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CONDITIONING OF SOLAR POWERED LED LIGHTNING SYSTEM WITH DC-DC SEPIC CONVERTER

Sakshi Shrivastava[1], Dr.Anmol Ratna Saxena[2], Dr.A.K. Wadhwani[3]

[1] Electrical Engineering Dept., MITS, Gwalior, India
[2]Electrical and Electronics Dept., NIT Delhi
[3]Electrical Engineering Dept., MITS Gwalior, India

Abstract— This paper presents the designing and performance of DC-DC SEPIC (Single Ended Primary Inductance) converter (in continuous conductance mode) driven Light emitting diode (LED) Lamps powered by Photovoltaic (PV) System. Since the efficiency of PV system is low, thus Maximum Power Point Technique is employed to maximize the power and to improve the efficiency. The mathematical model of the PV array is developed and transformed into MATLAB/Simulink and Incremental Conductance (InC) algorithm is implemented to improve the performance of PV system. The MPPT algorithm generates proper duty ratio for interfacing DC-DC SEPIC converter driving LED Lamps with PV system. The performance is evaluated under gradual and rapidly changing environment and found that Incremental Conductance tracks properly under steady state and changing weather condition.

Keywords—Light-emitting diode (LED), Maximum Power Point Tracking (MPPT), Photovoltaic (PV) system, Incremental Conductance (InC).

I. INTRODUCTION

With the depletion of Fossil fuel and increase in energy demand, there is a need to move towards the other sources of energy. Various known renewable sources of energy are Solar, wind, Biomass. Among all alternative sources, Solar is best suited, since it is free, clean, abundant and distributed over the earth and works as the primary factor of all other processes of energy production on earth [1]. The use of Stand-alone Photovoltaic system has increased in rural areas and towns. Conventional street lightning is energy intensive and can cause a high cost to local government. Thus Solar Powered light emitting diodes (PLEDs) lighting system can save a lot, because of the absence of moving parts thus no noise and wear. Still Photovoltaic suffers with two principal barriers: high installation cost and low energy conversion efficiency .For the increase in ratio of power/cost of installation it is important that PV panel operates at its maximum power point (MPP) for the absorption of maximum possible power. The combination of PV panel with power LEDs called as new green light sources. Battery is the energy storing element used in this system. Energy measurement and state measurement is the major issue since fast charging capability may not be obtained because of weather uncertainty thus reducing the life of the battery. The process of charging and discharging of battery needs to be made correctly for maximizing the use of stored energy. For reducing the size of PV panel it is important to maximise the power transference from PV panel to battery using some maximum power point tracker like constant voltage (CV) method, Constant Current method, Perturb and Observe, Incremental Conductance, Fuzzy control method and Artificial neural Network etc.[2] They differ on the basis of performance and implantation. Constant voltage and constant current method's use is limited to few hundred watts only. On the other hand fuzzy control method and artificial neural network can work for higher ranges. Among all Perturb and observe and Incremental Conductance uses the same concept by setting the operating point to represent voltage near to maximum power point (MPP) [3]-[6].

Light Emitting Diode (LED) has become a commonly used solid-state light source in general lighting application since it does not contain harmful mercury content as compared to conventional

fluorescent lamp. The longer life and smaller size of LED has come up as an attractive replacement of traditional incandescent and fluorescent lightings for efficient illumination use [7]-[10]. Multiple LED lamps are connected in parallel fashion so as to obtain enough lighting levels. However, attention needs to be given for LEDs application. The major issue is LEDs junction temperature, which affects efficiency, spectral power distribution, lifetime and forward voltage drop.
I-V characteristics of LED show that it's a current controlled device. Any change in the forward current results in the change in its luminous intensity.

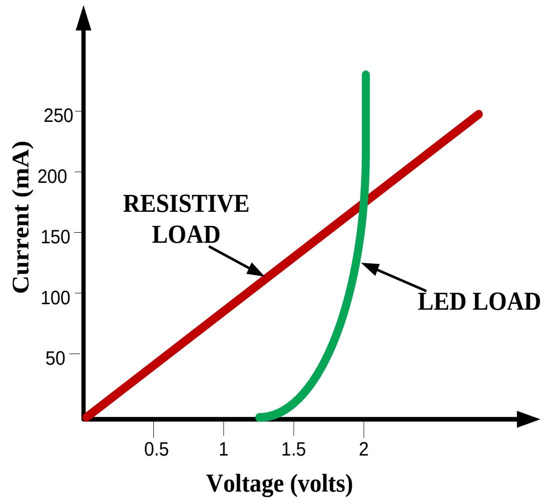

Fig.1 I-V characteristics of LED load and resistive load

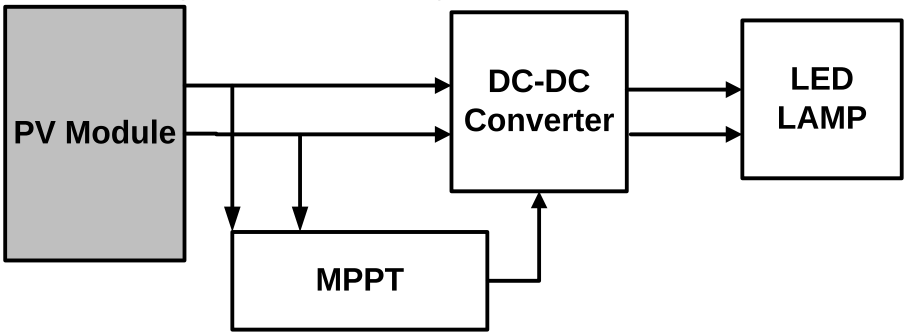

Fig. 2 Proposed System model

In this Paper, the SEPIC converter with their parasitic element is presented as a driver for LED lamp. For the transfer of maximum power from Photovoltaic system Incremental Conductance method has been employed and system is tested under rapidly and slowly changing irradiance. The DC-DC converter helps in matching the load impedance with the panel's internal impedance by adjusting the duty ratio provided from MPPT controller. Performance is discussed in results.

II. MODELING AND CHARACTERISTICS OF PV MODULE

The conversion of 'photon' energy into 'voltage' is known as Photovoltaic effect. The PV cell is basically a P-N semiconductor junction diode that converts solar energy into electrical energy [11].The Solar cell has very low output voltage, thus these are connected in series and parallel combination according to the required voltage and power requirement. Fig.3 shows the equivalent circuit of solar cell, which is the simplest equivalent circuit of PV cell, a current source in parallel with a diode [12]-[15].

Volume 0X, Issue 0Y, [Month – 2015] ISSN (Online):2349–9745 ; ISSN (Print):2393-8161

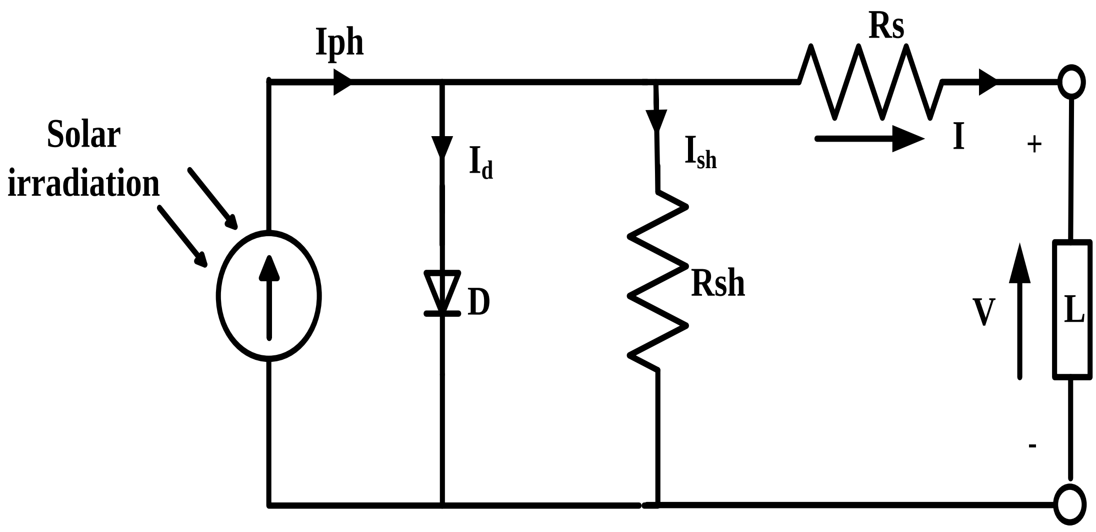

Fig.2 Equivalent circuit of Solar Cell

On applying Kirchhoff's current law in Fig. 2, equation form is

$$I_{pv} = I_{ph} - I_d - I_{sh} \quad (1)$$

Where, Iph is the photocurrent, Id is the diode internal diffusion current.

$$I_{ph} = \frac{S}{1000}\left[I_{scr} + K_i\left(T - T_{ref}\right)\right] \quad (2)$$

Here, Iscr is short circuit current at reference temperature of 25^{0}C and solar irradiance (S) of 1000W/m2, Ki is the temperature coefficient of cell, T and Tref is the operating and reference temperature respectively in Kelvin (K).

$$I_d = I_o\left[\exp\left(\frac{q\left(V_{pv} + I_{pv}.R_s\right)}{A.K.T}\right) - 1\right] \quad (3)$$

q is the charge of electron(=1.61*10-19C), A is the diode ideality factor, K is Boltzmann's constant. Io represents diode saturation current given by

$$I_o = I_{rs}\left(\frac{T}{T_{ref}}\right)^3 \exp\left[\frac{q.E_g}{A.K}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \quad (4)$$

Irs is the cell reverse saturation current in ampere (A). Eg is the semiconductor's band-gap energy. Finally the equivalent of the relationship between output current and voltage can be written as

$$I = I_{ph} - I_o[e^{\frac{q(V+IR_s))}{A.k.T}} - 1] - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \quad (5)$$

Here Rs and Rsh is the equivalent series and shunt resistance of PV cell. The value of Rs considers is very small and that of Rsh is very high, so under ideal conditions they are neglected. Eq.5 was used in Matlab/Simulink to set up electrical characteristics of PV cell, at different irradiation level and temperature level. The I-V and P-V characteristics at various insolation and temperature level are shown in Fig.4 and 5.

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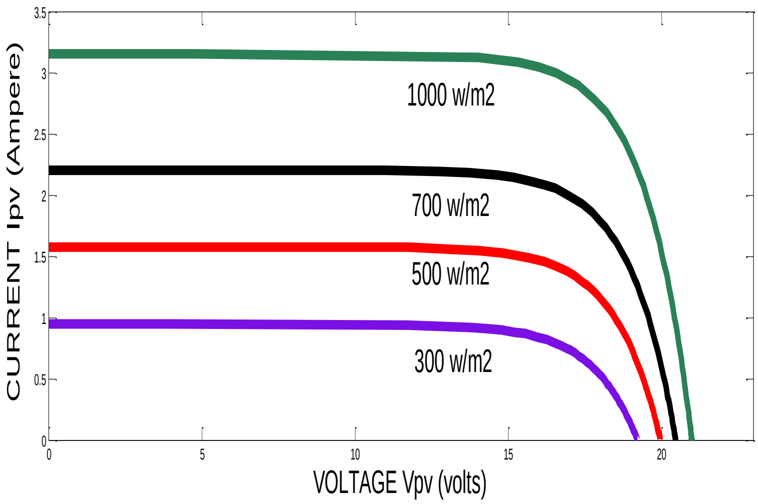

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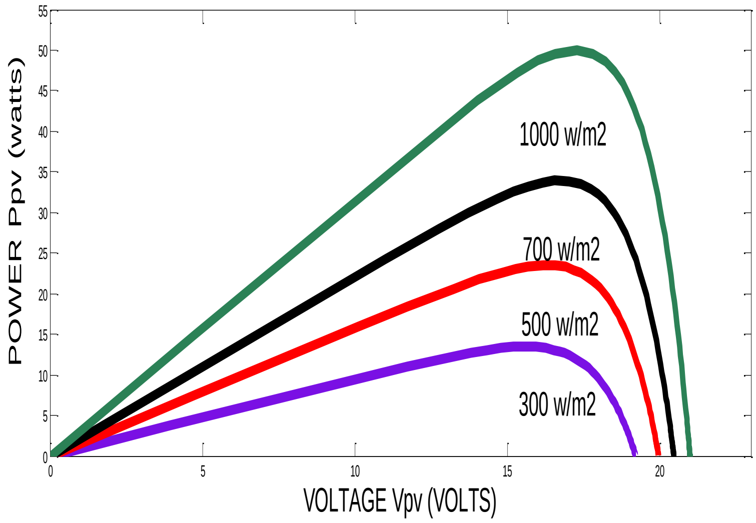
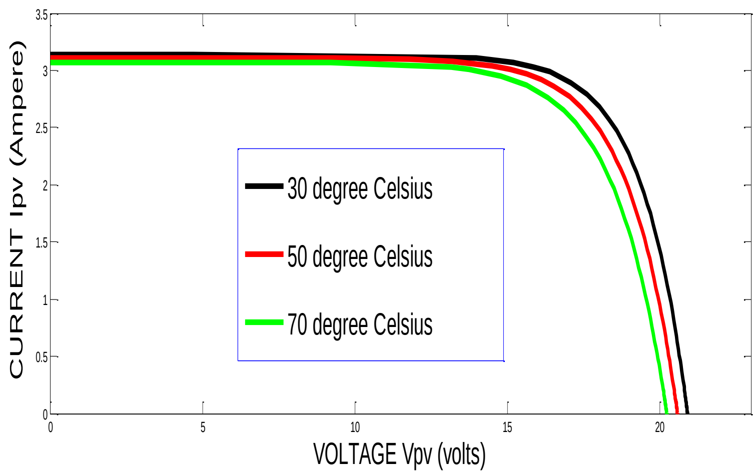


(b)

Fig.4 (a) I-V characteristics at different insolation level and (b) P-V characteristics at different insolation level



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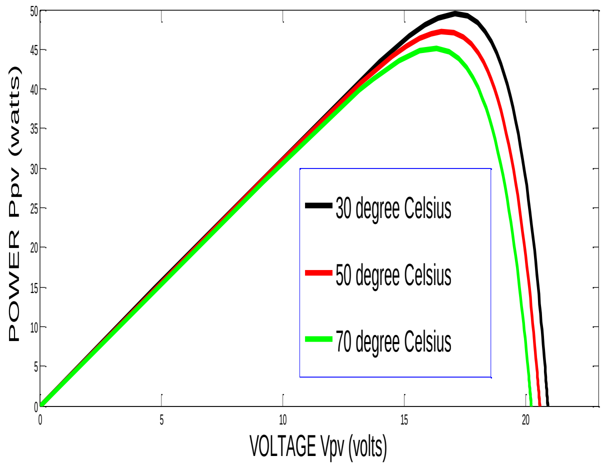


(b)

Fig.5 (a) I-V characteristics at different temperature level and (b) P-V characteristics at different temperature level

III. MPPT CONTROL ALGORITHM

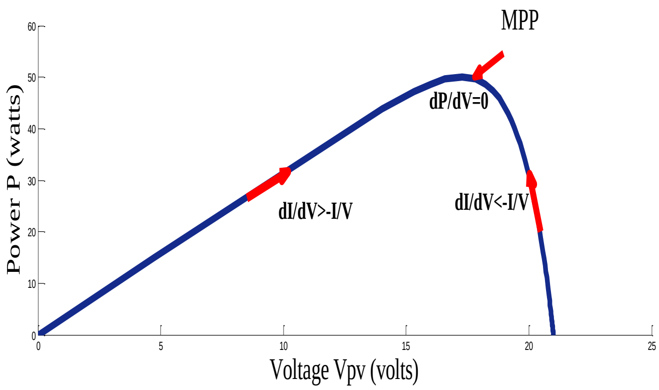
Performance of Solar PV system depends not only the environmental conditions but also MPPT plays a significant role. Maximum efficiency can be obtained by this approach. The objective of MPPT controller is to set the operating point in case of change in environment condition. Several MPPT techniques are known among them Incremental Conductance proves to give stable operation under steady state and varying environmental conditions. In this method the information of source voltage and current is used to find desired operating point. From the P-V curve of a PV module shown in Fig.5 it is clear that slope is zero at maximum point [17], the formulas are as follow

$$\frac{dP}{dV}mpp = \frac{d(VI)}{dV} \quad (6)$$

$$0 = I + V\left(\frac{dI}{dV}\right)MPP \quad (7)$$

$$\left(\frac{dI}{dV}\right)MPP = -\frac{I}{V} \quad (8)$$

Eq.8 is the condition for maximum power point it shows that when the variance of the output conductance is equal to the negative of output conductance, the module will work at maximum power point [18].



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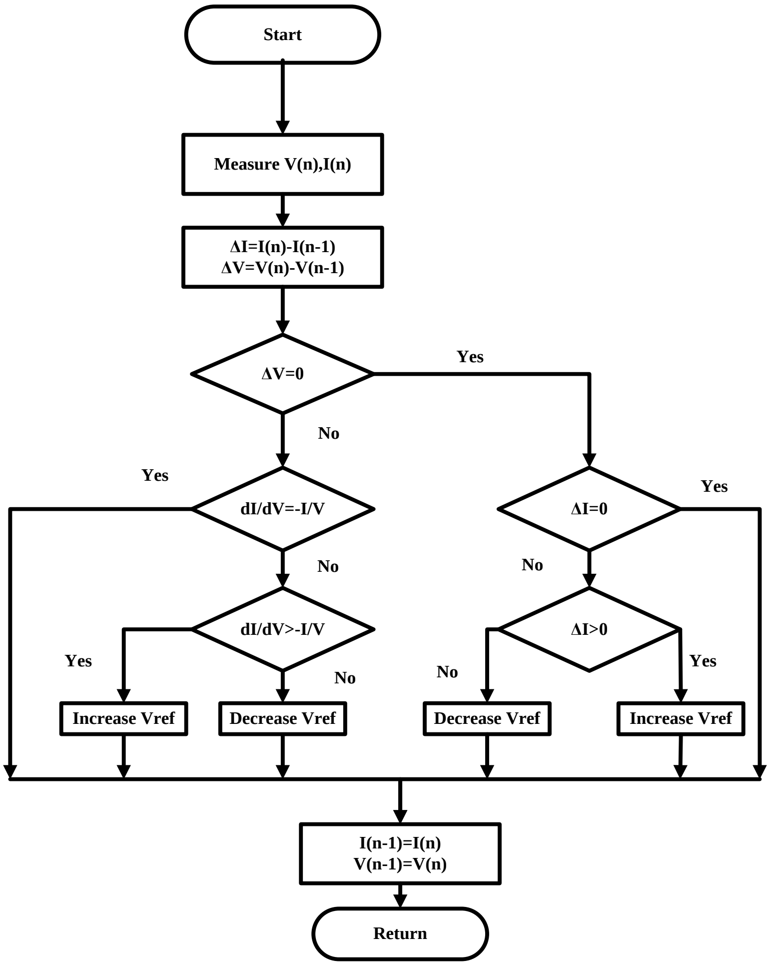

(b)

Fig 6 (a) Principle of InC on PV Characteristics and (b) Incremental Conductance Flow Chart

The flow chart explains the working approach of InC. Here, V(n) and I(n) is the new detected values of voltage and current, V(n-1) and I(n-1) is previously detected values. When new value enter in the program it checks the voltage difference is zero or not, and current difference too. If both of them are zero, it indicates that they have same value of duty ratio will remain same as before. If the voltage difference is zero, but the current difference is not zero, it indicates that insolation has changed and when the difference of the current values is greater than zero, duty ratio will increase else when the difference of current value is less than zero, duty ratio will decrease. If the voltage difference is not zero determine whether it satisfy the eq. 8 or not, if it 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 duty ratio is to be increased, otherwise it should be decreased [18]-[19].

IV. DC-DC CONVERTER

SEPIC (Single Ended Primary Inductance Converter) DC-DC converter is used to interface the PV module output to the load and to track the maximum power point of the PV module. SEPIC converter is capable of operating from an input voltage that is greater or less than the regulated output voltage. SEPIC Converter is made up of two inductors, two capacitors, one power switch consists of one MOSFET, and the fly back diode is of a fast switching type. The effect of parasitic elements has also been considered to increase the model accuracy [20]. The transistor operates as a switch, it is turned on and off depending on pulse width modulated (PWM) control signal. Fig 8 shows the two modes of SEPIC converter.

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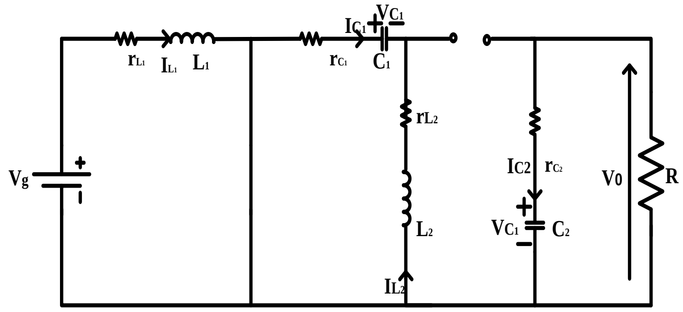
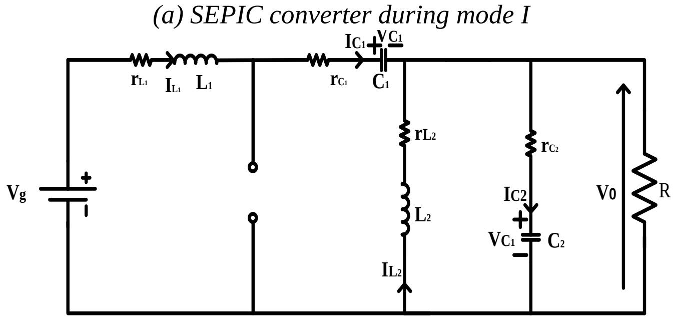
Volume 0X, Issue 0Y, [Month – 2015] ISSN (Online):2349–9745 ; ISSN (Print):2393-8161



(a) SEPIC converter during mode I



(b) SEPIC converter during mode II

Fig. 8 SEPIC converter in CCM

During Mode I current in inductor L_1 and L_2 rises, L_1 stores energy from the input voltage source. In this mode capacitor C_1 and inductor L_2 are connected in parallel. The instantaneous voltage across C_1 is approximately equal to V_g, so the voltage across L_2 is approximately equal to $-V_g$. During mode 2, diode D gets forward biased, hence the same current flows through L_1 and C_1. The Current i_{L1} and i_{L2} flows through diode into the load get decreases during this mode [21]. Continuous input inductor current is helpful in achieving a high maximum power point tracking accuracy. For the ideal SEPIC converter, the voltage conversion ratio which is the ratio of V_o to V_g is given as

$$M = \frac{V_o}{V_g} = \frac{D}{(1-D)} \qquad (9)$$

The SEPIC converter connected to the PV module with LED load is shown in fig.7 and fig.9 shows the associated waveform showing the inductor current during Continuous conduction mode.

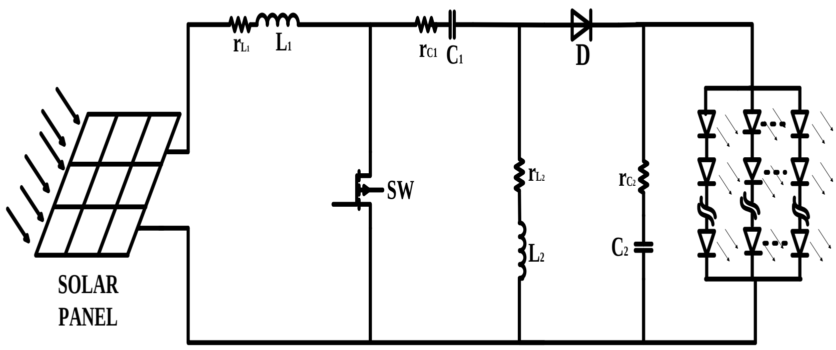


Fig.7 Solar Powered SEPIC converter with LED load

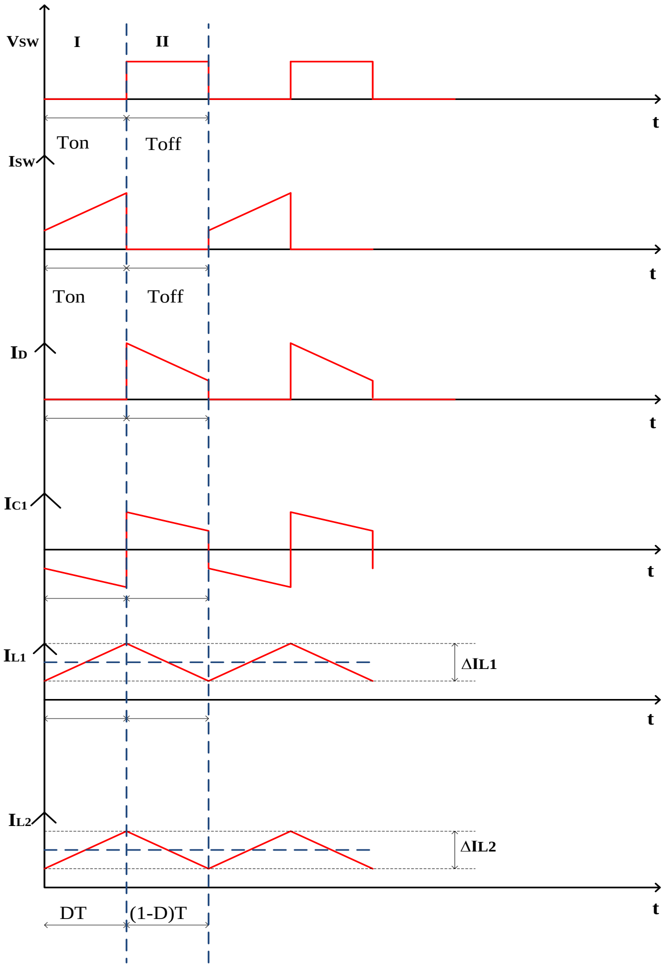


Fig.9 Associated waveforms of SEPIC converter in CCM

According to the maximum power transfer theorem the following relationship equation can be derived

$$R_{th} = \frac{V_{mp}}{I_{mp}} = R_{in} = \frac{R_b(1-D^2)}{D^2} \qquad (10)$$

Here, V_{mp} and I_{mp} represent the PV panel voltage and PV panel current at maximum power point, respectively. The input resistance R_{in} of the SEPIC circuit can be regulated by directly controlling the converter duty cycle D. As long as the circuit is operated under maximum power transfer condition, MPPT can be achieved.

The intersection of current-voltage (I-V) curve and load line gives the operating point of directly coupled PV module to the load which is shown in Fig 9.

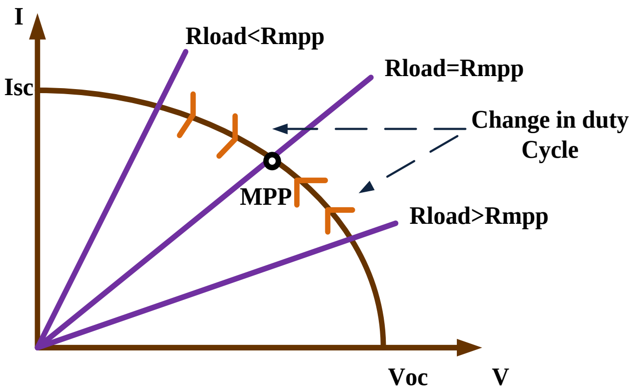


Fig.9 Operational and non-operational regions of the I-V curve for SEPIC converter

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V. SIMULATION RESULTS AND DISCUSSION

The MATLAB Simulink model of the complete system is shown in fig.10, for ease in understanding the complete system has been divided into three parts i.e. PV model, MPPT algorithm (InC) and DC-DC SEPIC converter with LED load. Detailed model has been shown in fig.11. The details of parameter used are shown in table 1. The complexity and simplicity of the circuit have been determined based on literature. For analysing the robustness of the converter a step change in insolation is provided at 0.1s which changes the insolation from 700W/m^2 to 1000W/m^2 at fixed ambient temperature 25^0 C. The LED load has been modelled as a simple resistive load. Fig. 13, 14 and 15 shows the variation in input power, voltage and current and fig. 16, 17 and 18 shows the variation in load side Power, voltage and current. Fig 18 (a) and (b) shows the variation in duty cycle. Inc algorithm takes only 0.03s settling time for achieving the fixed duty ratio. Thus with the MPPT algorithm the system efficiency can be highly improved and can be used to street lightning and other LED application with photovoltaic module.

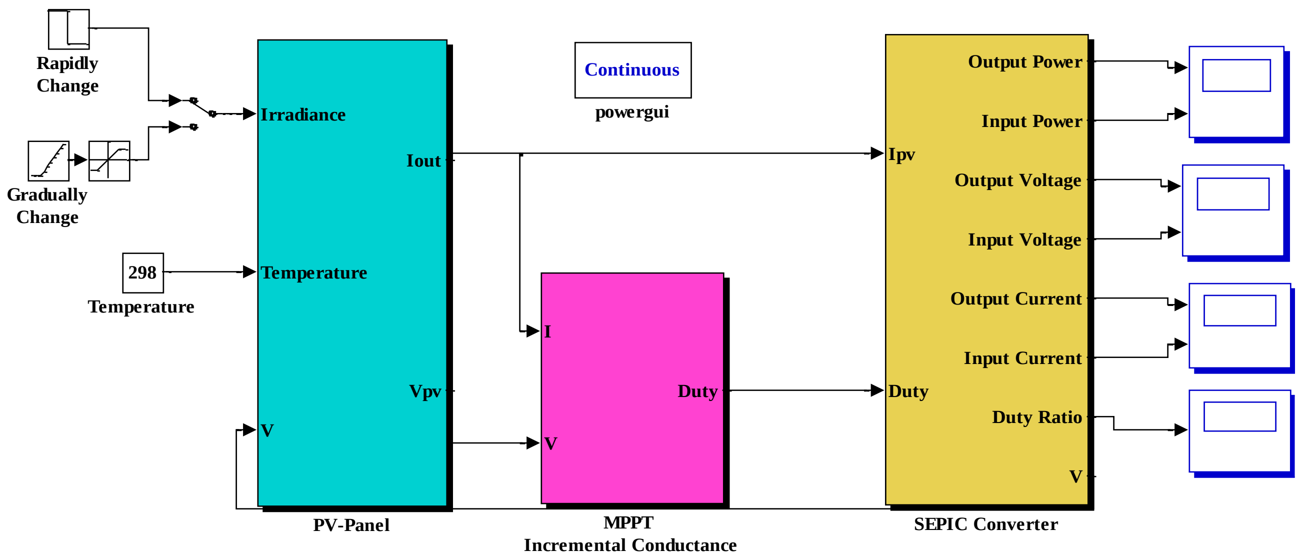


Fig.10 Simulink Block diagram of complete system

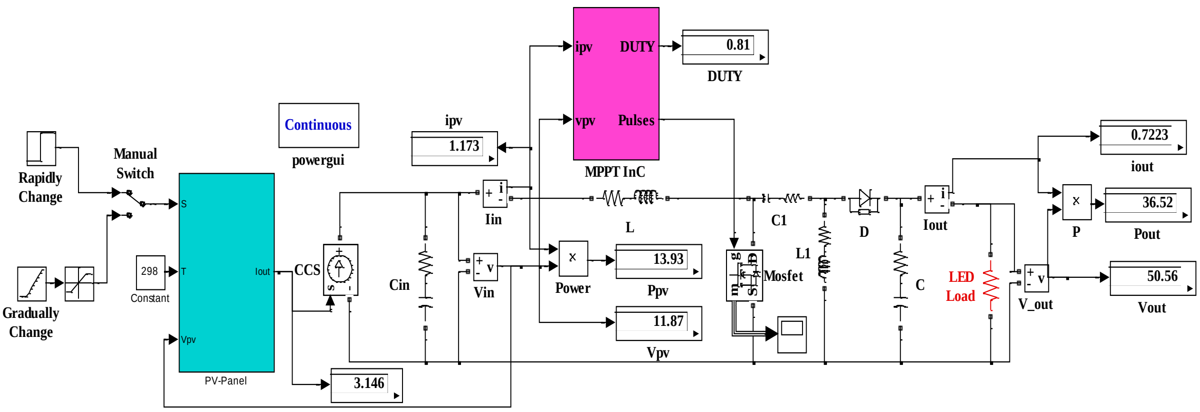


Fig.11 Complete System model

TABLE I

Parameters	Values
Diode ideality factor, A	1.6
Temperature coefficient, K_i	0.0017A/K
Series resistance of cell, R_s	0.01Ω
Parallel resistance of cell, R_{sh}	1000Ω
Band Energy gap, E_g	1.12eV
Parallel no. of PV modules, N_p	1
Series no. of PV modules, N_s	36
Reference cell temperature, T_{ref}	298 k
Reference Photo current, $I_{ph\ ref}$	3.15 A
Reference solar irradiance, S_{ref}	1000w/m^2 -500w/m^2

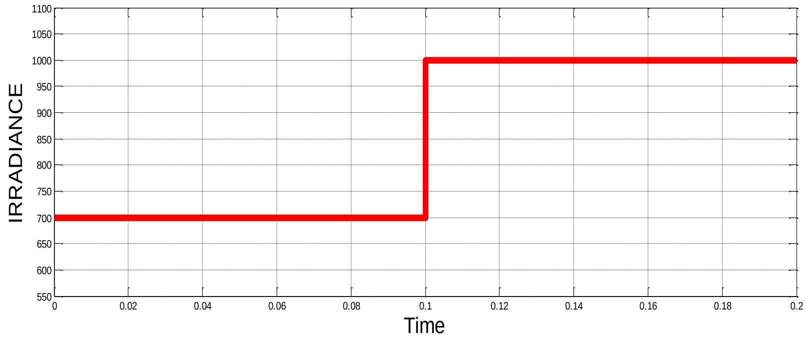


Fig. 12 Change in Solar irradiance

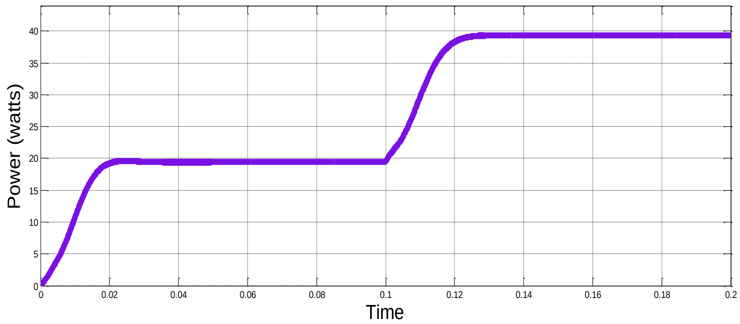


Fig.13 Panel power

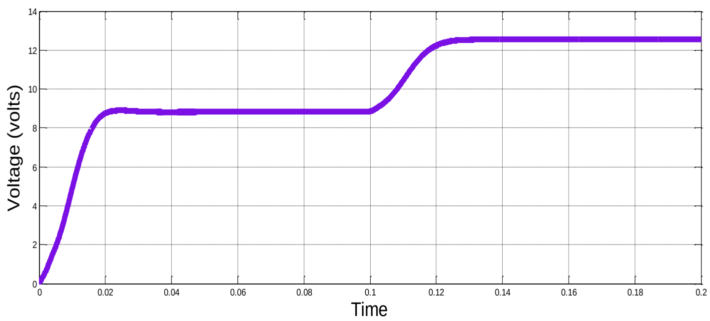


Fig. 14 Panel Voltage

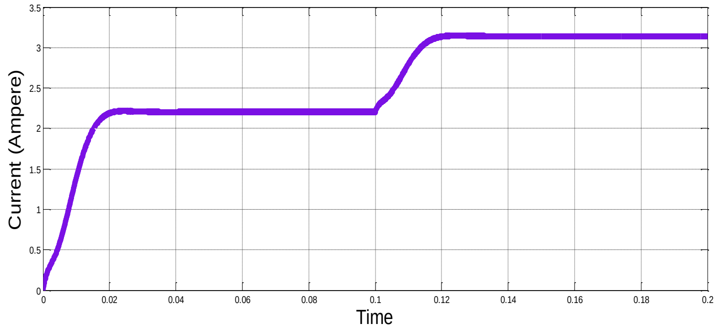


Fig. 15 Panel Current

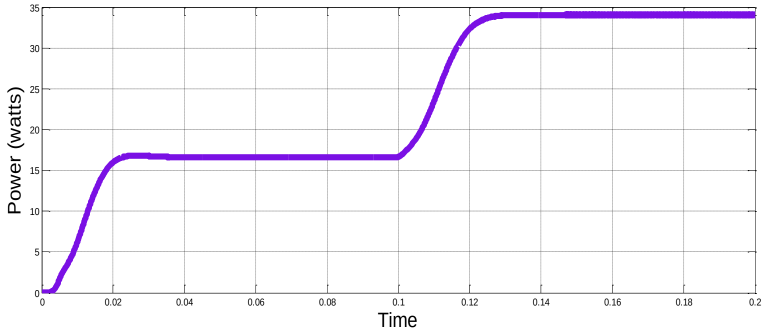


Fig.16 LED load Power

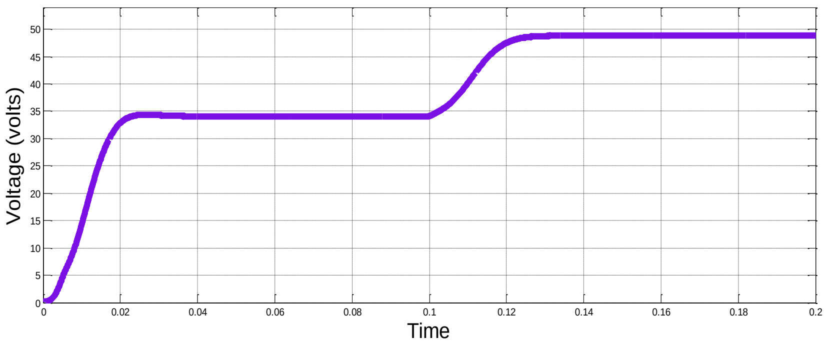


Fig.17 LED load Voltage

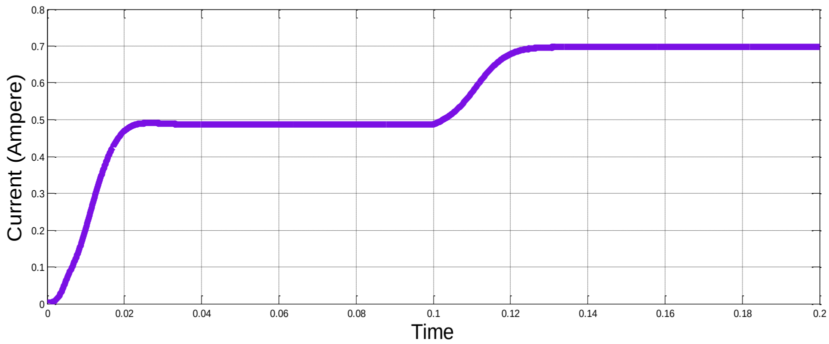
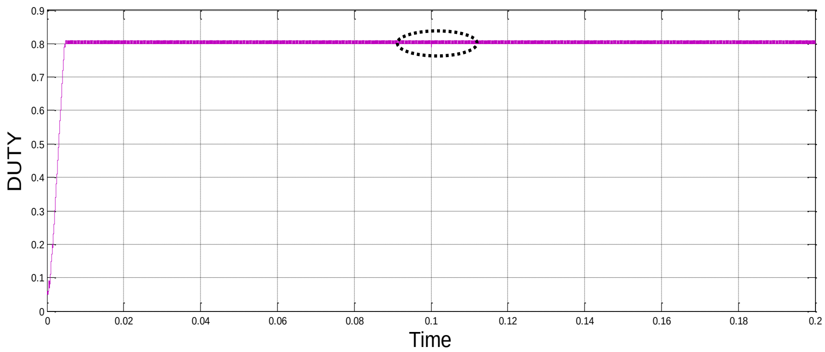


Fig.18 LED load Current



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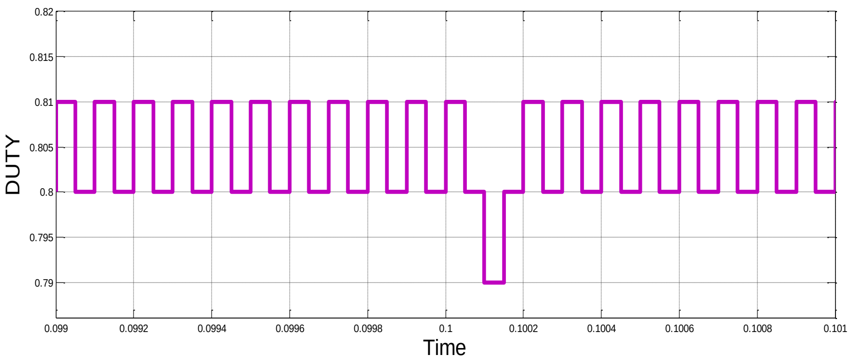

(b)

Fig.19 Duty Ratio variation

VI. CONCLUSION

A standalone Photovoltaic system connected with SEPIC converter with LED load along with Incremental conductance algorithm for the extraction of maximum power at different condition is proposed. Analysis revealed that primary function of DC-DC converter in PV system is like an intermediate power processor which changes the current and voltage level so as to extract the maximum power from the PV array. Change in voltage and current is nothing but the converting a fixed load to a variable load. Simulation result verifies the validity of proposed model.

VII. ACKNOWLEDGMENT

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