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A Universal Multistage High Brightness LED Driver for Domestic and Industrial Lighting Application

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Abstract— This paper presents the multistage high brightness (HB) LED driver for the application of domestic and industrial lighting. This paper focus on the reliability because of the LED's life 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 stages 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. This paper focussed on life and efficiency of the HB LED driver.

Index Terms— AC-DC converters, Buck converter, current regulator, HB-LED, soft switched converters.

1 Introduction

The offline LED lighting is used in many applications today like, office lighting, public buildings, and street lighting which is predicted to increase in upcoming years. In these applications, HBLEDs replace the CFL, fluorescent lamps, high-intensity discharge (HID) lamps and high-pressure sodium and also incandescent lamps. These domestic and industrial applications require an LED driver, which typically ranges from 20 W to 180 W. For many applications the LED load comprises an array of HBLEDs, often packaged in multiple array form. The drive current for the total HBLEDs in the array at least needs 1 ampere.

HBLEDs works also in AC power but DC based driven HBLEDs are more often easy to control as well as we get an optimal driving condition. Normally the first stage called AC-DC converter is commonly needed to all the LED drivers. But the second stage is essential, which is called isolation stage. This stage is mainly designed for isolating the source and load by using an isolation transformer and this stage also protect from electric shock. This is why fluorescent light does not need to be isolated for safety. For thermal conductivity, a heat sink is necessary, which precludes the possibility of adding insulating material in between that would be thick enough to satisfy isolation requirements. The two possibilities are the flyback converter or a multi-stage converter that includes a Power factor control stage, then an isolation stage, and finally current regulation stage using a buck converter with a closed loop system. Of the two, the multi stage HB-LED driver is proposed in this paper.

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

1. Rectifier and PFC section.
2. Isolation section.
3. Current regulation by BUCK converter

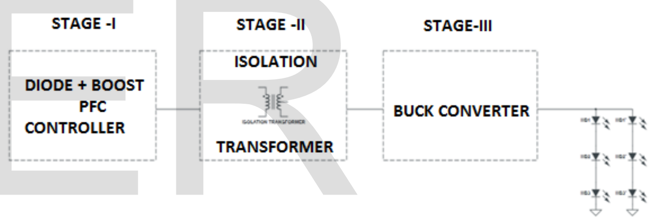

Fig. 1. Block diagram of Multistage HB-LED driver

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 sapplication of this LED driver is lighting, 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

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amplitude-mode driving technique as it has lower current stress on LEDs and semiconductors than the PWM one.

The merits and demerits of this proposed universal multi-stage topology compared to other topologies used in LED-based lighting are:

1) Having high efficiency nearly up to 95% in the second stage and 90% taking into account Power factor control and AHBs. [1].

2) The quality of the Colour is lower than it is with digital dimming but it is not a critical issue due to the final application (i.e., street lighting).

3) The reliability is higher than the two stage method because of adding a current regulation stage finally.

4) The Galvanic isolation is provided by the proposed multi stage topology. This requirement is sometimes necessary in order to comply with certain regulations or customer demands. In the two stage HBLED driver by using galvanic isolated topologies in the second stage increases the size of the whole converter when the number of outputs is high, but here the number of second stage is independent of output. Actually the number of third stage is only depends on the output. If the galvanic isolation is provided by the second stages, the first stage can be a boost converter in critical mode, which has efficiency as high as 96%.

Also, the size of this capacitor is not determined by the chosen switching frequency, but by the line frequency (in fact, twice the line frequency).

In this paper a three stage topology is proposed for HB-LED based 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 as a current regulator. The comparison between existing two stage topology with the proposed multi-stage topology is discussed below.

2 Comparision between Two Stage Topology and Multi Stage 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

	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 higher
Reliability	Moderate	Higher
Maintenance	Needed	Not needed for the driver

3 Operation Of Multistage High brightnees 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.

3.1 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 without electrolytic capacitors [5].

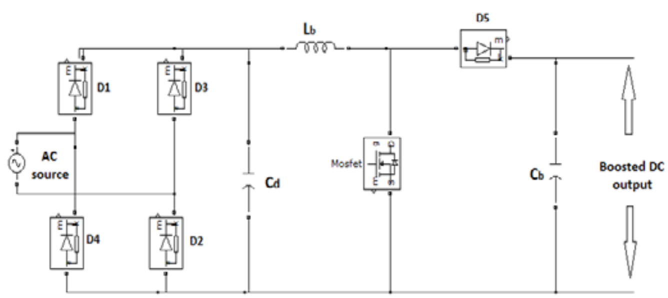

Fig. 2. Block diagram of Multistage HB-LED driver

The PFC boost converter is used here to boost up the voltage with PFC operation. The first stage has the efficiency of 97%, [2]. The Power Factor (PF) 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.

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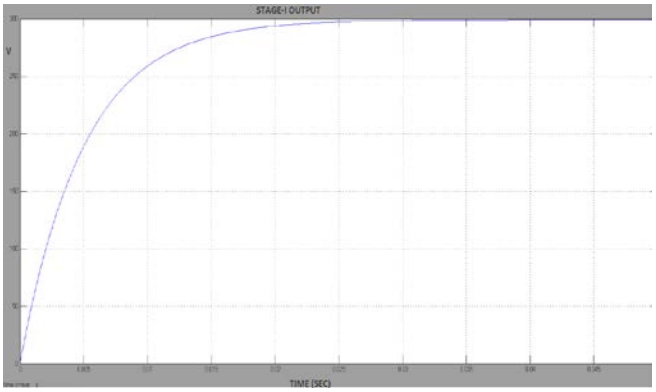

Fig. 3 Output of Stage - I

The output of stage one is shown in Fig.3. This shows the output of 300V DC from the PFC boost converter and it will be fed to the input of second stage as follows.

3.2 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 [3], [4].

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.

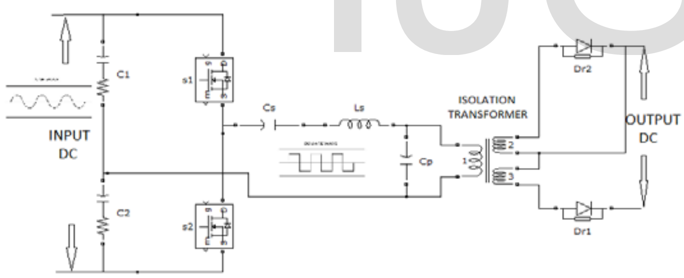

Fig. 4. Asymmetric Half Bridge (stage – II)

The simulation of the AHB can be found in Fig. 4 [7], [8]. As can be seen, it consists of an AHB converter with their switches controlled with complementary switching technique that is ideally, one of the two primary switches is always ON, different from what happens in standard half bridge or symmetrical half bridge. 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.

$V_{C1} = (1 – D)\ V_{in.}$
$V_{C2} = D\ V_{in.}$

where Vc1 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.

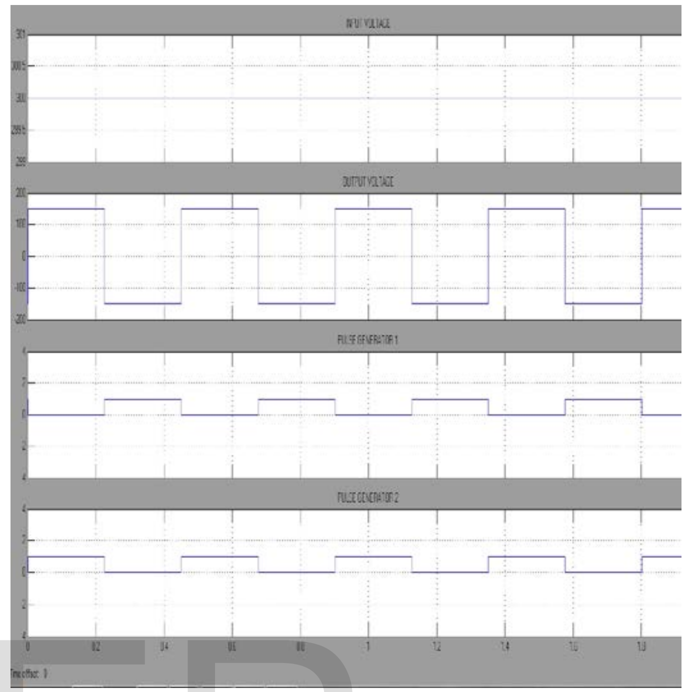

Fig. 5. Complementary pulse input to the AHB

So as per the simulation shown above the complementary input pulses are given to the switches S1 and S2.

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

$V_o = n1\ V_{C1}\ D + n2\ V_{C2}\ (1 – D) = V_{in}\ D\ (1 – D)\ (n1 + n2).$

$I_{C\,1}$ and $I_{C\,2}$ are the currents through the input capacitors C1 and C2, The average value of IC 1 and IC 2 is zero because they are capacitor currents. During DT, the current through the ideal transformer is equal to Io n1, while during (1−D) T, is equal to $-I_o$ n2. The analysis of AHB was done in ref [1] and [2].

3.3 Stage-III

The third stage of this multistage LED driver consists of a current regulating circuit using buck converter. This can be achieved by using a linear regulating model; such a methodology is inherently inefficient and it also suitable for low output currents application, which will not be applicable in a multi-stage system. The alternative way making current regulation is a simple buck converter circuit with a current feedback to limit the output current from exceeding the intended LED drive current.

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,

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thereby proteccting the circuit from high fault current. And also this topology has only one transformer (there is only one second stage) and the cost is not significantly increased due to increase in number of third stage.

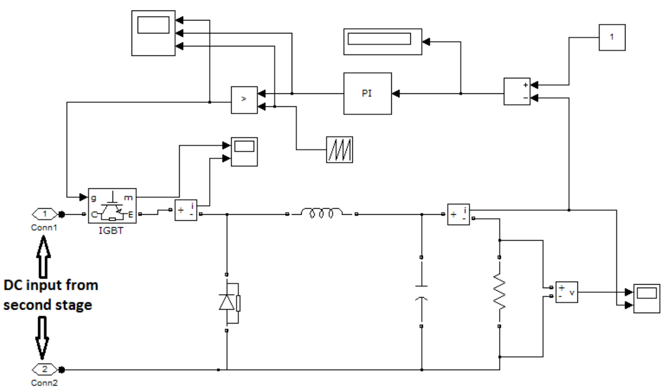

Fig 6 Buck regulator (Stage-III)

It may be considered as a two-stage topology with equalizers, but it has two important differences with it:

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

• The second stage in this topology only provides the galvanic isolation and does not have to regulate the output current.

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.

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.7 shows the proposed multistage HB-LED driver with masked blocks of all the three stages.

4 Simulation 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.

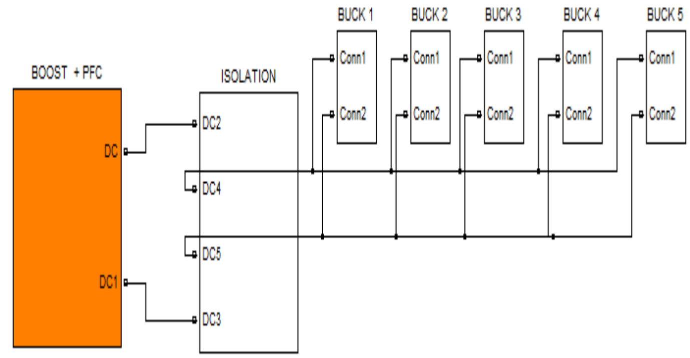

Fig 7 Multi Stage HB-LED Driver

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 is given to the second stage which gives isolation. The isolation transformer is nothing but a 1:1 transformer. The simulation output will be as like below.

The 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 produces 9 volts and 1 amp at the load side.

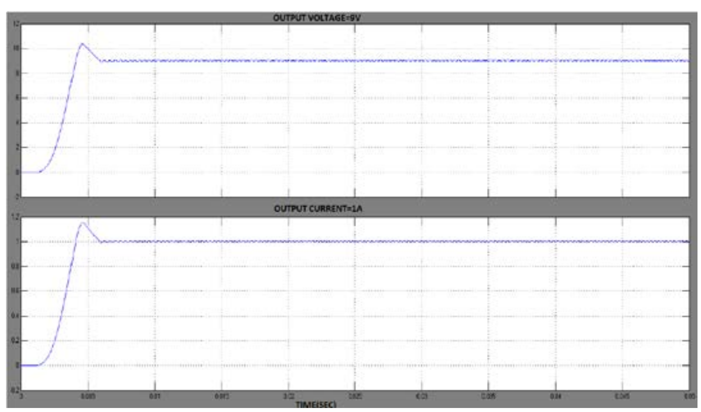

Fig 8 Multi Stage HB-LED Driver Voltage and Current Output

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. This can be taken from the MATLAB simulation as in fig.8

For industrial lighting application the output power must be between 40W to 180W which is enough to achieve the same illumination of HID or high pressure sodium lamps except the third stage all other stage of the driver is same for the above output power and the third stage is decided by the output power level as discussed.

5 CONCLIUSION

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. Although for DC-DC 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 prevented by the current regulator using the buck converter in this paper. So the life time of the driver can be improved and it is expected more than 75000 hours which is near or equal to the life time of the HBLEDs.

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REFERENCES

[1] Diego G. Lamar, Francisco F. Linera, Didier Balocco, Almadidi Aguissa Diallo, and Javier Sebasti "Design of a Soft-Switching Asymmetrical Half-Bridge Converter as Second Stage of an LED Driver for Street Lighting Application" IEEE Transactions On Power Electronics, Vol.27, No. 3, March 2012

[2] W. Beibei, R. Xinbo, Y. Kai, and X. Ming, "A method of reducing the peak-to-average ratio of LED current for electrolytic capacitor-less AC-DC drivers," IEEE Trans. Power Electron., vol. 25, no. 3, pp. 592–601, Mar. 2010.

[3] L. Xingming and Z. Jing, "An intelligent driver for light emitting diode street lighting," in Proc. World Automation Congr. (WAC), 2008, pp. 1–5.

[4] W. Eberle, H. Yongtao, L. Yan-Fei, and Y. Sheng, "An overall study of the asymmetrical half-bridge with unbalanced transformer turns under current mode control," in Proc. 19th Annu. IEEE Appl. Power Electron. Conf. Expo. (APEC), 2004, pp. 1083–1089.

[5] D. G. Lamar, J. Sebastian, M. Arias, and M. M. Hernando, "A low-cost AC-DC high-brightness LED driver with power factor correction based on standard peak-current mode integrated controllers," in Proc. IEEE Energy Convers. Congr. Expo. (ECCE), 2010, pp. 463–470.

[6] X. Qu, S. C. Wong, and C. K. Tse, "Resonance-assisted buck converter for offline driving of power LED replacement lamps," IEEE Trans. Power Electron., vol. 26, no. 2, pp. 532–540, Feb. 2011.

[7] T. Siew-Chong, "Level driving approach for improving electrical-to-optical energy-conversion efficiency of fast-response saturable lighting devices," IEEE Trans. Ind. Electron., vol. 57, no. 4, pp. 1342–1353, Apr. 2010.

[8] "LED driver circuit with series-input-connected converter cells operating in continuous conduction mode," IEEE Trans. Power Electron., vol. 25, no. 3, pp. 574–582, Mar. 2010.

[9] L. Wai-Keung, K. H. Loo, T. Siew-Chong, Y. M. Lai, and C. K. Tse, "Bilevel current driving technique for LEDs," IEEE Trans. Power Elec- tron., vol. 24, no. 12, pp. 2920–2932, Dec. 2009.

[10] B. R. Lin and C. L. Huang, "Analysis and implementation of an integrated sepic-forward converter for photovoltaic-based light emitting diode light- ing," Power Electron., IET, vol. 2, no. 6, pp. 635–645, Nov. 2009.

[11] D. Gacio, J. M. Alonso, A. J. Calleja, J. Garcia, and M. Rico-Secades, "A universal-input single-stage high-power-factor power supply for HB- LEDs based on integrated buck-flyback converter," IEEE Trans. Ind. Electron., vol. 58, no. 2, pp. 589–599, Feb. 2011.

[12] H. Yuequan and M. M. Jovanovic, "LED driver with self-adaptive drive voltage," IEEE Trans. Power Electron., vol. 23, no. 6, pp. 3116–3125, Nov. 2008.

[13] ST, "AN3105 Application note: 48 V–130 W high efficiency converter with PFC for LED street lighting applications - European version," ST online database.

[14] Q. Xiaohui, W. Siu-Chung, and C. K. Tse, "Noncascading structure for electronic ballast design for multiple LED lamps with independent bright- ness control," IEEE Trans. Power Electron., vol. 25, no. 2, pp. 331–340, Feb. 2010.

[15] W. Jian-Min, W. Sen-Tung, J. Yanfeng, and C. Huang-Jen, "A dual-mode controller for the boost PFC converter," IEEE Trans. Ind. Electron., vol. 58, no. 1, p. 369-372, Jan. 2011.

[16] T. Jiun-Ren, W. Tsai-Fu, W. Chang-Yu, C. Yaow-Ming, and L. Ming-Chuan, "Interleaving phase shifters for critical-mode boost PFC," IEEE Trans. Power Electron., vol. 23, no. 3, pp. 1348–1357, May 2008.

[17] J. Sebastian, J. A. Cobos, O. Garcia, andJ. Uceda, "An overall study of the half-bridge complementary-control DC-to-DC converter," in *Proc. 26th Annu. IEEE Power Electron. Spec. Conf. (PESC)*, 1995, pp. 1229–1235.