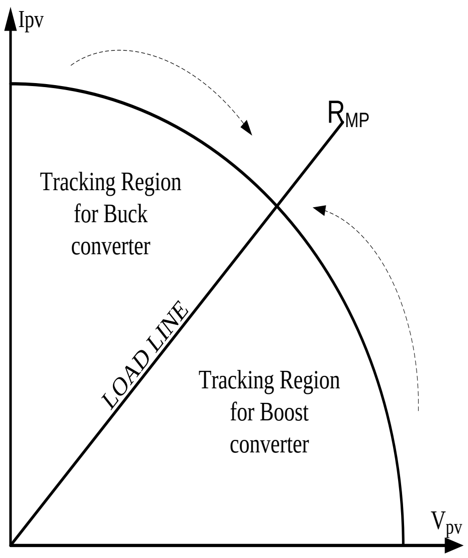


Fig. 10 Tracking of optimal resistance for Buck and Boost converter

This point should be at the MPP of the PV module to extract the maximum power. The performance of DC-DC converter depends on the input impedance and the connected load R_L. For the boost converter the selected load resistance R should be greater than the R_{MP} i.e ($R>R_{MP}$). And the tracking region for boost converter lies below the load line. For the buck converter the selected load resistance R should be less than the (R_{MP}) ($R<R_{MP}$) [24], [25]. And the tracking region for buck converter operation should be above the load line.

For boost converter voltage gain is given by eq. (19)

$$\frac{V_0}{V_g} = \frac{1}{1-D} \tag{19}$$

Load matching resistance for boost converter is given by eq. (20)

$$R_{in} = R_L(1-D)^2 \tag{20}$$

For buck converter voltage gain and load matching resistance expression are given in eq. (21) and (22)

$$\frac{V_0}{V_g} = D \qquad (21)$$

$$R_{in} = \frac{R_L}{D^2} \qquad (22)$$

Where V_g,V_0 are the input and output voltages, R_{in} is the input resistance seen by the PV panel at the source side of the converter, R_L is the resistance which is connected at the load side of the converter and D is the duty ratio [26].

V. RESULT AND DISCUSSION

All simulation results for buck and boost converter have been recorded to make sure the comparison of the circuit can be determined accurately. The input, output voltages, current and power is the main comparisons to take in to the consideration. The complexity and simplicity of the circuit have been determined based on the literature. For checking the robustness of the converters a step change in insolation is given at a simulation time of 0.05 which changes insolation from 500W/m^2 to 1000W/m2 at a fixed ambient temperature 25^{0}c. Fig. 11, 12 and 13 shows the variation in input voltage, current, power and Fig. 14, 15 and 16 shows the variation in output voltage, current and power respectively. From the expression shown in eq (20) it is clear that the load connected across the boost converter should be maximum then the Rin (resistance seen by PV panel) show a fixed resistance of 100Ω is connected across the load side of the boost converter to extract the maximum power from the PV panel. Fig. 17 shows the change in duty cycle with change in solar insolation to provide the suitable duty ratio for the converter so that it may operate at the MPP.

Similarly form the eq (22) the load matching resistance for the buck converter i.e RL should lower than the input resistance. A fixed resistance of 4.5Ω is connected at a load side of buck converter to match the input resistance. Fig. 18, 19 and 20 shows the variation in input voltage, current and power for the change in insolation level from 500W/m2 to 1000W/m2 at a simulation time of 0.05. Fig. 21, 22 and 23 shows the change in output voltage, current and power respectively. Change in duty cycle for buck converter is shown in Fig. 24

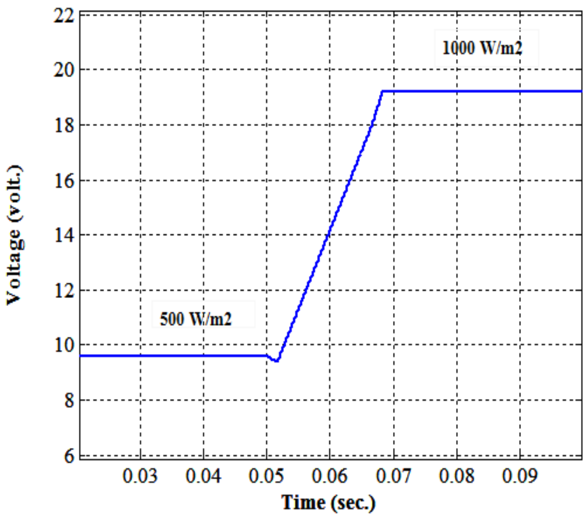


Fig.11 Input voltage of boost converter

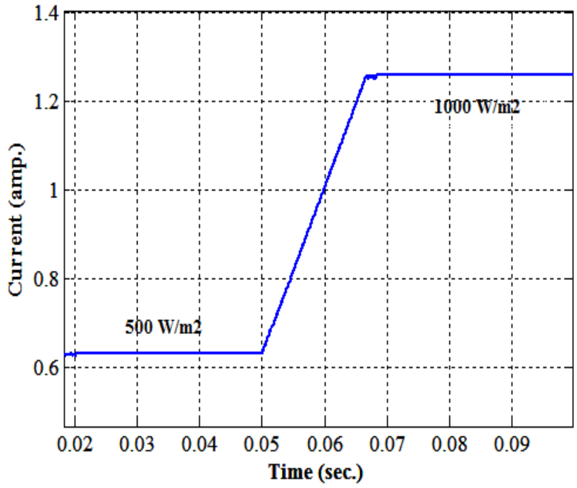


Fig. 12 Input current of boost converter

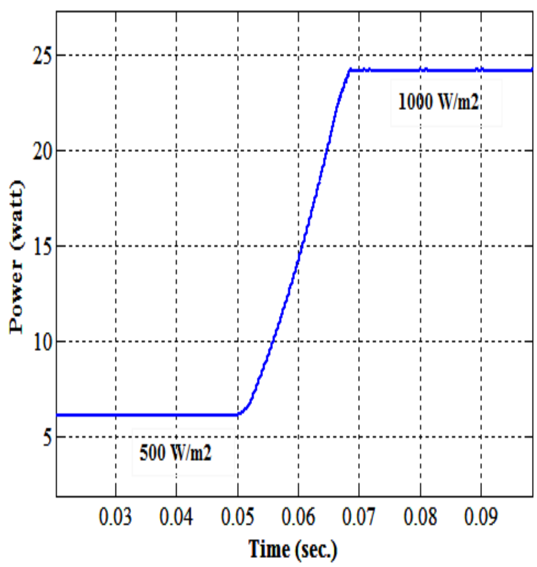


Fig. 13 Input power of boost converter

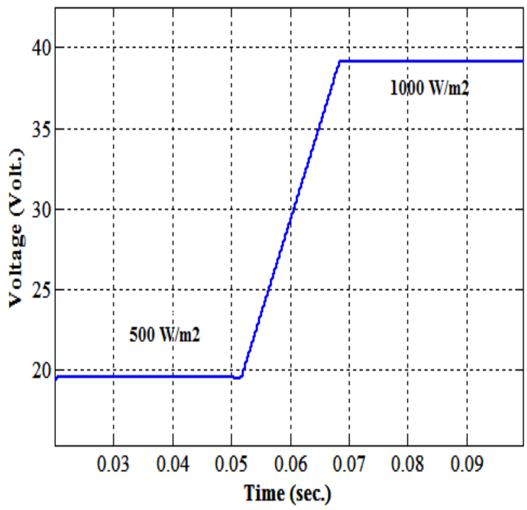


Fig. 14 Output voltage of boost converter

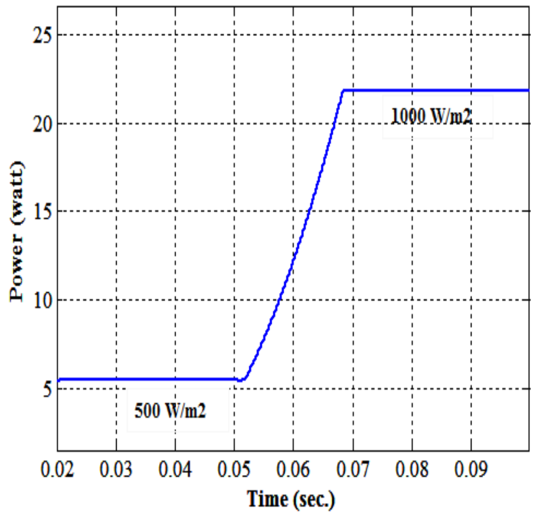


Fig. 16 output power of boost converter

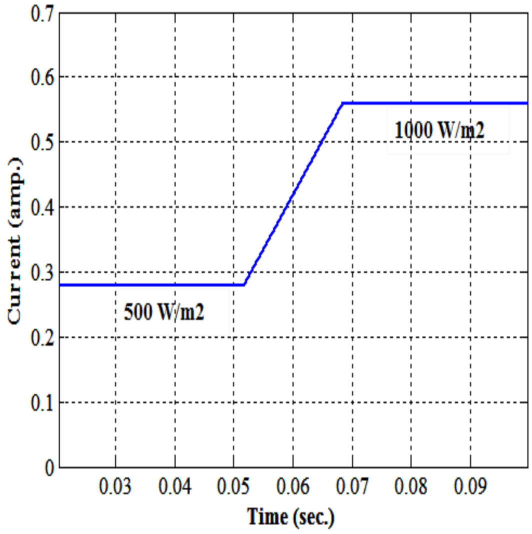


Fig.15 Output current of boost converter

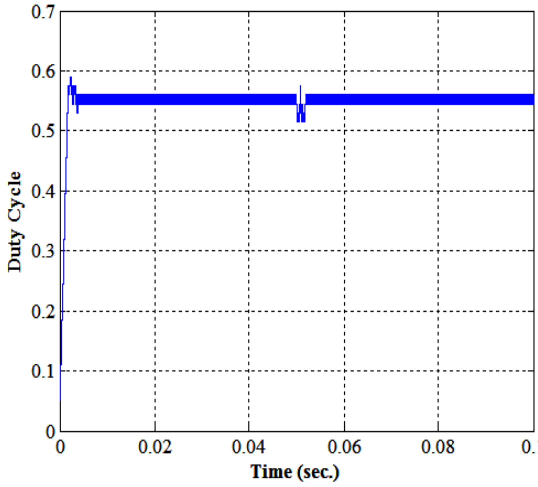


Fig. 17 Duty cycle for boost converter

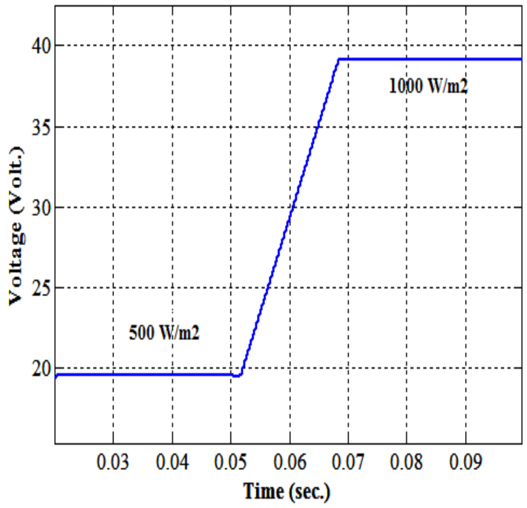


Fig. 15 Output voltage of boost converter

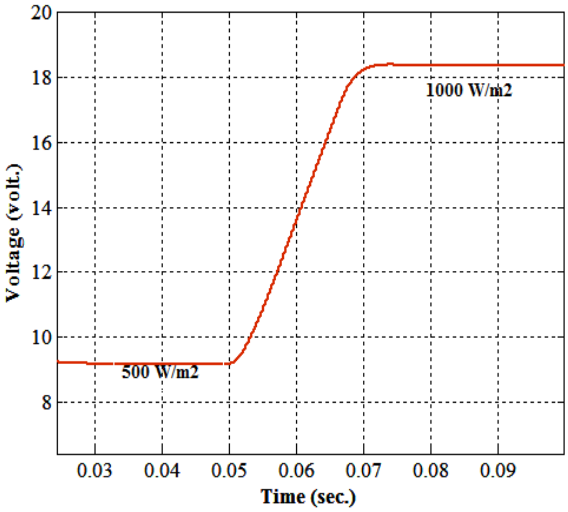


Fig.18 Input voltage of buck converter

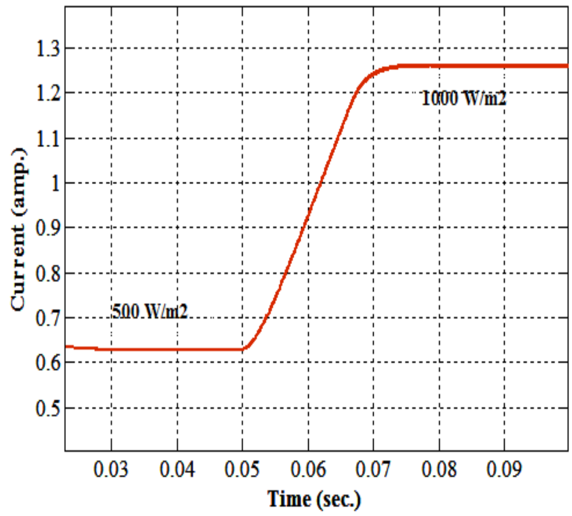


Fig. 19 Input current of pv panel

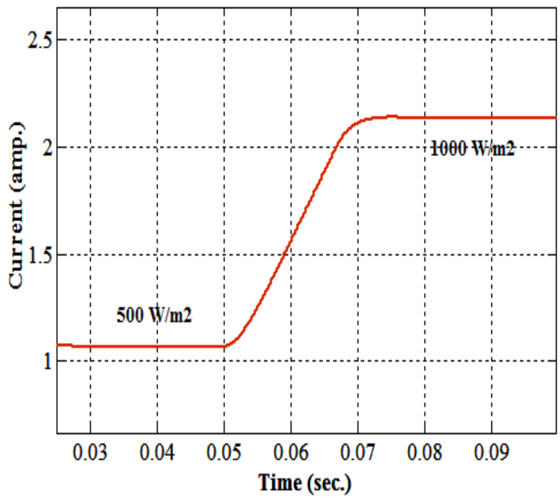


Fig.22 Output current of buck converter

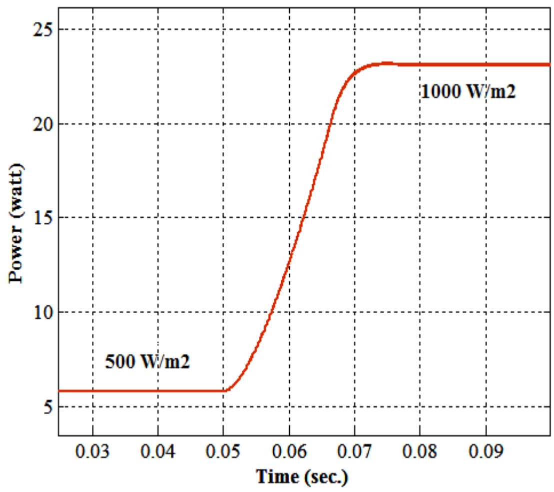


Fig. 20 Input power of buck converter

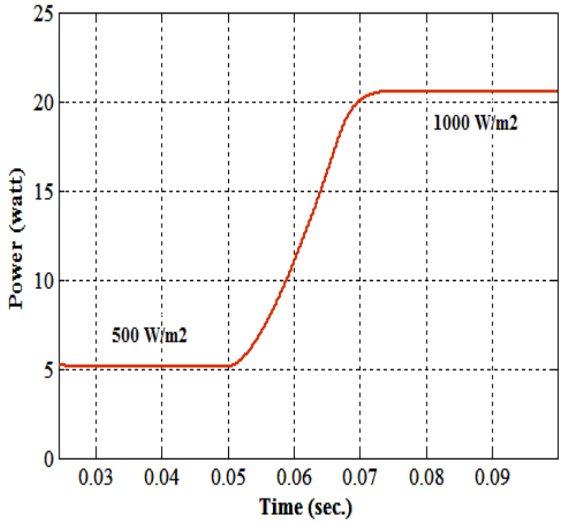


Fig. 23 output power of buck converter

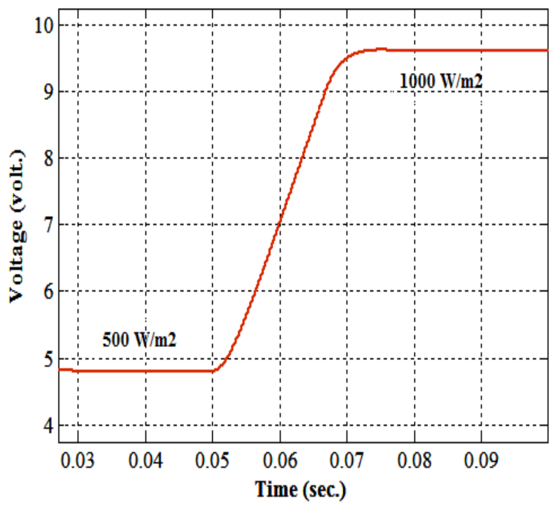


Fig.21 output power of buck converter

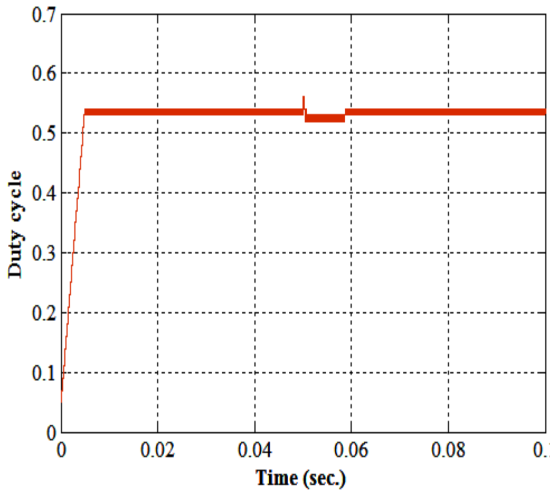


Fig. 24 Duty cycle modulation of buck converter

VI. CONCLUSION

A standalone photovoltaic system connected with buck and boost converter had been implemented using IC MPPT algorithm for extracting maximum power at different environmental condition. The nature of load plays an important role during the operation of DC-DC converter operating at MPPT by analyzing both the converter we have found that for the Boost converter operating at MPP the load resistance R should be greater than R_{mp} ($R>R_{mp}$). Similarly for buck converter ($R<R_{mp}$). This study reveal that the IC algorithm gives the satisfactory results with both the converter and it get less confuse due to change in environmental conditions.

VII. ACKNOWLEDGEMENTS

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