Electrolytic Capacitor-less Transformer-less AC-DC LED Driver with Current Ripple Canceller

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Abstract— This paper proposes an electrolytic capacitor-less transformer-less AC-DC LED driver with a current ripple canceller. The proposed LED driver includes a diode bridge, a buck-boost converter, a negative feedback controller and a current ripple cancellation circuit. The current ripple canceller works as a bi-directional current converter using a sub-inductor, a sub-capacitor and two switches for controlling current flow. LED voltage is controlled in order to regulate LED current by the negative feedback controller using a current sense resistor. There are two capacitors which capacitance is 5 uF.

We describe circuit topologies, operation principles and simulation results for our proposed circuit. In addition, show the line regulation for input voltage variation from 85V to 130V. The output voltage ripple is 2V and the LED current ripple is 65mA which is less than 20% of the average of LED current of 350mA.

Keywords: AC-DC converter, buck-boost converter, current ripple canceller, electrolytic capacitor-less, LED driver

I. INTRODUCTION

MANY AC-DC converters for LED drivers are offered that use electrolytic capacitors or transformers. In typical AC-DC converters, the AC input is rectified using a diode bridge, a bulky electrolytic capacitor and a buck converter in order to create the desired DC output voltage. In this case, a transformer is bulky or electrolytic capacitors are low reliability.

In this paper, first we introduce a few types of fundamental AC-DC converters and a conventional AC-DC LED driver. Next, we propose a new direct AC-DC converter for LED driver with current ripple cancellation circuit. This LED driver comprises a diode bridge, DC-DC buck-boost converter and bi-directional current converter that works as current ripple canceller in order to regulate the LED voltage.

II. CONVENTIONAL AC-DC LED DRIVER

A . Fundamental AC-DC Converters

The direct AC-DC converters using a buck or buck-boost type circuit are shown in Fig.1 , Fig.2 and Fig.3. In Fig.1, input AC voltage is rectified with a diode bridge, two electrolytic capacitors and a buck converter. In Fig.2, input AC voltage is directly rectified with three switches, two diodes and an electrolytic capacitor. In this converter, the red solid line shows current flow when the inductor is charged, and the blue dashed line shows the current flow when the inductor is discharged.

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Three switches are controlled in operation modes which vary with change of input voltage polarity and with change of charging or discharging of the inductor.

Fig.3 shows the LED driver with a diode bridge, a non-inverted buck-boost converter and two electrolytic capacitors. Current of LED is detected with the sensed resistor Rs and the output voltage is controlled by the feedback loop in order to regulate the LED current.

These three converters use bulky electrolytic capacitors in order to reduce the output voltage ripple or to regulate the LED current ripple. For LED driver, it is desired to use no electrolytic capacitors in order to keep high reliability.

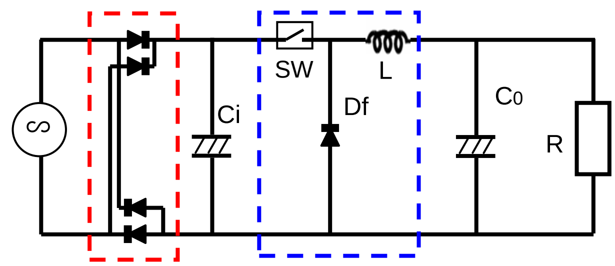


Fig. 1 AC-DC buck converter with diode bridge

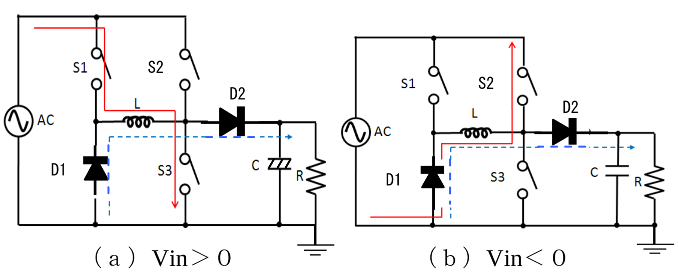


Fig. 2 AC-DC buck-boost converter with H-Bridge

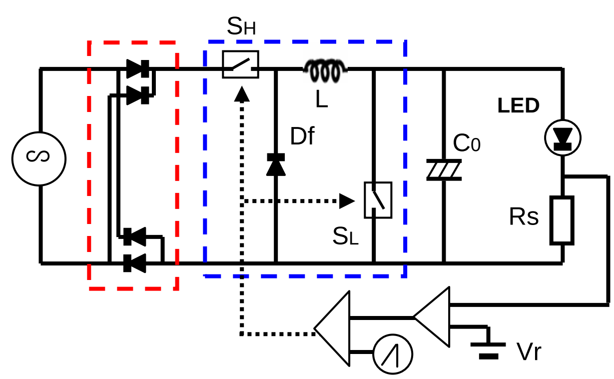


Fig. 3 LED driver with buck-boost converter

B. Conventional LED Driver with Transformer

Fig. 4 shows the AC-DC converted LED driver with a diode bridge, a transformer and a bi-directional buck-boost converter called a current ripple canceller. In this system, two capacitances Co and C_B are smaller than 10uF and they are not electrolytic capacitors. There is a serial inductor Lo in a load line of LED in order to reduce the current ripple.

The operation is that the input current from the transformer include DC current for the LED and AC current caused by the input AC sine wave. AC current of this input current is almost controlled to the bi-directional buck-boost current converter that consists of the capacitance C_B, a inductor L_B and two sub-switches Q_2, Q_3, which are controlled by same frequency of a main switch Q_1. Fig. 5 shows the simulation results, where the input voltage Vin is 110Vrms, the output current Io is 300mA and the current ripple is about 42mApp. In this case, the parameters are F=58kHz, L_B=2.2mH, Co=6.8uF and C_B=3.7uF. These capacitors are not electrolytic capacitors.

In this system, the voltage across the capacitor C_B is over 250Vdc and it needs another inductor in a line of the LED, Lo=2.0mH.

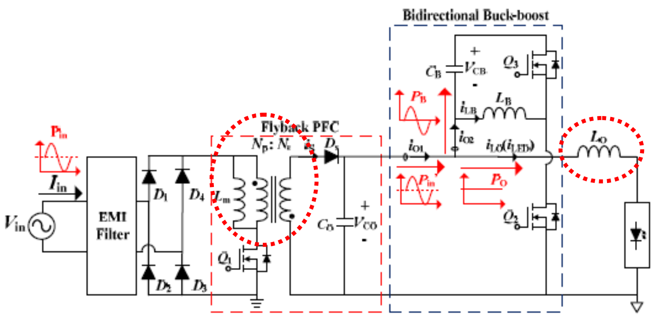


Fig. 4 Conventional LED driver with transformer

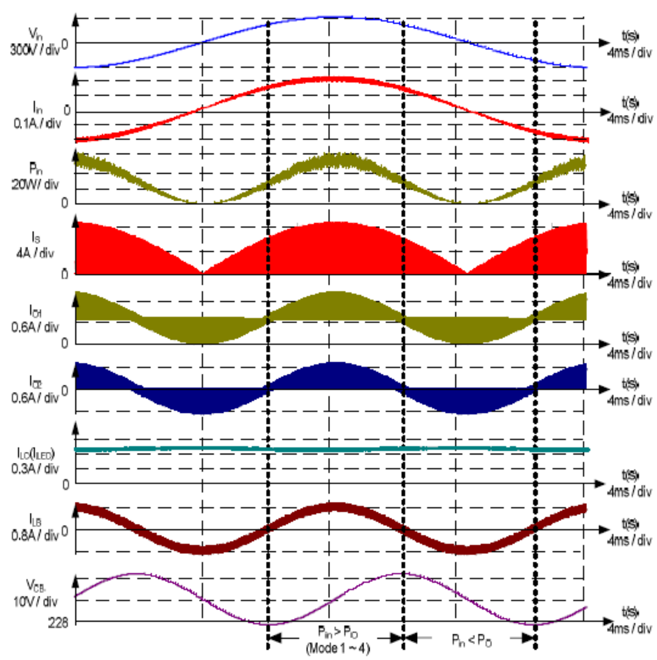


Fig. 5 Simulation results of conventional driver

III. PROPOSED LED DRIVER WITH CURRENT RIPPLE CANCELL CIRCUIT

A. Proposed LED Driver with Bi-directional Converter

The direct AC-DC converted LED driver is shown in Fig. 6 that consists of a diode bridge, a non-inverted buck-boost converter (enclosed in the dashed blue line) and a new bi-directional converter (enclosed in the dashed red line). Two main switches (S_H, S_L) are simultaneously controlled by the feedback PWM signal made from the current sensed voltage. Sub-switches (S_1, S_2) are controlled another independent sub-PWM generator, which is synchronized with main feedback PWM signal and its duty D_B is usually constant (D_B=0.8~0.9)

When the main PWM signal is "H", two switches S_H and S_L are ON and the inductor is charged with current through S_H and S_L. Then the PWM signal turns "L", two switches are OFF and inductor current flows through the free-wheel diode Df into the capacitor Co. The current value of the main inductor Lm depends on the input voltage Vi, and the voltage of the main capacitor varies in proportion with the input voltage.

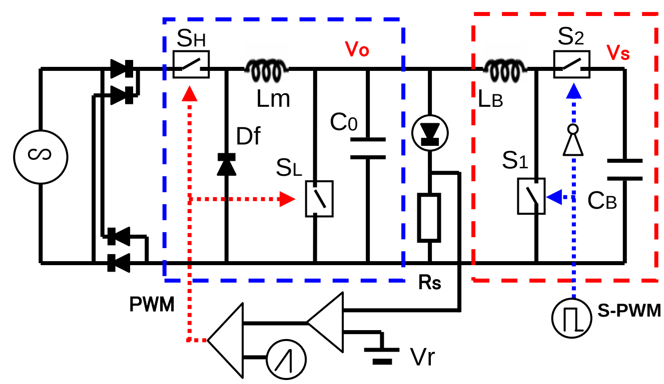
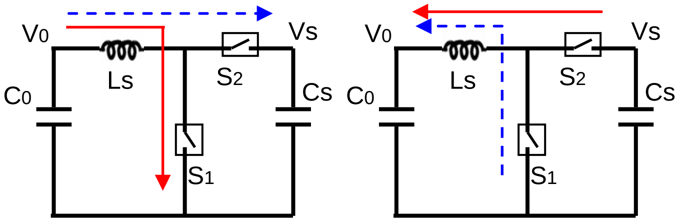


Fig. 6 Proposed LED driver with current ripple canceller

The bi-directional converter consists of a sub-inductor, two switches, a sub-converter and a sub-PWM generator. Two switches are complementally controlled. The relationship between output voltage Vo and sub-voltage Vs is shown in equation (1) because of working as a boost converter in a steady state.

$$Vo = \frac{1-Ds}{Ds} Vs \qquad (1)$$

When the input voltage is a sin wave, Vo(t) varies up or down level of the value shown in Eq.(1). When Vo(t) is higher than Vo, the bi-directional converter works as a boost converter and inductor current flows from Vo to Vs in order to decrease Vo shown in Fig.7 (a). When Vo(t) is lower than Vo, the bi-directional converter works as a buck converter and inductor current flows from Vs to Vo in order to increase Vo shown in Fig.7 (b). The bi-directional converter works as a input current ripple canceller in order to regulate the output voltage ripple that is related with LED current.



(a) Vo(t) > Vo (b) Vo(t) < Vo

Fig. 7 Operation of bi-directional converter

Table I
Simulation parameters of simulation circuit

Lm	50 uH
Ls	50 uH
Cm	5 uF
Cs	5 uF
Ds	0.82
Fck	200 kHz

B. Simulation Results of Proposed LED Driver

The simulation results of the proposed LED driver is shown in Fig.8. In this case, the input voltage is 100Vrms with a frequency of 50 Hz and we use PWM operating at 200 kHz. We set the output voltage to about 40V and the output current to Io=350mA. The other parameters are shown in Table 1. In Fig.8, there is some voltage ripple in the output voltage Vo and large voltage ripple in the sub-voltage Vs across the sub-capacitor Cs. These ripples appear around the zero-cross points of the input voltage.

The current of the sub-inductor I_B is shown in Fig.9 and enlarged in Fig.10. The waveform is almost triangle signal and the polarity of the current is changed in positive or negative direction. The output current Io (ie. LED current) shown in Fig.9 has large current drop about ⊿Io=280mA. In this case, we will feel the flicker of lighting that should be corrected.

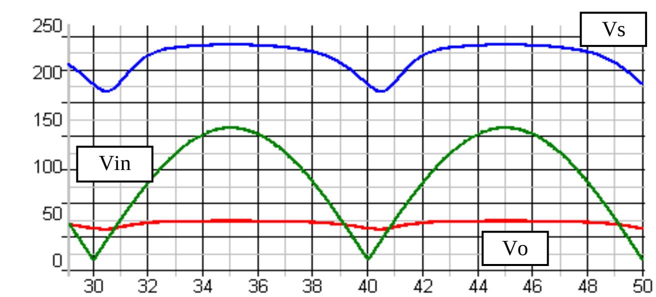


Fig. 8 Simulation results of proposed driver

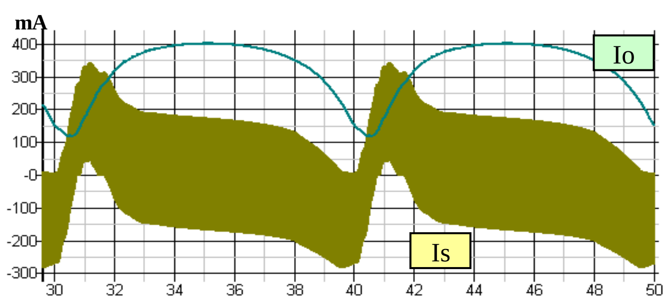


Fig. 9 Bi-directional current in sub-inductor L_B

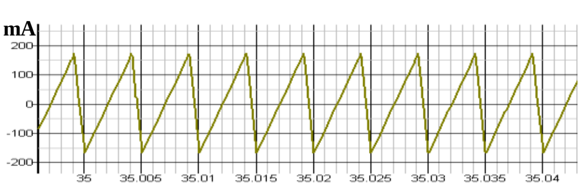


Fig. 10 Sub-inductor current I_B (enlarged)

IV. FEED-FORWARD CONTROL USING INPUT WAVE

A. Compensation with Feed-forward Control

The waveform of output voltage is similar to the input signal and the input source is always the sine wave. So it should be effective to use the input waveform in compensation for the output voltage ripple. Fig. 11 shows the compensative circuit to provide the PWM signal that consists of the LED current sensor, adder circuit and the PWM signal generator in the feedback circuit. The additional gain is adjusted with an attenuator located before the adder.

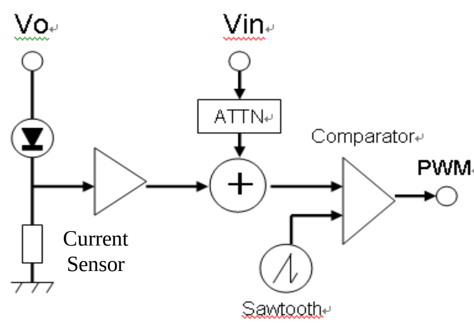


Fig. 11 Feed-forward compensative circuit

B. Simulation Results of Feed-forward Compensation

Fig.12 shows the corrected output voltage with feed-forward compensation when the additional gain is changed as 0, 2.5 and 5.0%. The bottom voltage of voltage valley is not changed but the top of the output voltage is down according to the additional gain. As a result, the output voltage difference is reduced from 15V to 7V. The output current difference is also reduced from 520mA to 220mA shown in Fig. 13. There still remains the large voltage valley or the large current valley to be improved.

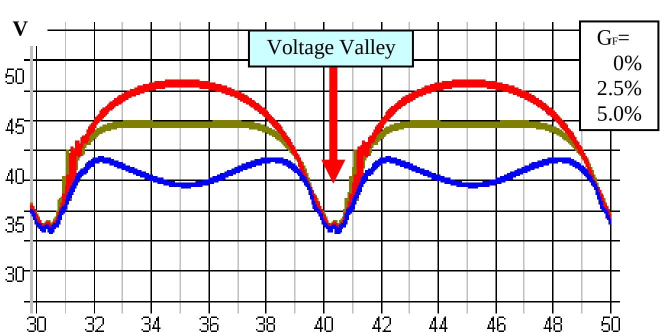


Fig. 12 Output voltage Vo with feed-forward control

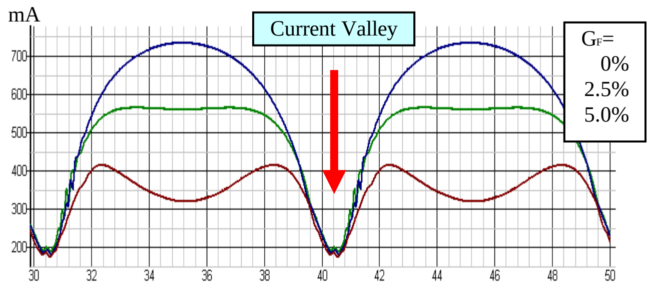


Fig. 13 Output current Io with feed-forward control

It is well known that the input voltage is usually changed about ±10%. So we have checked the variation of the output voltage for the input voltage. Fig. 14 shows the simulation result for the variation of the input voltage that is from 85V to 130V at step of 15V with the constant additional gain G=2.5%. The value of center is changed down but the variation width of the output voltage is almost equal to that of the typical input.

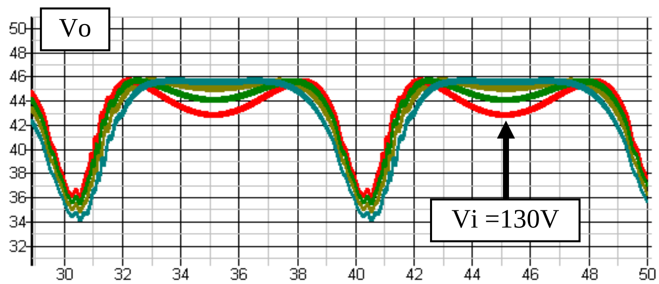


Fig. 14 Output voltage for input voltage variation

V. IMPROVEMENT FOR VOLTAGE VALLEY

There appears voltage/current valley at the input voltage bottom at Vi=0V shown in Fig. 12 and 13. We have considered two method to compensate this valley, (1) changing the sub-duty Ds at the valley period and (2) adjusting the valley period.

A. Compensation with Ds arrangement

Fig.15 shows the simulation results of the first compensation (1) which varies Ds at 81, 82 and 83%. To correct the voltage valley of Vo, Ds should be lower than typical value of 82% in order to increase Vo. In this case, it is better to shift the start timing of the compensation period delay and the stop timing fast. We have set Ds 81.2% and additional gain G=5.0%.

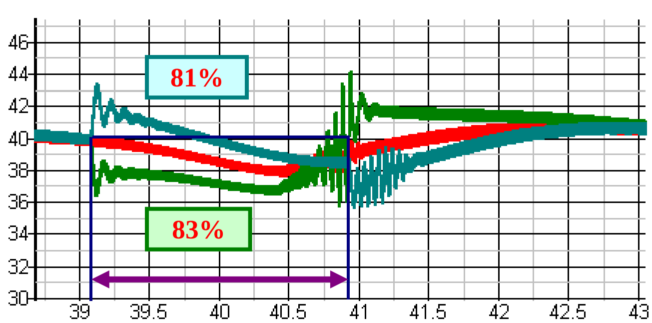


Fig. 15 Compensation results with Ds arrangement

B. Compensation with timing arrangement

Next we have adjusted the timing of the compensation period with Db=81.2%. To determine the start/stop timing, the input voltage is compared with the reference voltage which is obtained by holding the peak of the input voltage. Fig.16 shows the simulation results with arranging the timing of compensation period. The start timing is almost at the bottom of Vi. The stop timing is good for the period from 2.0 to 2.5ms delay. Finally the output voltage ripple is reduced to about 2V. In this case, the output current ripple is about 65mA and it is less than 20% of the average of LED current. It is enough not to feel the flicker in LED light.

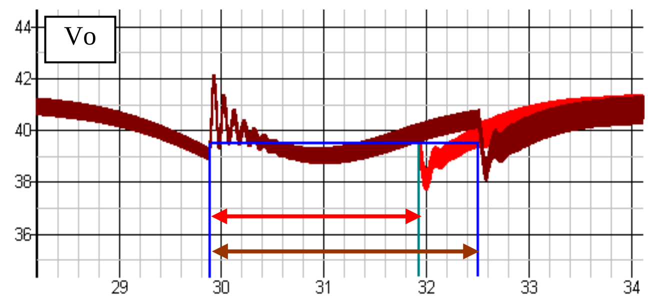


Fig. 16 Compensation results with timing arrangement

V. CONCLUSION

In this paper, we have described a new electrolytic capacitor-less, transformer-less AC-DC LED driver with current ripple canceller. In addition, we have proposed two compensation methods to reduce the voltage valley that are to change the sub-duty Ds and to shift the timing of the compensation period.

The proposed current ripple cancellation circuit works as a bi-directional current converter. LED voltage is controlled in order to regulate LED current by the negative feedback controller using a current sense resistor. There are two none-electrolytic capacitors of 5 uF.

Simulation results show that the output voltage ripple is about 2V and the LED current ripple is 65mA which is less than 20% of the average of LED current.

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