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ENHANCED POWER QUALITY BASED HIGH POWER LED LAMP DRIVER USING CUK CONVERTER

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ABSTRACT

This paper presents a high power factor LED driver for enhanced power quality which is used in residential and commercial application as energy efficient lighting lamp. Because it has number of advantage as compared to other gas filled lamps. The proposed LED driver consists of a power factor corrected CUK AC-DC converter which operates in continuous conduction mode using PID controller to improve the power quality at input AC mains. LED driver is designed to operate a 18W (six 3W LEDs are in series) rated LED lamp works under 220V, 50HZ at AC mains and each LED has a forward voltage of 12 V and a forward current 0.25A. This paper is also targeted to provide wide area of various power quality problems when working under AC Grid Supply. A 18W hardware prototype has been designed and tested to validate the performance of converter under universal input voltage condition.

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1 Introduction

Lighting accounts for roughly 20-30% of the electricity consumption all over the world. Recently light emitting diodes(LEDs) are become increasingly attractive lighting source in daily lives because of their many advantages likes high luminous efficacy, long life, environmental friendly, due to less mercury contents , flicker less start, quickly start, low maintenance, robust in structure and least affected by vibration. Also the LED lamps consume less power and have better power efficiency. LED lighting system mostly consist of two parts: LED driver and LED module. Eventhough high power LEDs are available at high cost, their long life make economical to use. Since LEDs are special types of diodes, the default method for driving them is controlling the DC forward current through the resistor, but this kind of approach is considered as less efficient to glow the LED lamp due to excessive power loss in the resistor. If the primary source of energy is the AC mains, then some kind of AC-DC converter must be placed between the line and the high brightness (HB) LEDs. But as per international standard IEC 61000-3-2 for Class C equipments (International Electro technical Commission standards for lighting) harmonic contents of the line current must be within the specified limits. Therefore, the best method is to use power factor corrected (PFC) AC-DC converters. The commonly used PFC circuit are buck, buck-boost, Cuk, Sepic, Zeta in non-isolated and flyback converter families in isolated mode. These can operate in continuous conduction mode (CCM) or dis-continuous conduction mode (DCM) to achieve better power quality at input AC mains. In CCM, a perfect sinusoidal input current with almost unity power factor can be obtained with the help of one outer voltage feedback loop and one inner current feedback loop.

LED driver consists of a diode bridge rectifier (DBR) and a resistor which provides a constant current to avoid the damage of LEDs. A Proportional Integral and Derivative controller is a control loop feedback mechanism to adjust the variable parameters and widely used in industrial control system. A PID controller calculates an error values as the difference between a measured process variable and desired set point. Then the PIDs controller is used to reduce steady state error, getting steady state conditions quickly and also increase the stability of the system. To comply with IEC-61000-3-2 class C equipments, a PFC stage is required between DBR and then LED module to improve the power quality at AC mains. In this paper, a power factor corrected (PFC) AC-DC Cuk converter operating in CCM (Continuous Conduction Mode) is proposed for LED driver. Total harmonic distortion happens when multiple of the same frequencies occur. It is a distortion of normal electrical wave form caused by amplifiers, drivers, power supplies and circuits. In solid state, LED driver, power factor corrected (PFC) AC-DC converter improves the input power factor and reduces total harmonic distortion of AC mains current (THDi) and also maintains constant lamp voltage for the stable operation of lamp. Since PFC converter is operated at high switching frequency of 60 kHz, it reduces the size and weight of passive components like inductor and capacitor.

2. Proposed Topology LED Driver

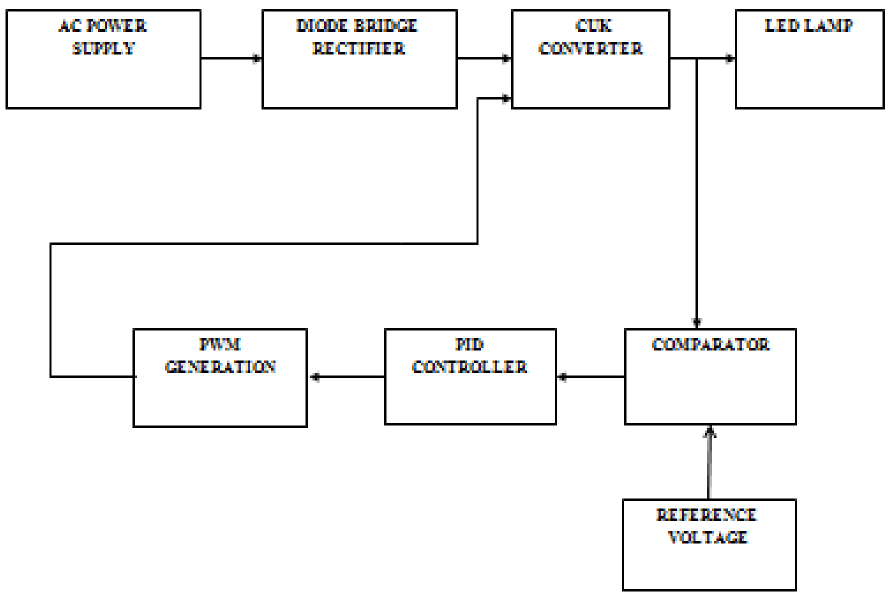

Fig.1. Proposed PFC Cuk converter based LED driver

The full model is connected to 230V, 50 HZ AC supply. A diode bridge is an arrangement of four (or more) diodes in a bridge circuit configuration that provides the same polarity of output for either polarity of input. Cuk converter is used to convert variable DC voltage into fixed DC, Output voltage high (boost) with input voltage magnitude Converter can operate in Continuous Conduction or Discontinuous Conduction mode to achieve better power quality at input AC mains. In CCM, a perfect sinusoidal input current with almost unity power factor can be obtained with help of one outer voltage feedback loop.

Also PID controller shown is a control loop feedback mechanism widely used in industrial control system. It calculates the error values as the difference between a measured process variable and desired set point. Error reduces by using control loop. Pulse width modulation is used to reduce the total power delivered to a load without resulting in loss, which normally occurs when a power source is limited by a resistive element. And this PWM technique maintain illumination of lamp. The underlying principle in the whole process is that the average power delivered is directly proportional to the modulation duty cycle.

2.1 LED Lamp Load:

A light emitting diode (LED) in essence is a P-N junction solid –state semi conductor diode that emits light. LED driver for powering 18W (six 3W LEDs are in series) rated each LED has forward voltage of 12V and a forward current 0.25A. LEDs consume less energy in comparison with conventional gas filled lamps. Today a LED flash light may last up to 200% longer with same batteries used to operate conventional filament flashlights.

The block diagram of proposed LED driver is shown in Figure 1 which consists of a DBR and PFC Cuk AC-DC converter connected in cascade configuration. The outer voltage feedback controller senses the DC voltage and compared it with the reference voltage to generate the error voltage, which is passed through the Proportional integral and derivative (PID) voltage controller to regulate the output voltage is given to the Pulse Width Modulation.

It generates continuous pulse is the input of MOSFET switch. In proposed LED driver as shown in Figure 1, a Cuk buck boost AC-DC converter is selected as the PFC converter to drive the lamp. The power switch M is operating at 60 kHz frequency.

Table 1. Block Diagram Description

AC supply	230V, 50HZ
DBR	AC to DC (variable)
CUK converter	BOOST output voltage
PID controller	Reducing steady state error and increase stability system
PWM	Generating variable pulse width Continuous to maintain illumination
LED load	for each LED have 3W, 12V, 0.25A

3 Analysis of Proposed LED driver

The following considerations are made to analyze the proposed topology of LED driver.

- All the components of LED driver are considered ideal.
- During steady state LED behaves as a pure resistor.
- DC link voltage must be selected properly to minimize component stress and to confirm CCM operation.

3.1 PID voltage controller

A Proportional integral and derivative (PID) voltage controller is selected for the voltage loop for regulation of the output voltage. The DC voltage Vdc is sensed and then compared with set reference voltage Vdc *. The resulting error voltage Ve is given as

$$V_e=V_{dc}*-V_{dc}$$

Calculated error in PID is defined as difference between measure process values to desired set point. Trial and error method is used for finding error in PID controller.

P=present error

I=past error accumulation

D=future error

Program for PID controller is given by

P-error=0;

Initial=0;

Start:

Error=starting point-measured value;

Integral=integral+error*dt;

Derivative=(error-previous error)/dt:

Output=K_p*error+K_i*integral+K_d*derivative;

Previous-error=error;

Wait(dt);

Go to start

Where K_p,K_i,K_d are the proportional integral and derivative gains.

Then the output of PID voltage regulator is given to pulse width modulation to generate gating signal for power MOSFET of the power factor corrected (PFC) CUK converter.

PID output >=repeating sequence then M=1;

Else M=0.

This gating signal(M) is given to the MOSFET of CUK converter.

4. MATLAB-Simulink

The model of the proposed PFC based Cuk converter for LED driver is developed in MATLAB/SIMULINK because all the electrical parts of the simulation interact with the extensive Simulink modelling library and it is shown in Figure 2 in which LED lamp is considered as a resistor at high frequency under the steady state condition.

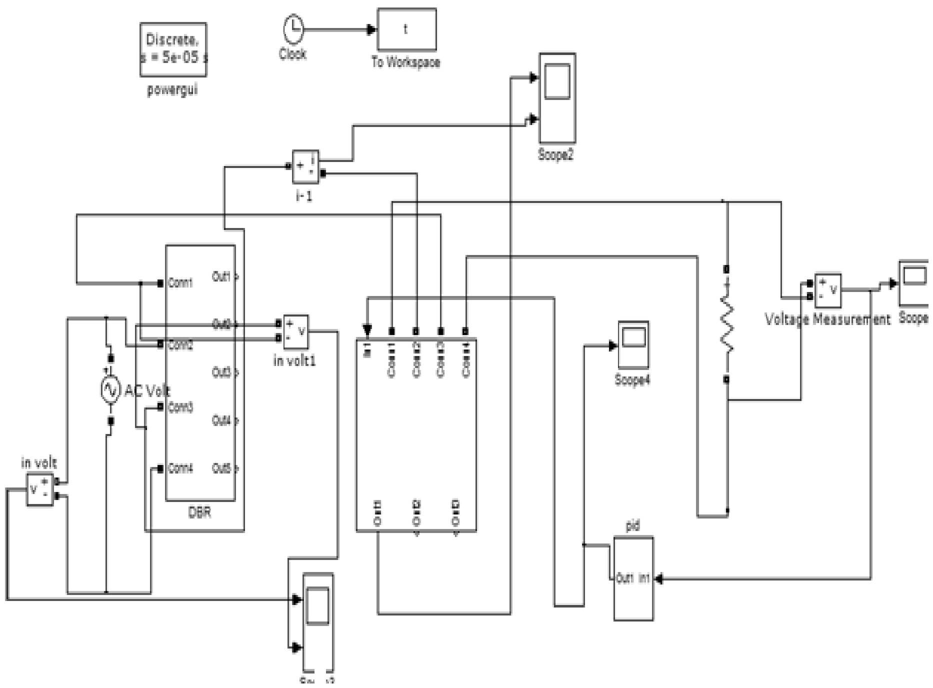

Fig .2. MATLAB model of proposed LED driver

PFC Cuk converter based topology is modeled using Proportional Integral derivative (PID) controller with the current multiplier approach for operating it in continuous condition mode (CCM). The switching frequency is maintained constant at 60 kHz for MOSFET switch.

5. Result and Discussion

The main objective of the modeling and simulation is to validate the design of proposed PFC based LED driver which has low THD of AC mains current and low crest factor for the wide input voltage applications. The DC link voltage is kept almost constant at 72V using closed loop control, thus the lamp current is maintained constant, which realizes the constant lamp power.

Figure 3 shows the input AC main voltage is operated at 230V, 50HZ frequency and diode bridge rectified output voltage with positive voltage only.

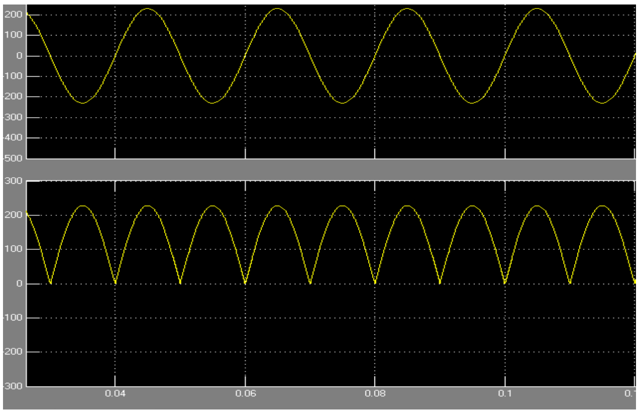

Figure.3.input voltage(Vs), DBR output voltage.

PFC CUK converter output wave form

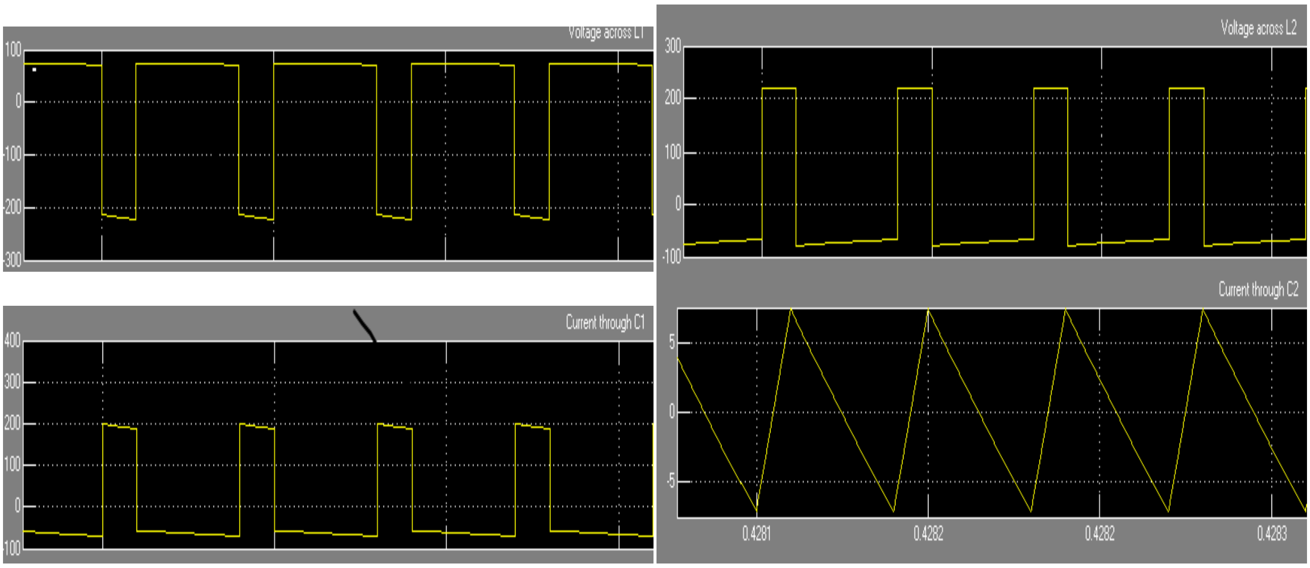

Figure .4.Output of Cuk converter

Figure4 shows voltage across inductor(L1), voltage across inductor(L2), current through (C1), current through (C2). The inductor current make sure of the Continuous Conduction Mode operation of the proposed LED driver.

PID controller output wave form

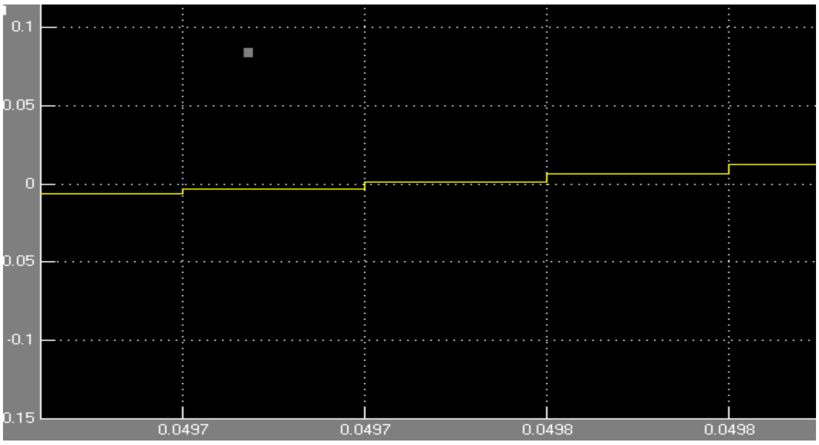

Fig .5.PID output wave form

PWM wave form

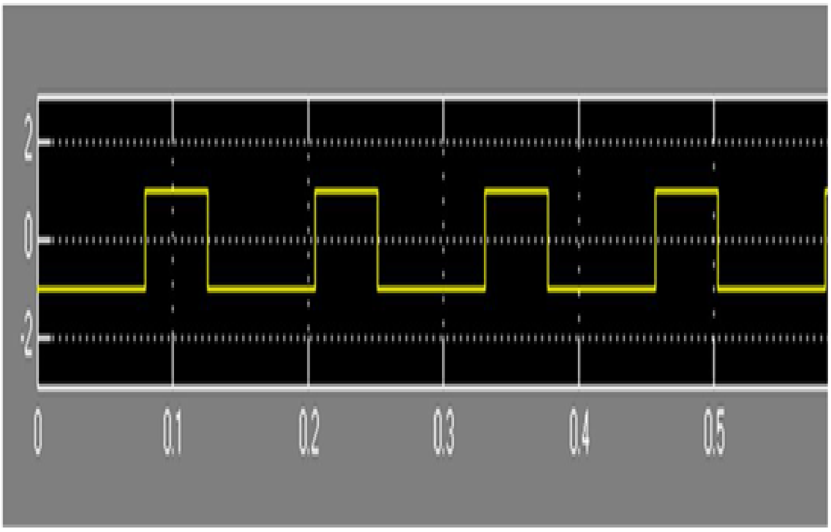

Fig .6.PWM output wave form

Final output wave form (lamp voltage)

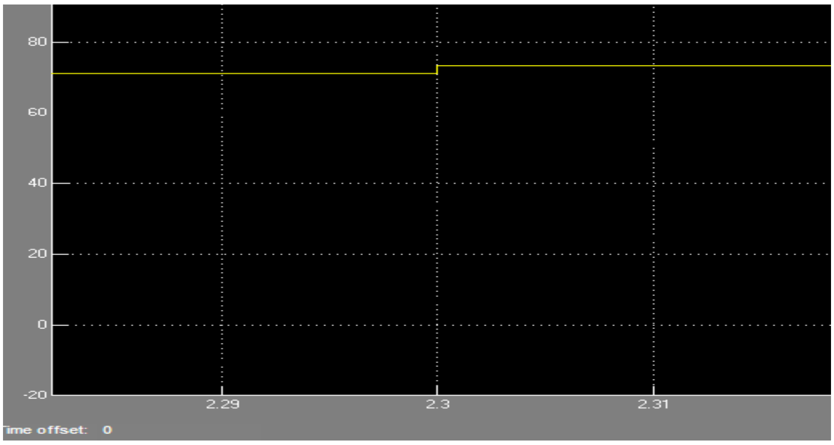

Fig .7.lamp output voltage

This output wave form is obtained from MATLAB/SIMULINK. The output lamp voltage is taken from CUK converter output before it is given to PID voltage controller. Its output is given to relational operator for power MOSFET switch of CUK converter. Then the output is given to LED lamp produce output DC voltage with few amount of harmonics.

Rated lamp power	18W
Rated lamp current	0.25 A
Rated lamp voltage	72V
Switching frequency of PFC switch	60 kHz
PID controller gains (KP)	0.0055
(Ki)	0.025
(Kd)	1e-7
PFC components: Inductor (L1)	20 mH
Inductor (L2)	20 mH
Coupling capacitor (C1)	0.1 µF
DC link capacitor (Co)	22 µF

Table .2. Simulation Parameters

6. Experimental Results

OFF Condition: LED Lamp Load

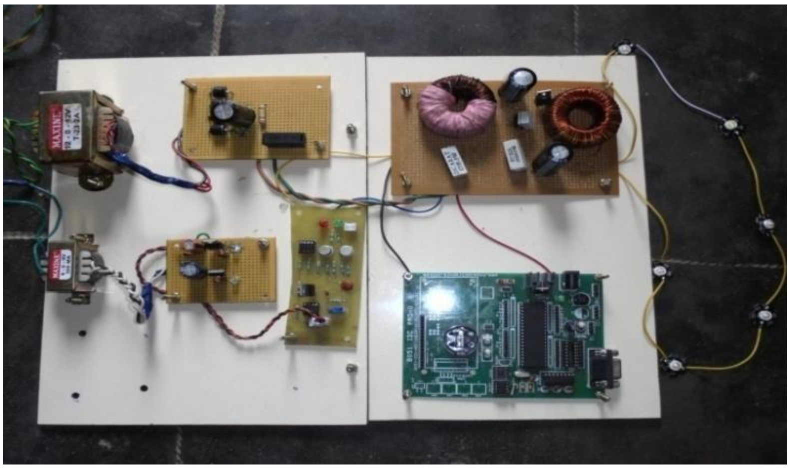

Fig .8. Hardware Details

6.1 High power LED with Heat Sink

Fig .9. Heat Sink

The design of heat sink plate fin model for the cooling of LEDs array during continuous operating conditions using commercially available CFD package. The LEDs arrays are modelled with sufficient details so as to capture accurate thermal behaviour of the package from the chip area to the boundary.

The objective is to ensure that the generated heat dissipated into the ambient air for the safe operating temperature less than 120°C is maintained.

ON Condition: LED Lamp Load

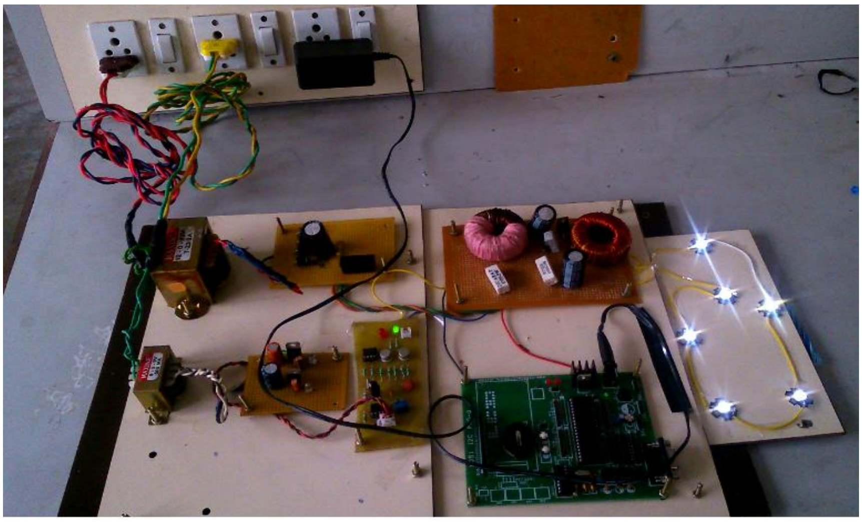

Fig 10. Hardware Result

Conclusion

A PFC Cuk AC-DC converter based on LED driver has been proposed with enhanced power quality for wide range AC mains voltage. The proposed LED driver with PFC Cuk converter has shown high level of performance such as nearly unity power factor. The current harmonics of the proposed LED driver have been compared with the current harmonic limits of IEC 61000-3-2 Class-C equipments and these have been found within the norms. The DC link voltage has been maintained constant, which realizes the constant lamp power irrespective of the change in AC mians voltage.

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