DESIGN AND IMPLEMENTATION OF SOLAR POWERED INTEGRATED DOUBLE BUCK BOOST CONVERTER WITH MPPT CONTROLLER FOR POWER LED LAMPS

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Abstract: In this paper, design and implementation of an integrated double buck boost converter fed from solar panel is presented. Here a 17W IDBB converter is designed and implemented which is fed from a solar panel and is used mainly for street lighting. Finally hardware results from a laboratory prototype are also developed.
Keywords: LED lamps, LED lamp power supply, double buck boost, MPPT controller

I. INTRODUCTION

LED is a passive element which comes under the category of Optoelectronic. The basic working principle of LED lamps is electroluminescence. There are many applications for white power LEDs which is used in home appliances, street light and even in decoration [1]. The LED runs in constant current mode. Normally high brightness LED comes under the range of 350 mA [2]. Due to their high color rendering index and good reliability it is necessary to take more care about the selection of LED. There have been many selection criteria for power LED lamps such as color of LED, color temperature, luminous flux and voltage and current [3]. It is not possible to connect a LED directly from the ac or dc supply because of their constant voltage behavior [4]. For meeting the maximum efficiency for the LED, they need to operate under certain conditions which are not possible in all circumstances. That's why it is very important to control a LED in a proper way. This paper introduces a solar powered integrated double buck boost converter (IDBB) which works as a LED driver with MPPT controller. Switching mode voltage regulator (pre-regulator with multiple current regulators), non – isolated buck converter, and series input – connected converter cells are also used as a LED driver [4]. In this paper, the proposed converter can manage the fluctuations in both input and load. There are two stages: first one is full output level and the second one is dimming level. The load can be control by controlling the MPPT controller. The MPPT controller used here is based on the hill climbing algorithm. The controller helps to track the maximum power from the solar panel. If there are variation in the load the controller is adjusted the duty cycle of the converter and provides constant voltage across the load.

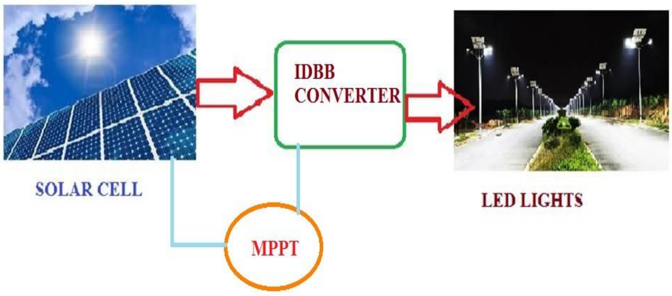


Fig. 1. Block diagram of integrated double buck boost converter with MPPT controller

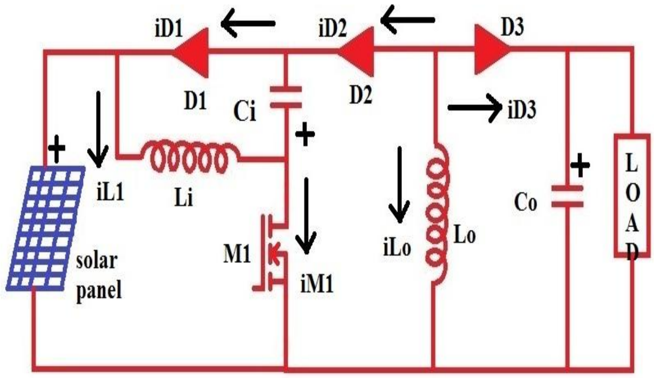


Fig. 2. Integrated double buck boost converter

II. INTEGRATED Double Buck Boost Converter

The operation of this converter is similar to that of conventional buck boost operation. Here, two buck boost converters are connected in cascade. One acts as an input converter and other acts as an output converter. The capacitor in the input converter has reverse polarity which is balanced by the second buck boost converter, and this will provide a positive output voltage. This will make the IDBB to reduce the circuitry of sensing and cost. Here the input inductor Li is in discontinuous conduction mode and the output inductor operates in continuous conduction mode. The design is such that for attaining low ripple current through the load it will direct to a high value of output capacitance. To avoid this problem the output inductance operates in CCM.

III. ANALYSIS OF IDBB CONVERTER

The IDBB converter is supplied from a 20W solar panel which is capable of providing low ripple current and high efficiency. The ripple current across the power LED also low in this case.

A. To find i_g and P_g

Through L_i the input current i_g is flowing in time interval of 0 – DT_s. Here the switching period of transistor is T_s, and the duty cycle of the transistor is D.

$$< i_g > = \frac{1}{T_s}\frac{1}{2}\, i_{g\_peak}\, DT \qquad (1)$$

$$P_g = \frac{1}{2} V_g < i_g >_{peak} = \frac{D^2}{4}\frac{V_g{}^2}{L_i f_s} \qquad (2)$$

B. To find the output voltage

$$P_o = \frac{V_o{}^2}{R} \qquad (3)$$

Where P_o is the output power. When equating the input and output power the output voltage V_o can be obtained.

$$V_o = \frac{DV_g}{2\sqrt{K}} \qquad (4)$$

where $$K = \frac{fsLi}{R} \qquad (5)$$

K is the non-dimensional factor, fs is the switching frequency, Li is the input inductance and R is the load resistance.

C. To find reactive elements

By assuming 100% efficiency, for a particular P_o the input inductance L_i is,

$$L_i = \frac{D^2 V_g^2}{4 P_o f_s} \qquad (6)$$

The input capacitance is,

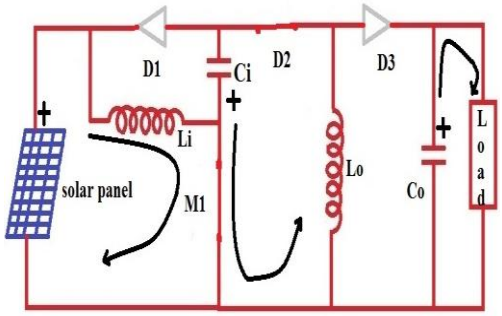
$$C_i = \frac{D^2 V_i^2}{8\pi V_o L_i f_s} \qquad (7)$$

The output inductance is,

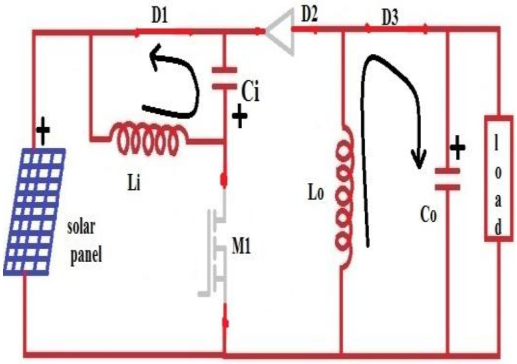
$$L_o = \frac{D V_i}{0.5 I_o f_s} \qquad (8)$$

The output capacitance is,

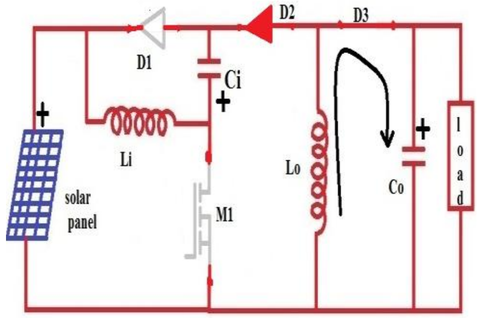
$$C_o = \frac{D I_o}{V_o f_s} \qquad (9)$$



(a)



(b)



(c)

Fig. 3. Modes of operation of IDBB. (a) Switch M1 in ON condition: (b) Switch M1 in OFF condition and D1 is conducting: (c) Switch M1 in OFF condition and D1 is reverse biasing.

IV. SPECIFICATIONS OF CONVERTER

With an output of 17W the load current rating is 350 mA. The equivalent LED load resistance at 17W output power is, R = 150Ω . The Li is calculated by selecting 70% duty cycle.

TABLE.1. Specifications Of Idbb

parameters	*specifications*
Duty Cycle, D	70%
Input voltage	16V
Input power	20W
Output power	17W
Switching frequency, f_s	20KHz
V_o(output voltage)	49 V
K (non-dimensional factor)	0.013
L_i(input inductance)	100 mH
$i_{D1-peak}$	2.166 A
i_{D1}	0.469 A
C_i(input capacitance)	80 μF
L_o(output inductance)	7.0 mH
C_o(output capacitance)	40μF

V. RESULTS

The output voltage is 49V for 84% efficiency and the output current is 0.346m A nearly 350 m A. So that, the output power is 17W. The efficiency of the converter lies in between the range of 84% - 85%.

VI. MODELING OF SOLAR PANEL

TABLE.2. SOLAR PANEL DETAILS

Rated power	20W
Voltage at maximum power(V_{mp})	16V
Current at maximum power(I_{mp})	1.3A
Open circuit voltage(V_{oc})	21V
Short circuit current(I_{scr})	1.8

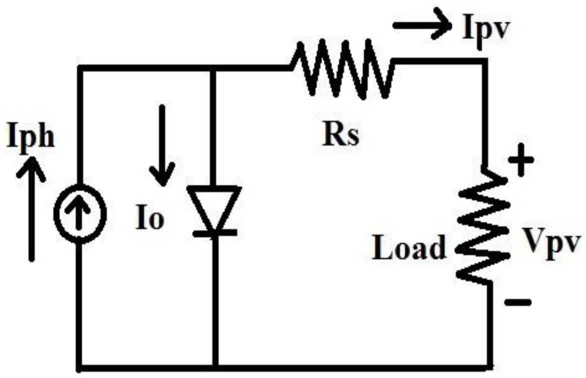


Fig. 4. Equivalent circuit of PV cell

V_{pv} - Output voltage of the pv
I_{pv} -Output current of pv
T_r – Reference temperature
T/T_a- Module operating temperature
Io- Module saturation current
A=B- Ideal factor =1.5
K= Boltzmann constant =1.3805*10^{-23} J/K
q = Electron charge =1.6*10^{-19}C
I_{scr} = Short circuit current at 25℃ and 1000W/m^2
K_i = Short circuit current temperature coefficient at I_{scr} = 0.0017A/℃
X = pv module irradiation
E_g = bandgap for silicon =1.1 eV

A . step 1
Substem 1 is used to convert the operating temperature in centigrade to Kelvin.

B. step 2
The subsystem 2 calculates the photon current at a given temperature. The equation for photon current is ,

$$Iph = [Iscr+Ki(TaK-TrK)X] \quad (10)$$

C. step 3
The subsystem 3 takes short circuit current Isc at reference temperature=1.80A and Module reference temperature TrK =25℃ as input. The Irs of the diode is calculated in subsystem 3. The equation of reverse saturation current is,

$$Irs = \frac{Iscr}{\exp\{(\frac{qVoc}{KAT})-1\}} \quad (11)$$

D. step 4
The subsystem 4 takes reverse saturation current Irs, Module reference temperature TrK=25°C and Module operating temperature TaK as input and calculates module saturation current. The equation for saturation current is ,

$$Io = Irs\ [\frac{T}{Tr}]^3 \exp[\frac{q*Ego}{AK}\{\frac{1}{Tr}-\frac{1}{T}\}] \quad (12)$$

E. Step 5
The subsystem 5 takes operating temperature in Kelvin TaK and calculates the product AkT, the denominator of the exponential function in equation (13).

F. Step 6

$$Ipv = Iph\text{-}Io\ [\exp\{\frac{q*(Vpv+Rs)}{AKT}\}\text{-}1] \quad (13)$$

VII. HILL CLIMBING ALGORITHM

Flow chart

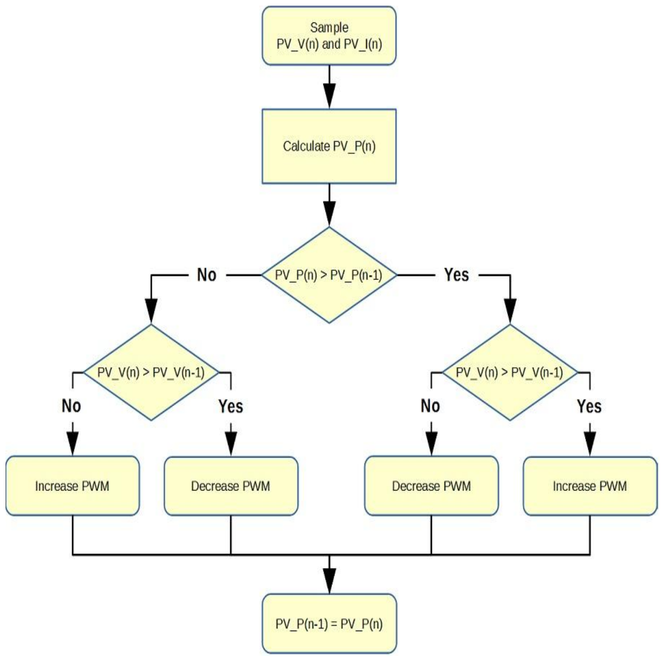


Fig. 5. Flowchart of hill climbing algorithm

VIII. SIMULATION CIRCUITS AND RESULT

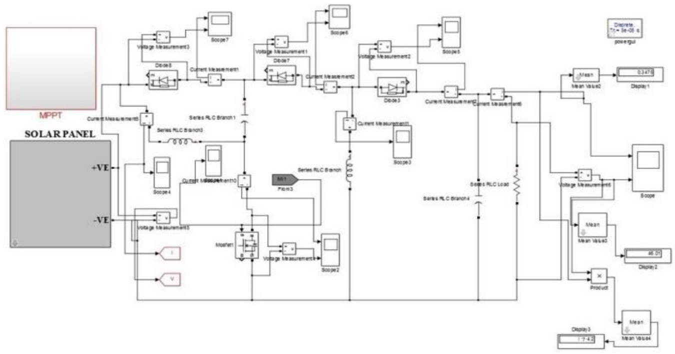


Fig. 6. Simulation circuit of solar powered IDBB with MPPT control

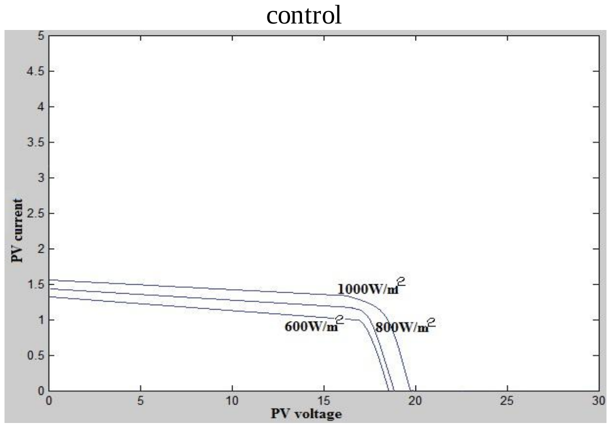


Fig. 7. VI characteristics with MPPT

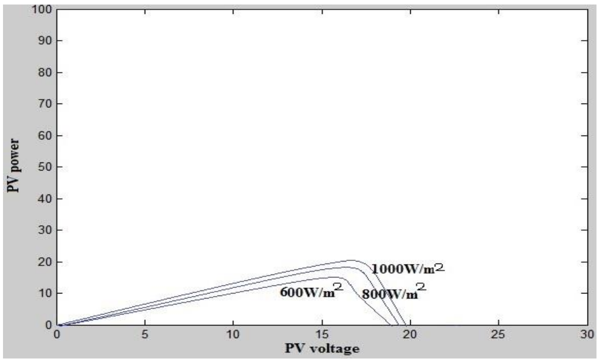


Fig. 8. PV characteristics with MPPT

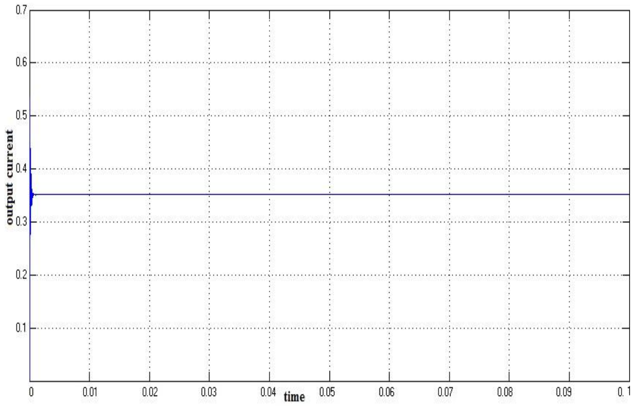


Fig. 9. Simulation result of output current

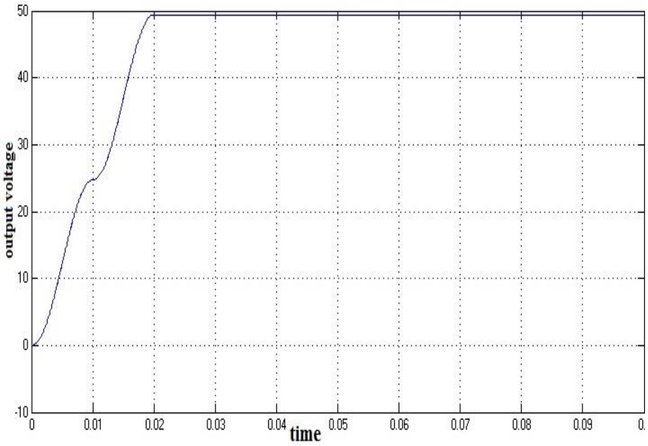


Fig. 10. Simulation result of output voltage

IX. HARDWARE RESULTS

A prototype of solar powered IDBB (Fig.2) has been developed. Here there are different types of components like capacitors, diodes, inductors, switch, regulators, amplifier etc. The model of capacitors is KELTRON. For diodes D1 and D3 HER207G selected and for diode D2 MUR3040 selected. The IRF250 model selected for MOSFET. The pulses are generated using dsPIC30F4011 microcontroller. A laboratory prototype has been developed by an input supply voltage of 16V from solar panel. The IDBB converter is supplied from a solar panel and developed an output power of 17W. As per equation no.4 output voltage of IDBB converter has been calculated. For a duty cycle of 70% the output voltage is 49V.

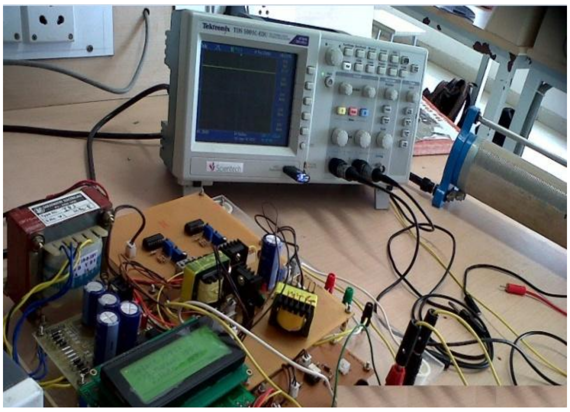


Fig. 11. Setup of solar powered integrated double buck boost converter

Here rectifier circuit, amplifier circuit, driver circuit support the converter circuit. The transformer 230V/9V, 15V gives supply for driver circuit(12V) and microcontroller(5V). In the converter circuit trim pot is used for measuring the voltage.


Fig. 12. Setup of 20W, 16V solar panel

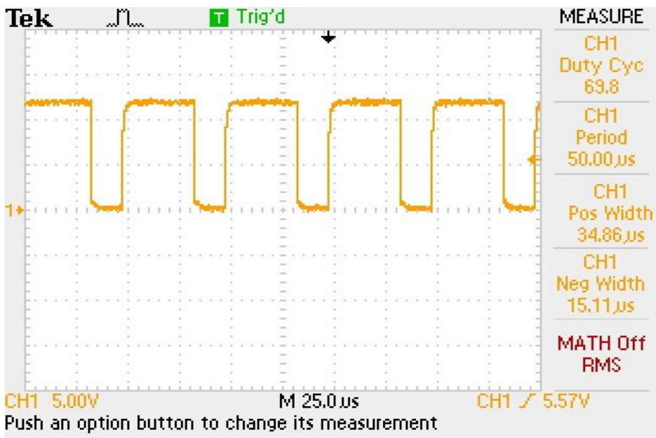


Fig. 13. Waveforms of gating pulses for MOSFET switch M1.

Fig. 13. shows the gate-source voltage and drain-source voltage of M1. The experimental result shows that these two waveforms are complementary to each other.

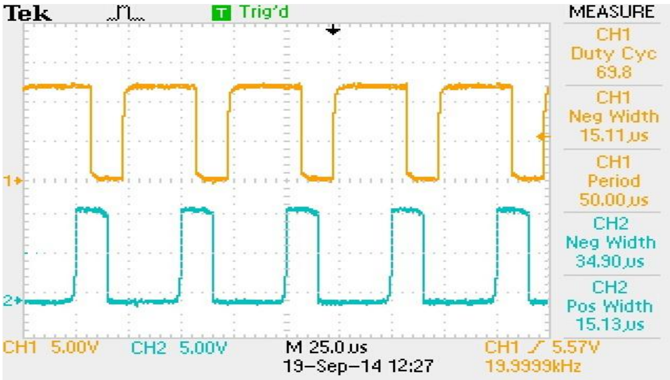


Fig. 14. Waveforms of Gate – source voltage (CH1) and Drain – source voltage (CH2) in M1.

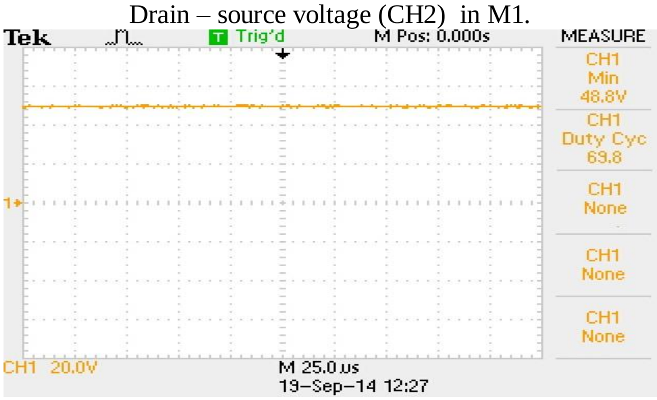


Fig. 15. Output voltage of solar powered IDBB

The efficiency of the solar powered IDBB converter is 84-85%.

TABLE.3. WITH AND WITHOUT MPPT

load	With MPPT			Without MPPT	
	Voltage(V)	Current(A)	Power	Voltage (V)	Current (A)
12W	16	1.3	20	18	0.63
17W	16	1.3	20	15	1.13

The input power will not change even if there is variation in the load. The MPPT controller tries to track maximum power.

X. CONCLUSION

This paper designed and implemented a 17W solar powered IDBB converter to provide high efficiency and to track the maximum power from the solar panel by using hill climbing algorithm. If there are any variations in the load, the controller adjusts the duty cycle of the converter and provides constant voltage across the load and tracking the maximum power from the solar panel. Here as per the experimental results solar powered integrated double buck boost converter capable of providing high efficiency. This converter is mainly used for street lightening applications.

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