Design and Hardware Implementation of Current Controlled Integrated Double Buck Boost Converter for LED Driver Circuit

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Abstract

This paper introduces a light emitting diode (LED) driver circuit with current controlled integrated double buck boost converter. In a LED, small change in forward voltage can produce a disproportional large change in forward current, which in turn can cause variation in light output, as LED light output is proportional to current and is rated for current range. If nothing limits the current, the junction will fail due to the heat, which leads to thermal runaway. By driving LED light sources with a constant-current power supply the light output variation and life span issues resulting from voltage changes can be eliminated. This paper discusses about the converter operation and closed loop simulation in detail. From the designed values MATLAB simulation is done. The hardware design is focused on pulse generation circuit for converter. A microcontroller from microchip family PIC16F877A is used to implement controller design. The output voltage is taken as feedback to control the PWM pulses to maintain optimal current in LED.

Keywords: Double Buck-Boost; PID Controller; Constant Current; Power LED Lamps.

Introduction

Light Emitting Diode (LED) is a new technology lighting device, which is popular due to its efficiency and cost. The basic working principle is electroluminescence for LED lamps. Applications for white power LEDs are used in home appliances and street lightening [1]. In power electronics type of circuits there are two types of control, namely constant voltage mode and constant current mode. In the case of LED based circuits constant current mode is used to control the circuits. Normally high brightness LED comes under the current range of 350 mA [2]. Due to their high colour rendering index and good reliability it is necessary to take more care about the choosing of LED. There have been many options for power LED lamps such as colour of LED, colour temperature, luminous flux [3].

It is not possible to connect a LED directly from the dc or ac supply because of their constant voltage behaviour [4]. So it is a mandate that semiconductor devices are required to control and use the LED. To operate LED in the maximum efficiency, they need to operate under certain conditions. Therefore a closed loop system is necessary to control LED in a proper way. This paper introduces integrated double buck boost converter (IDBB) which works as a LED driver using PID controller. The integrated double buck boost converter uses only one control switches and it performs the operation of the two buck boost converters. The IDBB converter operation is equivalent to the operation of the two buck boost converters, in which the control switch is shared by both the converter.

In this work, the skeleton of converter is obtained by connecting two buck-boost converters back to back, in which one controlled switch is used for operating both converters [5-7]. Thus, the IDBB converter includes three diodes, two capacitors, two inductors, and one controlled switch with respect to ground, indicating low cost and good reliability for LED lamp based applications.

IDBB Converter

The schematic diagram of the IDBB converter is shown in figure 1. As briefed in the introduction [8], the converter act as two buck–boost converters connected back to back. The first buck–boost converter is made up by L_1, D_1, C_1, and M, and the second buck–boost converter comprises L_2, D_2, D_3, C_2, and M. The capacitor C_1 produce reversing polarity similar to

conventional buck-boost converter this implies the converter act in buck mode, whereas in IDBB the polarity is non inverted, it is corrected by the second buck-boost converter capacitor C_2, thus obtaining lower output voltage with respect to ground. The basic schematic diagram of the IDBB converter is shown in figure 1.

The capacitor C_1 in the first converter has inverted polarity which is balanced by the C_2, and this will provide a positive output voltage. Here the input inductor L_1 is in discontinuous conduction mode and the inductor L_2 operates in continuous conduction mode. Since both the inductors are isolated and acts in different conduction mode, the ripple current is low.

Mode 1: 0 < t < DTS

The mode 1 operation (figure 2) is the time between 0 and DTS [9] where D is the switch M's duty cycle and the switching period is TS. During this period the switch M is ON. Initially voltage polarity as shown with C1, diodes D1 are reverse biased whereas D2 is forward biased.

This allows the charging of inductor L1 and L2 with the current directions as marked.

Mode 2: DTS < t < DTS + t1

Mode 2 is the time duration of t1 from DTS when the switch M is turned OFF (figure 3). During t1, the diode D1 becomes forward biased and the inductor is allowed to discharge to zero through D1 and C1. In the output stage, the inductor L1 discharges to the capacitor, charging it and also supplying the load.

Mode 3: DTS + t1 < t < TS

In mode 3, the switch M is OFF (figure 4) and the current through D1 is now zero. Because the output inductor L2 is in CCM, the current in L1 which supplies C1 and load, gradually drops but not to zero.

Finally, the expression for line current and input power, output voltages and reactive components are obtained [5,10].
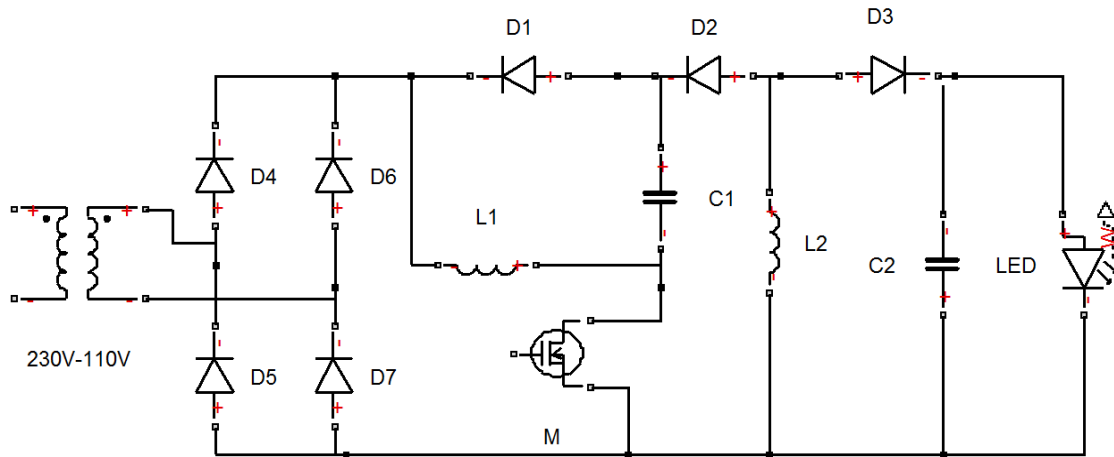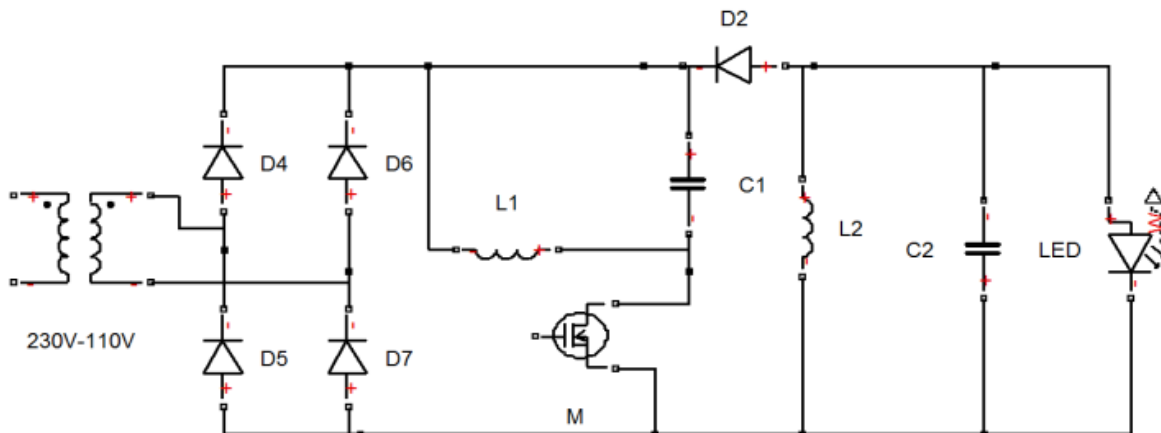

Figure 1. Schematic diagram of the IDBB converter

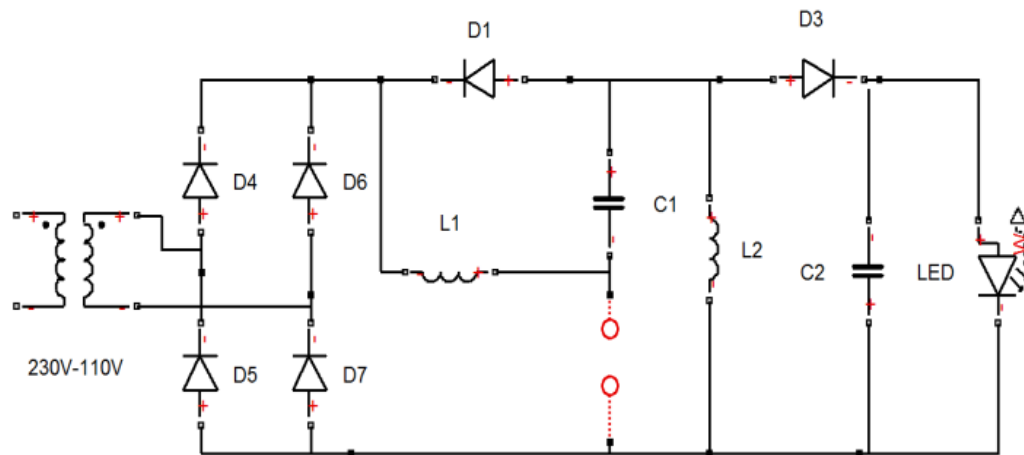Figure 2. Mode 1 operation of IDBB converter
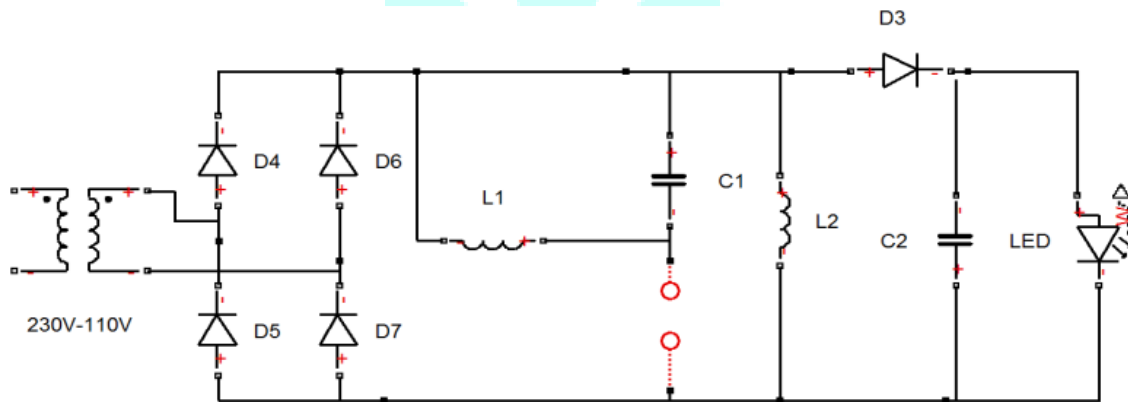
165

Figure 3. Mode 2 operation of IDBB converter

Figure 4. Mode 3 operation of IDBB converter

Design calculation

As mentioned, the line voltage is 230V from ac mains with a 50 Hertz line frequency. The 230V is stepped down using step down transformer to 12V. Thus three 1W white-light LEDs were connected in series in this preferred circuit. Each LED was operated at 5V and 0.2A using ac 12V that was rectified by a bridge rectifier. With an output of 3W the output current is 0.2A. The equivalent LED load resistance at 3W output power is, R = 76Ω. The Li is calculated by selecting 55% duty cycle.

Table 1. Design Calculation

Parameters	Specifications
Input voltage	12V
Output power	3W
Output voltage	15.2V
K(non-dimensional factor)	0.40
L_1(input inductance)	1.5Mh
Output current	0.2A
$iD1$	0.686A

Using conventional buck-boost expression [6] the output inductance, L_2 =7mH value is

calculated. The output converter capacitance has been calculated, C_2 =45 μF is obtained.

Simulation of IDBB converter with PID controller

The MATLAB SIMULINK model is shown in figure 5.The output current is taken as feedback and given to gain block. The IDBB [11,12] converter is designed for 0.5A.The gain block divides the output current by 1/0.5. In this event there occur two stages, (i) when the output of IDBB converter is less than or equal to 0.5A and (ii) when the output of converter is greater than or equal to 0.5A.The output of gain block is compared with step input in comparator to produce error. This error signal is given as input to PID controller. The controller output is so as to minimize the error generated [10]. The output of PID controller is compared with repeating sequence (saw tooth generator) to produce switching pulses. This switching pulse is given as input to relay block. The function of relay block is to prevent repeated turn ON and OFF of the switch. The pulse width of the switch is maintained at amplitude of 1 by a Boolean block.

The pulse width of the switch is will be decreased if the output current is high and pulse width of switch will be increased if the output current is low. The same pulse will be maintained if the output current is as desired.
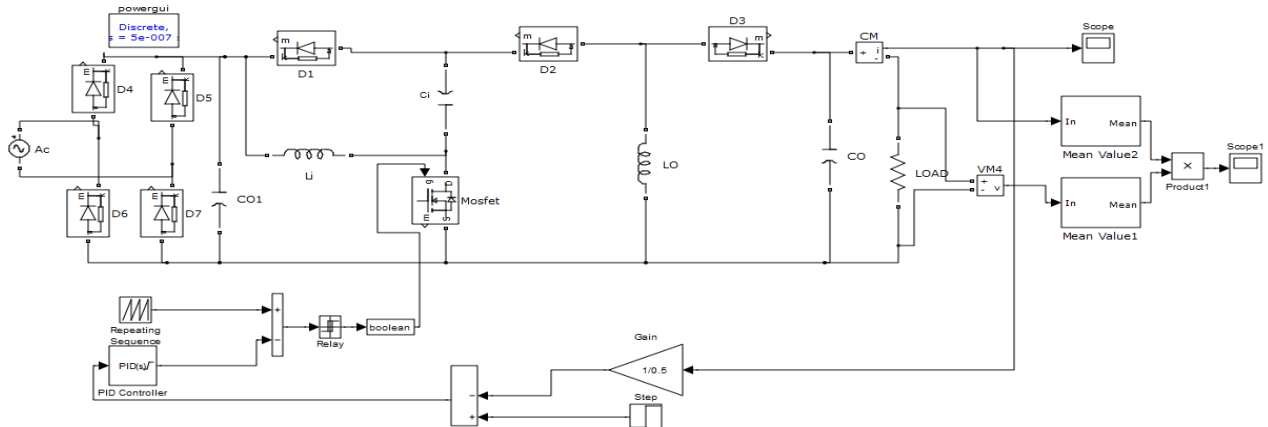

Figure 5. Simulation of the closed loop IDBB

Results and discussion

Simulation results

Output voltage and current waveforms of closed loop IDBB are shown in figure 5 (a) and figure 5 (b). The above waveform shows the output current of IDBB and as per design calculation the required current of 0.24A is obtained; the calculated output power is achieved. The closed loop system was simulated with control concept and results were proven.

Hardware implementation

The hardware implementation comprises of three stages (i) DC power supply circuit (ii) Power circuit (iii) Control circuit. The power supply circuit provides 12 V for driver circuit and 5 V for PIC microcontroller. The control circuit consists of PIC Microcontroller which is programmed to generate PWM pulses of switching frequency of 50 kHz and duty cycle of 55% as the gating pulses to the converter circuit.
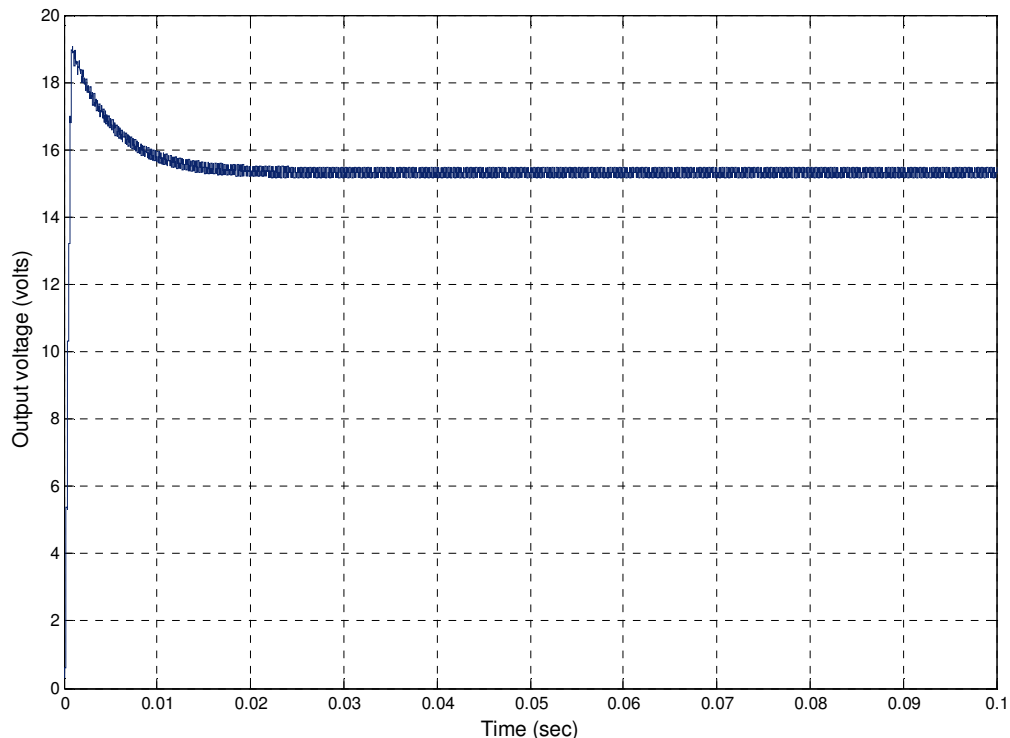

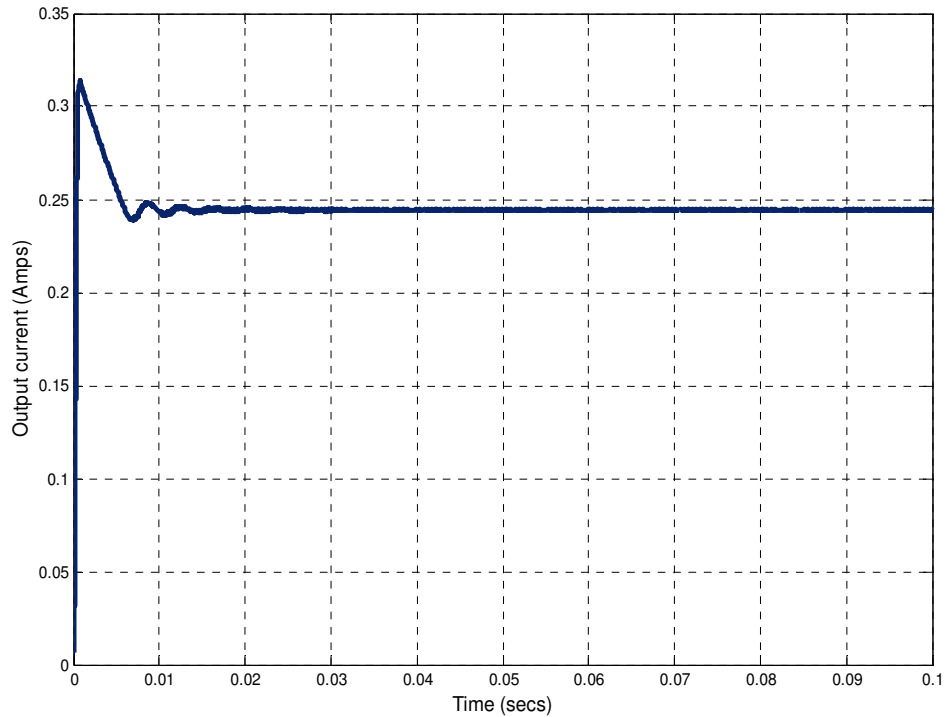Figure 5(a). Output Voltage waveform of closed loop IDBB

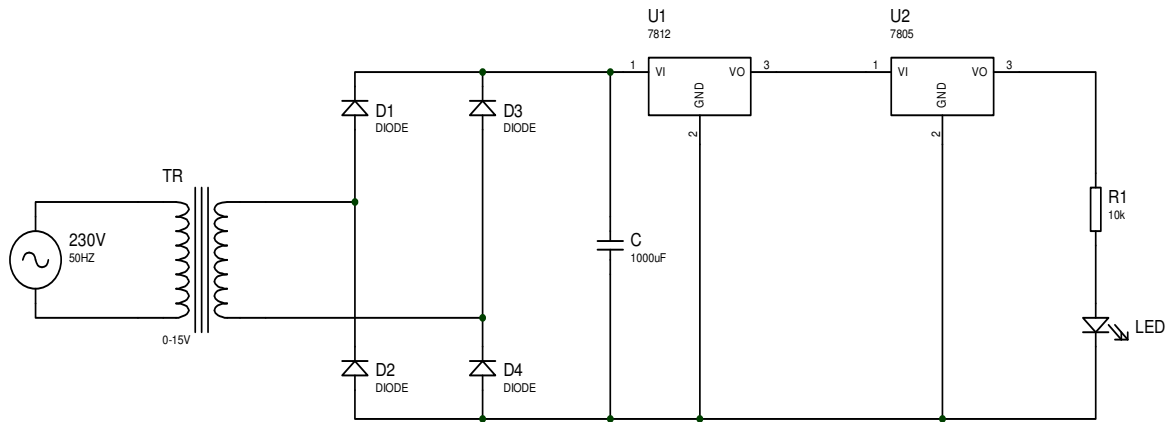Figure 5(b). Output Current waveform of closed loop IDBB

Figure 6. Power supply circuit

A 230V, 50Hz 1Φ AC power supply is stepped down to 12V. This 12 V ac voltage is rectified to DC voltage. The rectified DC voltage is filtered by a capacitor and then given to 7805 voltage regulator to obtain a constant 5V supply. This 5V supply is given to microcontroller for its operation.

The control circuit consists of 16F877A PIC Microcontroller to generate PWM pulse of 100 KHz. The output magnitude of PIC is 5V; this magnitude will not be enough to trigger the MOSFET. The IR2110 driver is used as a pulse amplifier. The driver amplifies the pulse from

PIC Microcontroller to the magnitude of 24V which is used to trigger the MOSFET switch used in the IDBB converter.

PIC 16F877A shown in figure 7 is a 40 pin 8 bit COMS FLASH microcontroller from Microchip. The core architecture of the microcontroller is a high-performance RISC CPU with only 35 single word instructions. 16F877A comes with 3 different operating speeds with 4, 8 or 20MHz clock input. Four operating clock cycles are used for each instruction cycle, and then each instruction takes 0.2 µs when 6MHz oscillator is used. Port C is

     168

taken as output port. In that RC2 pin is used to generate gate pulse. Based on the data given in the datasheet of PIC Microcontroller we need to give 5V supply to the pin 11 and 32 also we need to ground the pin 12 and 31.
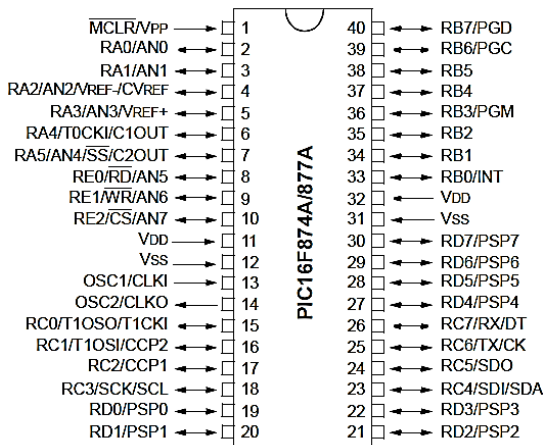

Figure 7. Pin diagram of PIC 16F877A

The 6MHz crystal oscillator is used to generate clock pulse to the microcontroller. It is connected between the pins 13 and 14. Also capacitor (22pF) is connected to the pins 13 and 14. The figure describes the pin details of PIC Microcontroller 16F877A.

The driver circuit is used between the microcontroller and the power converter. It is used to amplify the voltage and the current rating of the gate pulse produced from the microcontroller to make it suitable to drive the switch used in the power converter. An IR 2110 has both high side and low side. The 5V pulse signal generated from PIC 16F877A is amplified to 12V pulse at the low side output and 24V pulse at the high side which is suitable for turning on the MOSFET switch. The following figure 8 shows the pin diagram of the driver IR 2110.
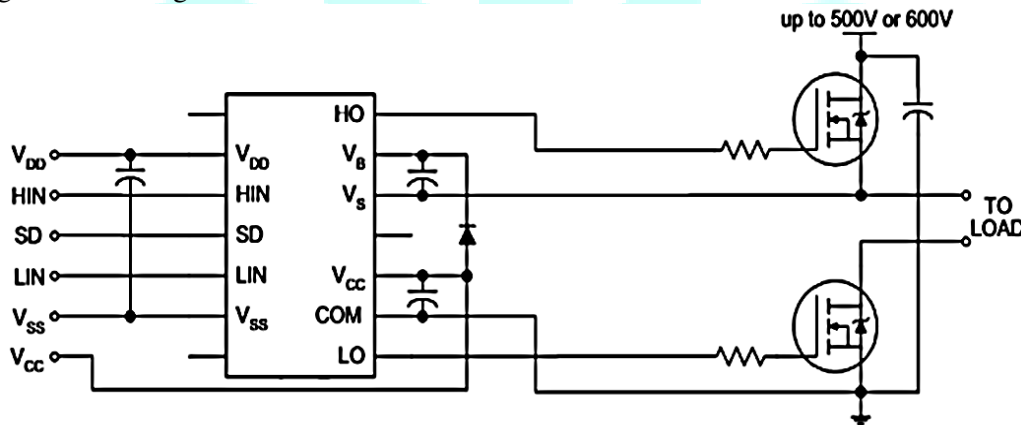

Figure 8. Pin diagram of IR2110

In case of low side switch the pulse input is given to the twelfth pin (Lin) of the driver and the output is taken from the 1st pin (Lo) of driver. 2nd pin is grounded. The driver IR2110 is fed with the 12V input supply Vcc. In case of high side switch the pulse output from the PIC is fed to the tenth pin (Hin) and the amplified output is taken from the 7th pin of the driver and the 5th pin Vs is connected to the   source of the MOSFET switch.

In order to implement the closed loop operation using PIC Microcontroller, the obtained analog output voltage of the IDBB converter is converted into an equivalent digital voltage by using analog to digital conversion programming technique in PIC Microcontroller. Embedded C programming language is used to execute the program. The change in duty ratio with respect to the current variations in Vsense is incorporated in this program. To Burn this

program in to the Microcontroller, first the program in high level language is convert in to hexadecimal by using the power soft 16F87X communicator. The output of the inverting amplifier is given to the RA0 pin of the PIC Microcontroller is enabled and the corresponding changes in the duty ratio of the triggering pulses to the MOSFET switch of the IDBB converter is made and the output voltage is maintained constant irrespective of the variations.

Hardware design and results

The complete hardware set-up which includes control unit along with a 1Ω sensing resistor (Vsense), converter unit, separate power supply unit for driver IR 2110 are shown in the figure 9. The figure10 shows the hardware output generated for the duty ratio of 55% with LED and the input voltage of 12V and the output voltage obtained is 15.2V.
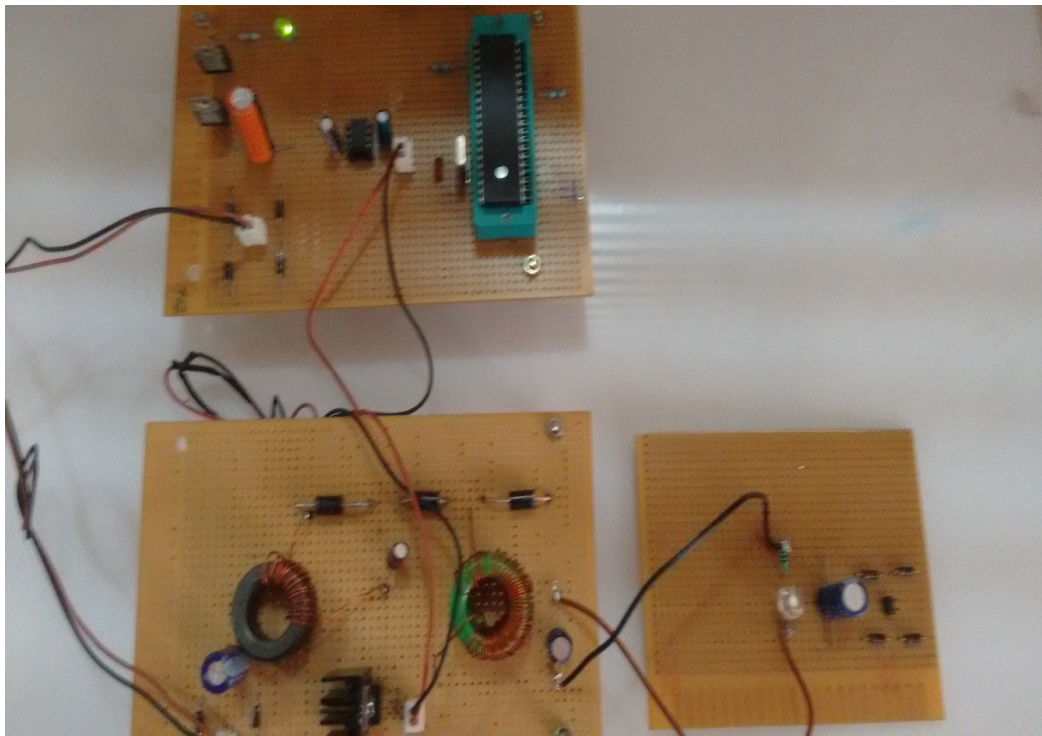
Figure 9. Overall hardware setup

Table 3. Hardware specification

| Components	Ratings	No. of items
MOSFET (IRF 840)	Voltage=200V Current=15A Frequency=1MHz	1
MICRO CONTROLLER (PIC16f877A)	Current=25mA, Frequency=20MHz, 40 Pin, 8bit	1
DRIVER IC (IR 2110)	Input Voltage=5V, Output Voltage=5V, Output Current=2A	1
DIODE (IN4007)	Voltage=1000V Forward Current=1A	12
REGULATOR (L7805),(L7812)	Output Voltage=12V,5V Current=1A	2
TRANSFORMER (230/15V)	Output voltage=15V Current=1A	3
CAPACITOR	1000µF,40µF,80µF, 33µF,22Pf	9
CRYSTAL	6MHz	1
LINE PCB BOARD	----	3
INDUCTOR	7mH,1.3mH	2
RESISTOR	10kΩ , 47kΩ,1 kΩ	5
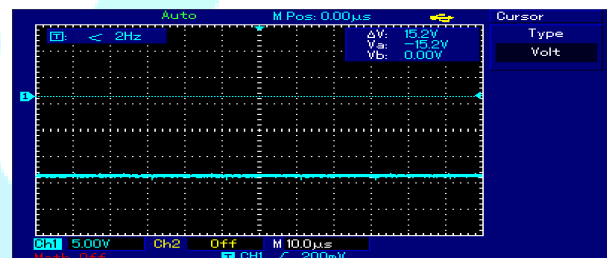
Figure 10. Hardware output for the duty ratio of 67%

The figure 11 shows the pulse output from PIC 16F877A of magnitude 5 V as output. The figure 12 shows the pulse output from driver IR2110 of magnitude 24.8 V as output which is required for operating the converter.
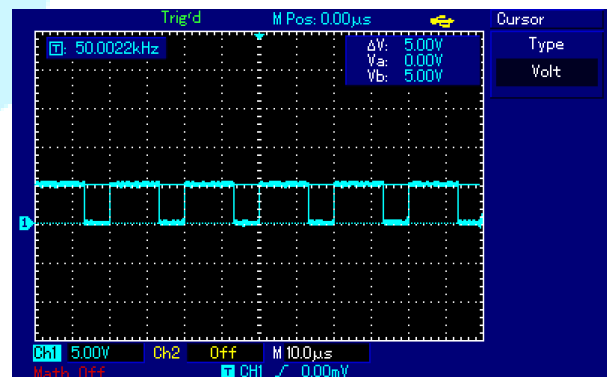

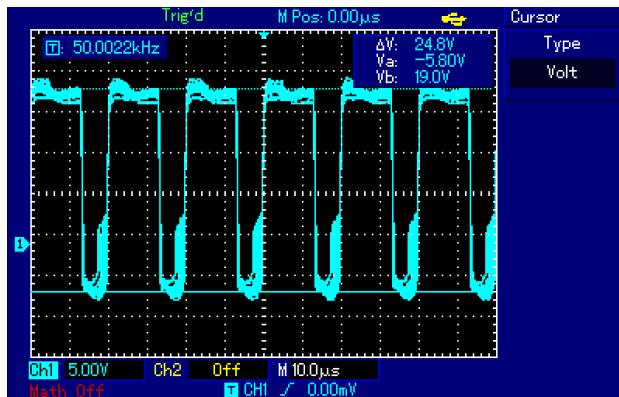Figure 11. Pulse output from PIC 16F877A of 5V

     170

Figure 12. Gating pulse from the driver IR2110

The figure 13 shows the gate to source voltage of MOSFET 840 with generated voltage of magnitude 17.4 V. The figure 14 shows the drain to source voltage of MOSFET 840 with generated voltage of magnitude 13 V.
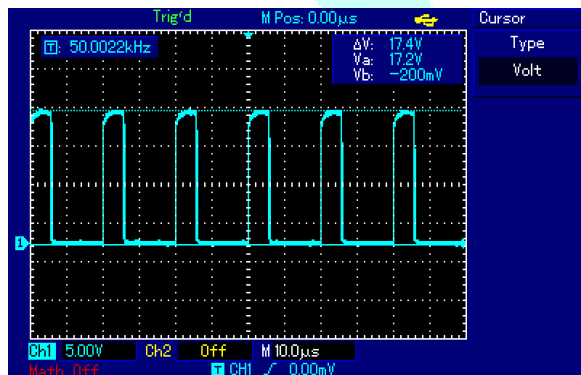

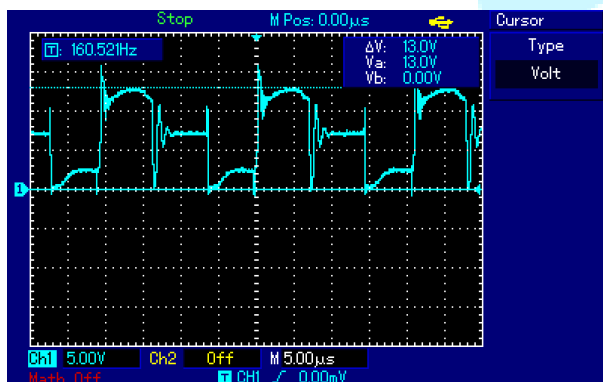Figure 13. Gate to source voltage of the converter

Figure 14. Drain to source voltage of the converter

Analysis of converter for various duty ratio through LED

The ADC program is programmed for various duty ratios such as 30%,40%,50%,60% and 67% at 50 KHZ (i.e Total time = 20µs) for which the corresponding input voltage, output voltage and the optimal current through LED obtained are tabulated in table 4.

Table 4. Analysis of Converter for various duty ratios

Sl. No.	Duty Ratio (%)	R Load (Ω)	Input Voltage (v)	Output Voltage (v)	Optimal Current through LED
1	25	26	12	4	0.15 Amps
2	55	70	12	15.2	0.2 Amps
3	75	78	12	39	0.5 Amps

Conclusion

As LED technology matures, some of current issues surrounding the measurement, lifetime and reliability may abate. Innovative luminaire designs and control strategies-such as closed loop current control system is used in this paper to maintain constant current in LED. On the other hand, the operation of second converter works in CCM mode, which leads to low ripple current in LED. Performance and applicability of this converter is presented on basis of simulation in MATLAB SIMULINK. The design concept is validated through simulation and result obtained show that a closed loop system using IDBB converter for LED driver circuit is highly stable with high efficiency. Further, from the hardware implementation it is proved that optimal current flows through LED using PIC with IDBB converter.

Conflict of Interest

Authors declare there are no conflicts of interest.

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171

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