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Design and Simulation of an Efficient LED Driver for Street Light Application

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Abstract*—This paper presents the multistage high brightness (HB) LED driver for the application of street lighting. This paper focus on the reliability because the LED's may last for greater than 50,000 hours but the drivers may not; hence the driver design has to be such that they outdo the life of LED's .The existing two stage HB LED driver is modified here as three stage (multistage) to improve its reliability as well as the performance. The three stages are PFC boost converter, asymmetric half bridge converter and a current controlled buck converter. Each stage performs separate tasks to improve the efficiency of the driver circuit. The simulation of three stage HB-LED driver was done and it is presented in this paper using MATLAB software.

***Keywords*— AC-DC converters, soft switched converters, HB-LED, Buck converter, current regulator**

I. INTRODUCTION

The adoption of LED lighting in offline applications, such as office lighting, public buildings, and street lighting is increasing, and that increase is predicted to continue for the next few years. In these applications, high-brightness LEDs replace linear or high-power CFL fluorescent lamps, high intensity discharge (HID) lamps such as metal halide and high-pressure sodium, as well as incandescent lamps. These applications require an LED driver, which typically ranges from 25 W to 150 W. In many cases the LED load comprises an array of high-brightness white LEDs, often packaged in multiple die form. The DC current required to drive these loads is often at least one ampere. AC current-driven LED systems also exist, but DC systems are generally considered to provide more optimal driving conditions for LEDs. In LED light fixtures, galvanic isolation is required to prevent electric shock risk where LEDs are accessible which is the case in most situations unless a mechanical system of isolation is employed. This is because unlike fluorescent light fixtures that does not need to be isolated for safety, the LED die need to be connected to a metal heat sink. For good thermal conductivity, a thermal barrier between the LED die and the heat sink is necessary, which precludes the possibility of adding insulating material in between that would be thick enough to satisfy isolation requirements. Therefore, it is the best option to provide isolation within the LED driver itself, and this dictates the power converter topologies that are suitable. The two possibilities are the fly back converter or a multi-stage converter that includes a PFC stage, followed by an isolation and step down stage, and finally a backend current regulation stage. Of the two, the multi stage HB-LED driver is proposed in this paper ref [19].

The multi-stage LED driver in this proposed scheme will be broken down into three sections:

A. *The front end, PFC section.*
B. *The isolation and step down section.*
C. *The back end, current regulation section.*

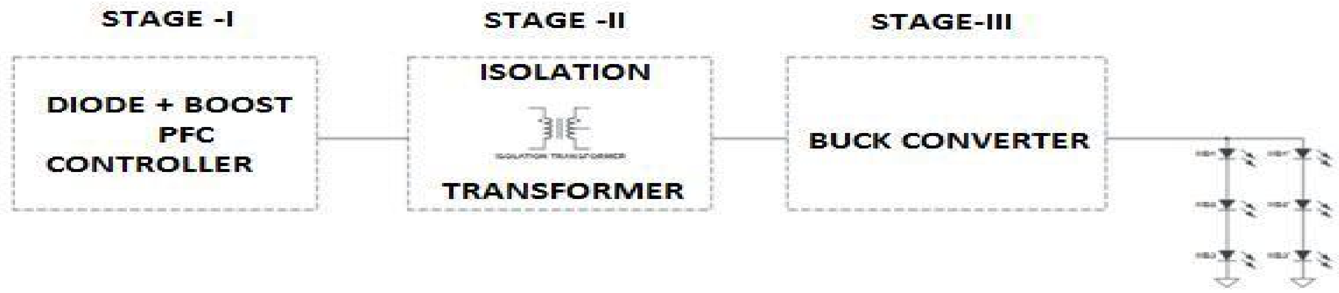


Fig.1 Block diagram of Multistage HB-LED driver

When several LED strings are connected in parallel and galvanic isolation is mandatory, the two stage topology can evolve into a three-stage topology as the one shown in Fig.1. The idea is that each stage is responsible for just one task [1]. In this way, the first stage would provide the PF correction, the second stage would provide the galvanic isolation and the third stage would regulate the output current. The main advantage of this topology is that the first and the second stages are common to all the strings, while there are as many third stages as strings in parallel. Therefore, the topology has only one transformer (there is only one second stage) and the cost is not significantly increased. The first stage boost converter operating in boundary condition mode. The second stage is an LLC resonant converter that cancels the low frequency ripple and provides galvanic isolation. The regulation of each LED string current is achieved by means of buck converter. Because the final application of this LED driver is street lighting, some additional details should be taken into account. Wavelength (colour) quality is less important than other issues such as cost and efficiency (including electricity-to-light conversion efficacy). Besides, the current stress on the LEDs should be the lowest as means to boosting the reliability, and indirectly, reducing the cost. These points can be achieved by means of, among other things, the amplitude-mode driving technique as it has lower current stress on LEDs and semiconductors than the PWM one.

In this paper a three stage topology is proposed for HB LED based street lighting application. The main objective of this topology is the achievement of high efficiency and high reliability while providing galvanic isolation and by using the buck converter. The comparison between existing two stage topology with the proposed multistage topology is discussed below.

II. COMPARISON BETWEEN TWO STAGE TOPOLOGY AND MULTISTAGE TOPOLOGY

The two stage topology is the existing one which was the advancement of single stage topology. The main difference between two stage and multi stage topology is implementation of buck converter and the requirement of isolation transformer. So in two stage topology, the isolation transformer is connected with each HB-LED strings separately and there is no current regulation made for the HB-LEDs. Thus the reliability of the two stage solution is moderate and it can only be increased by providing a current regulator. In the proposed multi stage HB-LED driver the second stage that is isolation transformer is common to all the LED stings and a current regulation for each string is separately controlled by the buck converter. Thus the multi stage solution gets higher reliability than the existing two methods.

The operation and simulation of multi stage HB-LED driver is discussed later. The table.1 gives the comparison between two stage and multi stage topology

Table.1 Comparison between Two stage and Multi stage HB-LED driver

	TWO STAGE TOPOLOGY	MULTI STAGE TOPOLOGY
Stages	Two	Three
Types	1. With galvanic isolation 2. Without galvanic isolation	1.With galvanic isolation
Current Regulation	Not used	Used
Cost	Lesser Compared to multi stage	Comparatively High

III. OPERATION OF MULTISTAGE HIGH BRIGHTNESS-LED DRIVER

In multi stage topology there are three stages, which have three independent operations to improve the performance as well as the efficiency of the driver. So the energy conversion between the input and output is discussed below.

A. Stage-I

The first stage comprises of full bridge diode rectifier and the power factor controlled boost converter. The input 220 volts AC is converted into 220 volts DC. The full bridge diode rectifier is used for the conversion of AC to DC. The ripples produced by the rectifier can be reduced by using a capacitor across the rectifier. Therefore the goal of multistage implies that the whole topology needs to be implemented with-out electrolytic capacitors ref [2]. The PFC boost converter is used here to boost up the voltage with PFC operation, shown in figure 2. The first stage correction may have to be taken into account in the driver design if the handled power is high enough (Greater than 60Watts). So in this paper the LED driver is made for lighten 45Watts high brightness LED only.

So that, a capacitor provided in the boost converter, is able to do the power factor correction operation if needed. The output of Stage-I is 300V, which is shown in figure 2.

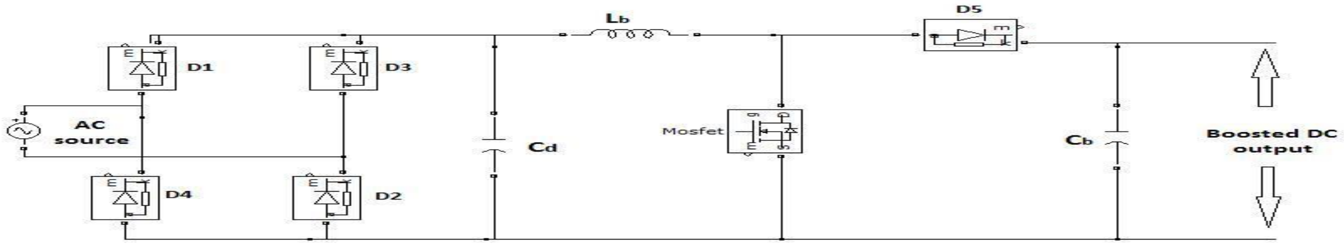
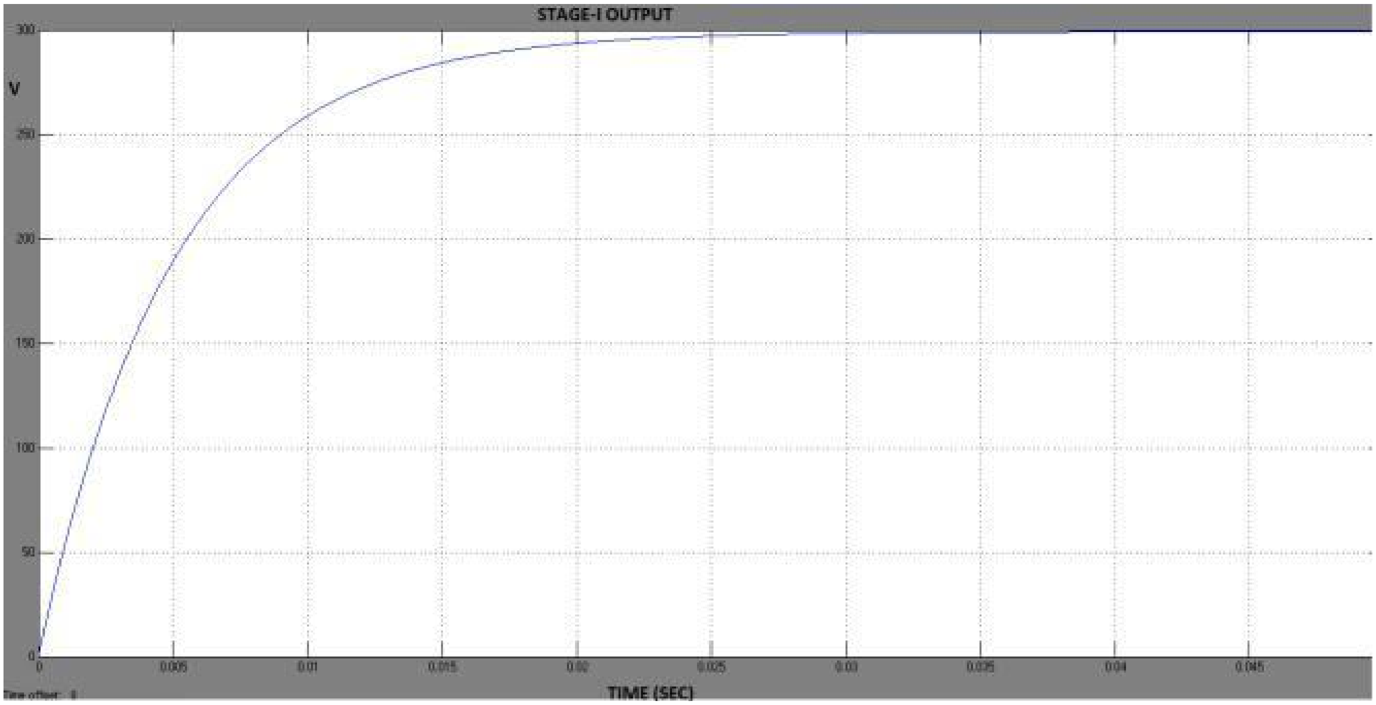


Fig.2 Diode rectifier and Boost converter (Stage-I

Fig 2.1 Output of STAGE-I



B. Stage-II

The first stage of the proposed topology is a boost converter used in order to achieve PFC with high efficiency. The principle of operation of this kind of converter is very well known [4], [5]. For the proposed two-stage topology, the main issue is that implementing this boost converter without electrolytic capacitors implies a considerable low-frequency ripple at the output. This ripple is then determinant in the design of the second stages [1]. The relative value of this peak-to-peak ripple will be denoted as *rv* in this paper and is referred to the nominal output voltage *Vg*. It should be taken into account that the ripple of the first stage will not affect the output voltage of the second stage because its closed-loop control can be fast enough to cancel this ripple. Asymmetric half bridge is a soft switching converter. Primary two switches can achieve ZVS with the help of leakage inductance. Since the two switches works complementarily, there is no ring problem caused by leakage inductance to achieve soft switching. AHB is very popular level less than 1KW.

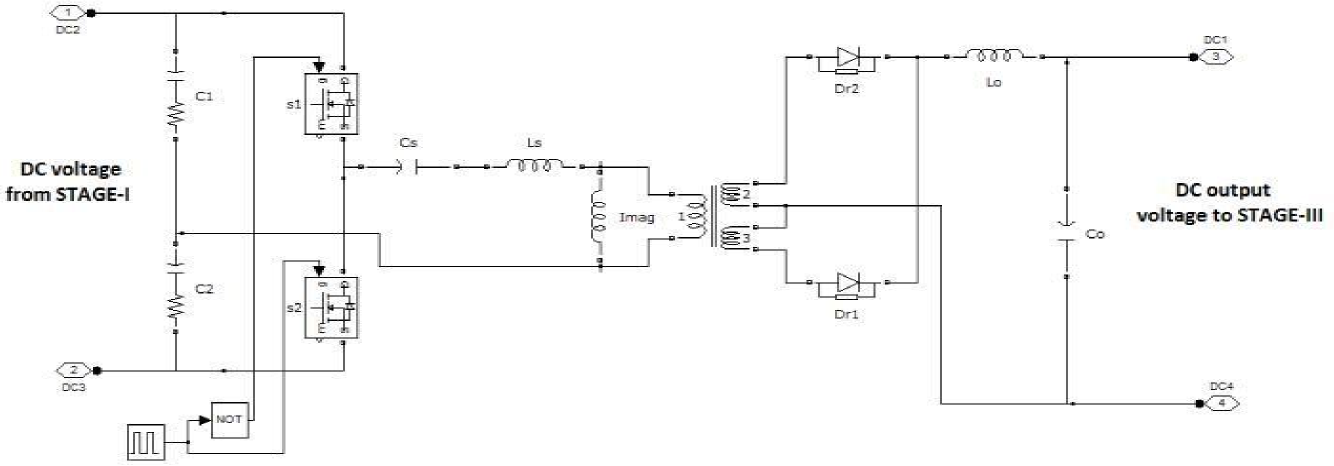


Fig.3 Asymmetric half bridge (stage-II)

The schematic of the AHB can be found in Fig. 2 [4] and [17]. As can be seen, it consists of an HB converter with their switches controlled with complementary signals (i.e., ideally, one of the two primary switches is always ON, different from what hap-pens in standard HBs). The main consequence of this control technique is that due to the necessity of maintaining the volt– second balance in the transformer magnetizing inductor, the input capacitor voltages will vary according to the following equations

$$VC\,1 = (1- D)\,Vg$$

$$VC\,2 = DVg$$

where Vci is the voltage across each input capacitor, D is the duty cycle of $S1$, and

Vg is the input voltage of the AHB.

It should be taken into account that in the AHB, D must always be lower than 0.5

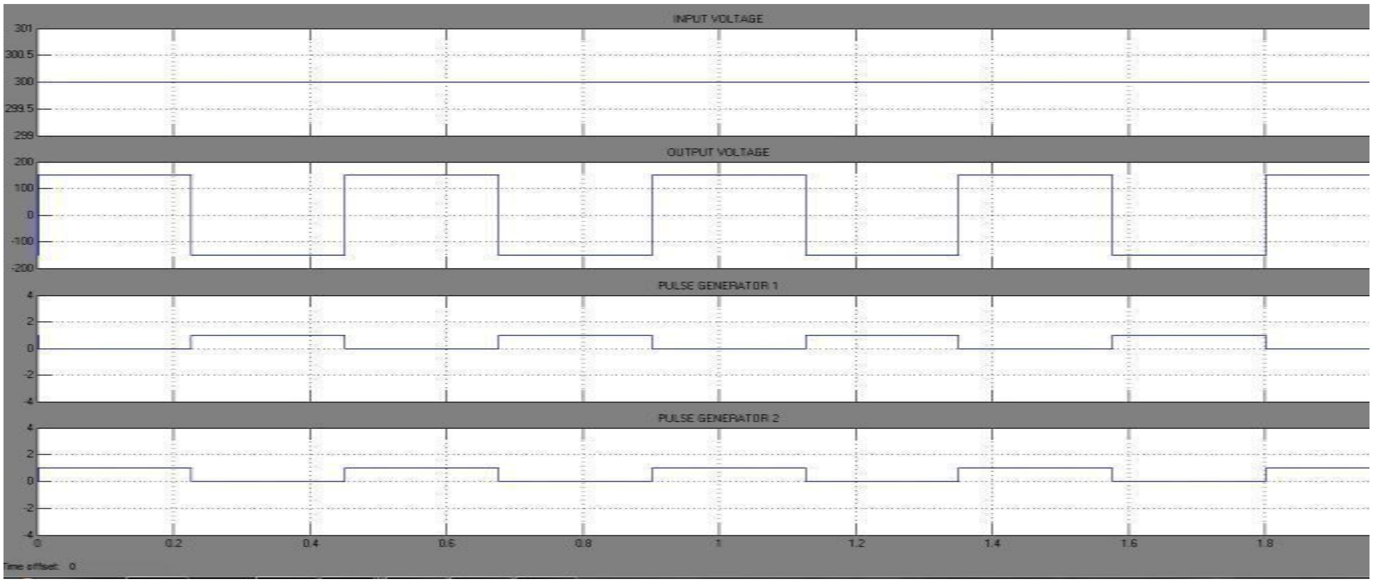


Fig.3.1 Output of STAGE-II

The output voltage will depend on the input voltage, the duty cycle, and the turns ratios of the transformer (n1 = Ns 1 /Np and n2 = Ns 2 /Np)

$$Vo = n1\ VC1\ D + n2\ VC2\ (1 – D) = Vin\ D\ (1 – D)\ (n1 + n2).$$

Analysing the current balance in the primary side, it should be noted that the current through the leakage inductance satisfies

$$Ilk = IC\ 1 − IC\ 2 = Imag + ITR$$

Where ITR ideal is the current through the ideal transformer, Imag is the current through the magnetizing inductor, IC 1 and IC 2 are the currents through the input capacitors C1 and C2, and Ilk is the current of the leakage inductance.

The average value of IC 1 and IC 2 is zero because they are capacitor currents. Hence, in average value, Imag is equal to ITR ideal with different sign. Also, during DT, the current through the ideal transformer is equal to Io n1, while during (1−D) T, is equal to −Io n2. The analysis of AHB was done in ref [1] and [4]. Apart from galvanic isolation, which is an important feature in order to comply with some regulations and/or customer requirements, another important advantage of the proposed topology is the size of the output filter. The voltage at the output of the AHB rectifier is easier to filter (see Fig. 3).Hence, the size of the output inductor and/or the output capacitor can be smaller. This is especially important since electrolytic capacitors cannot be used. The output of second stage is shown in figure 3.1. The input to the second stage is 300 V delivered by the Boost converter (see Fig.3.1). Due to the complementary switching the DC is converted into AC then isolation is provided to keep the load separately from the source and finally the rectifier at the secondary side rectifies the AC in to DC. It is the input for the StageIII.

C. Stage-III

The back end stage of the LED driver consists of a current regulating circuit with short circuit protection. This can be realized with a linear regulating circuit; such an approach is inherently inefficient and therefore only suitable for low output currents, which will not generally apply in a multistage system. The alternative is a simple buck regulator circuit with a current feedback to limit the output current from exceeding the intended LED drive current ref [6].

This compensates for variations in total LED forward voltage over temperature and device tolerance, and limits the current in the event of a short circuit or other fault condition, thereby protecting the river against Therefore, the topology has only one transformer (there is only one second stage) and the cost is not significantly in- creased. It may be considered as a two-stage topology with equalizers, but it has two important differences with it:

1) The equalizers have poor efficiency in comparison to the third stages proposed here. They are switching mode power supplies with very high efficiency.

2) The second stage in this topology duty cycle of the pulses only provides the galvanic isolation and does not have to regulate the output current. If we neglect the voltage drops across the transistor and diode then:

$$Vout=DVin$$

So it is clear that the output voltage is related directly to the duty cycle of the pulses.

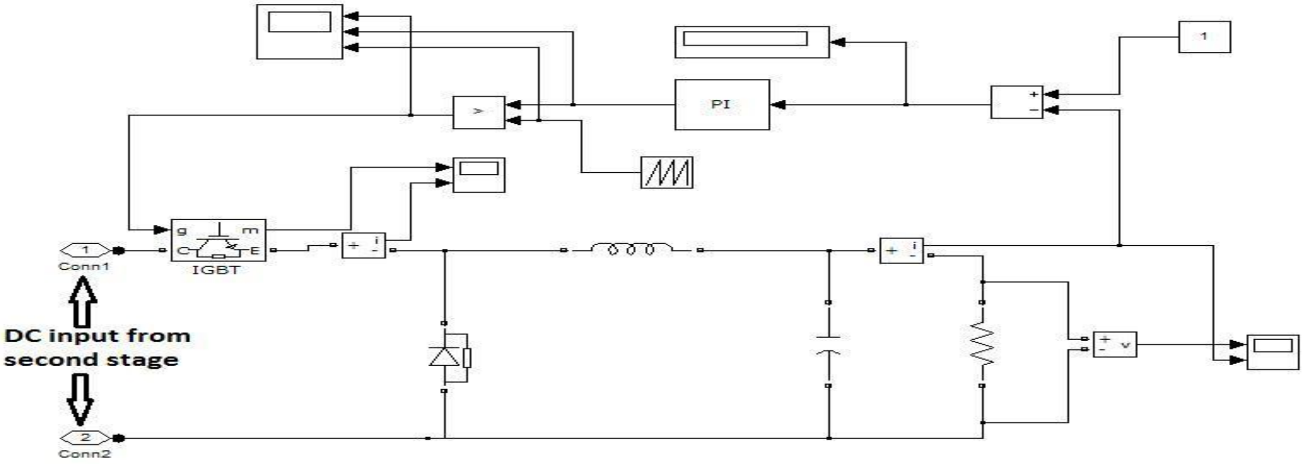


Fig.4 Buck converter (Stage-II)

Therefore, this multistage can be regulated and, consequently, being based on the Electronic Transformer (ET) concept [4], which may reach an efficiency as high as 97%- 98%. It should be taken into account that the ET may be considered as a transformer that can operate with DC voltages, ref [18].

Therefore, although it is unregulated, it can apply a fixed gain (turns ratio in a real transformer) to its input voltage. In the two-stage topology with several second stages, these second stages have to provide the galvanic isolation and they also have to regulate the output current ref [11]. As they have to accomplish two different tasks, their optimization is worse. The figure 4 shows the proposed multistage HB-LED driver with masked blocks of all the three stages. Fig.4 Proposed Multistage HB-LED driver model

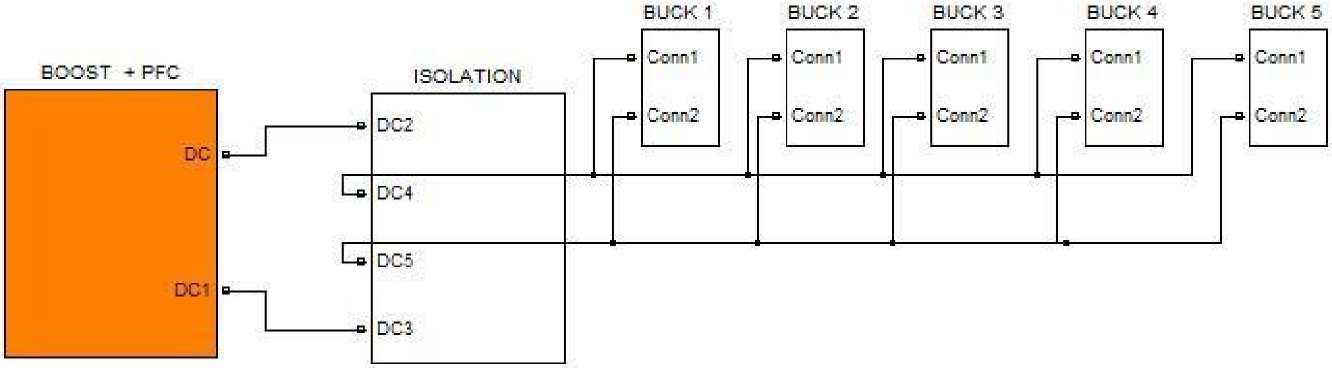


Fig.4 Proposed Multistage HB-LED driver mode

IV. ADVANTAGES

- *A. High Efficiency*
- *B. Colour Quality*
- *C. High Reliability*

V. APPLICATIONS

Electricity applications i.e., Offline applications like Street Lighting etc.,

VI. RESULT

The simulation was done by using MATLAB software. The proposed multi stage model having three stages each stage was implemented for different purposes as mentioned above. The first stage is consisting of diode rectifier and PFC boost rectifier and the input of this first stage is connected to the single phase 220volts, 50HZ AC supply. This 220volt was rectified by using the full bridge rectifier then it will be boosted by using the boost converter. That boosted voltage of 300V is given to the second stage which gives isolation. The isolation transformer is nothing but a 1:1 transformer

This second stage is a DC to DC converter. So the output of this second stage is a DC supply and this will be given to the third stage called a buck converter which is act as a current regulator for each string, this can be achieved by taking the output inductor current as reference and connected to one of the input to the PI controller. The buck converter is made of 1 mF capacitor and the inductance of 1.1 mH. The error which is come from the PI controller is used for controlling the gate pulse of the buck converter, so that we can regulate or maintain the output current constant. So each string produce 9 volts and 1 amps at the load side.

Therefore the proposed third stage buck converter is capable of making 9Watts per string. Here there are 5 strings connected across at the end terminal of the third stages therefore the total output is going to be 45Watts.

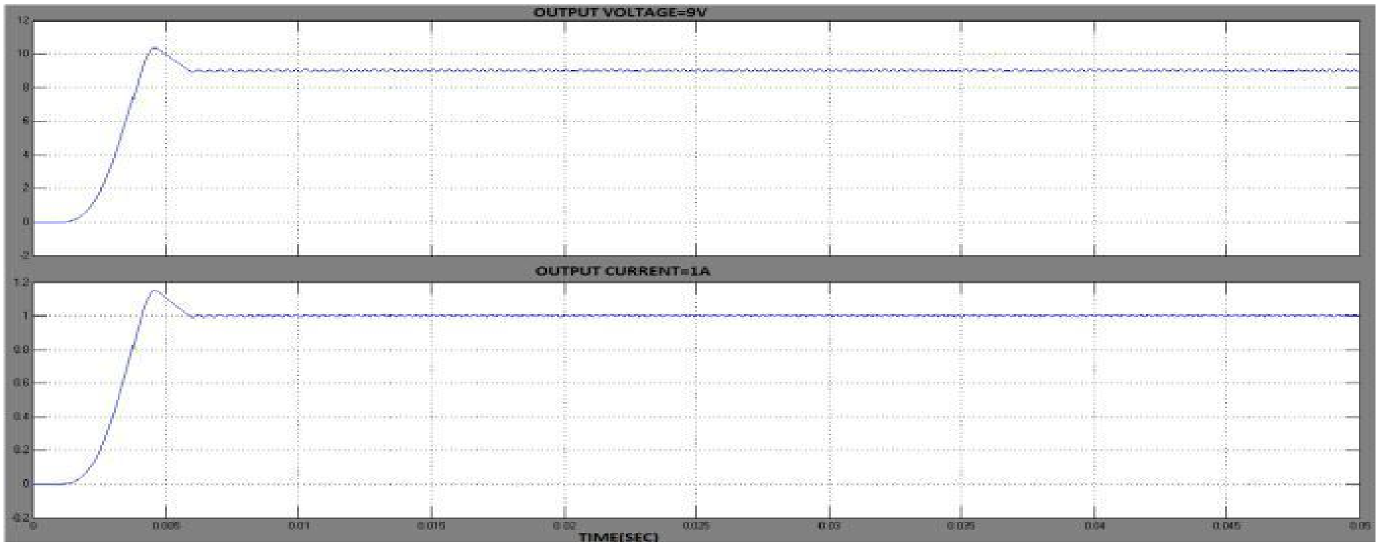


Fig.5 Final output of multistage high brightness LED

VII. CONCLUSION

LED represents a very interesting alternative to the traditional lighting devices due to, among other reasons, their high efficiency and reliability. Nevertheless, they need the development of converters specially designed for taking advantage of their characteristics. This implies the design of converters with very high efficiency and without electrolytic capacitor so that their lifetime is extended. Al- though for DCDC converters this is not a big problem, for AC-DC topologies (when PFC is mandatory) this means a big design effort. Besides, the control technique for regulating the amount of light emitted by the LED may benefit from its fast response. So the proposed multistage model gets a higher efficiency and reliability as above mentioned. In two stage driver model the only possibility of the driver was due to fault current through the device. This problem can be protected by the current regulator using the buck converter in this project. So the life time of the driver can be improved which is capable of maintaining the life period as LED have.

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