A High Power Factor Two-Channel PSR Flyback LED Driver with Controllable Output Current Sharing Based on Open-looped SSPR Control

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***Abstract-* A new control strategy for two-channel flyback LED driver is proposed in this paper. With the new control strategy, the equivalent total output current is regulated in the primary side of the flyback converter transformer with primary side regulation (PSR) technology, while output current sharing between the two channels are realized with open-looped secondary side post regulation (SSPR). Compared to the traditional secondary side regulation (SSR), PSR eliminates the secondary sampling circuit and optocoupler, which also eliminates the stability and reliability problems caused by optocoupler. The proposed open-looped SSPR technology is very simple and easy to realize because of open-loop control. Moreover, precise output current sharing between the two output channels can be achieved. Detailed theoretical analysis for the proposed control strategy is presented. An 18W two-channel flyback LED driver is built up to verify the theoretical analyses.**

***Keywords*—LED driver, PSR flyback; Two-Channel; SSPR**

I. Introduction

In recent years, research on control technology for flyback LED driver gets increasingly attention. The secondary side regulation, featured with high precision and fast response, was widely used in traditional flyback LED driver. However, the secondary side regulation needs complicated current sampling circuit and optocoupler, which makes the control circuit complex and brings the problems of the stability and reliability [1]. PSR technique, which has been popularly applied in flyback LED drivers, can resolve the problems above, thus simplifies the control circuit and also reduces the cost of the entire system [2]-[4].

The existing multi-output current sharing method can be divided into two main categories according to the principle of current sharing: One is active current sharing technology, which includes linear mode current sharing [5] and switch mode current sharing [6]. The other is passive current sharing technology including the coupling inductor current sharing [7]-[8] and the capacitor-based method [9]-[10]. The linear mode current-sharing causes large conduction loss, which deteriorates the efficiency of the converter. The system is complex and the cost is high when switch mode current sharing is applied. The precision is low and the extensibility is not high with coupling inductor current sharing. The capacitor-based method can make up the shortcomings of the above methods, but the capacitor-based method can not be applied to conventional flyback, forward and other single port topologies.

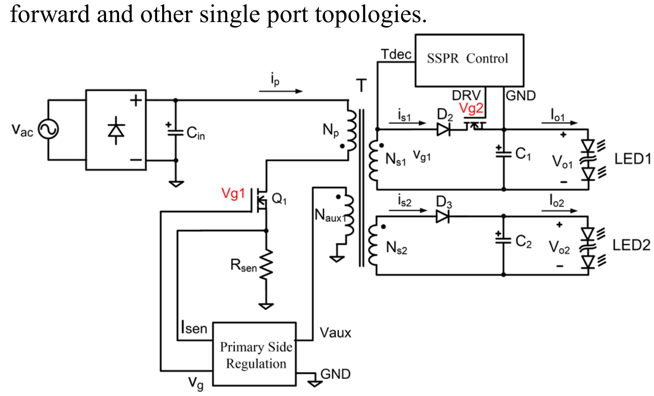


Fig.1 Proposed two-output flyback converter with open-looped SSPR control

In this paper, a new control strategy for two-channel flyback LED driver is proposed, as shown in Fig.1. The flyback converter is designed to operate in BCM (Boundary Conduction Mode) to achieve high power factor and high efficiency. At the same time, PSR control is adopted to regulate the equivalent total output current on the primary side. A low cost switch is inserted in one output channel and an open-looped SSPR control is proposed. The output current sharing between these two channels can be controlled by the inserted switch with a preset duty cycle. Because the equivalent total output current is constant, the output currents of both channels are also constant.

II. Principle of Operation

As shown in Fig.1, the proposed current sharing method is based on open-looped SSPR control. Due to the voltage blocking characteristics of the post regulation technology, the secondary freewheeling current is separated into two parts and flows the two channels in turn.

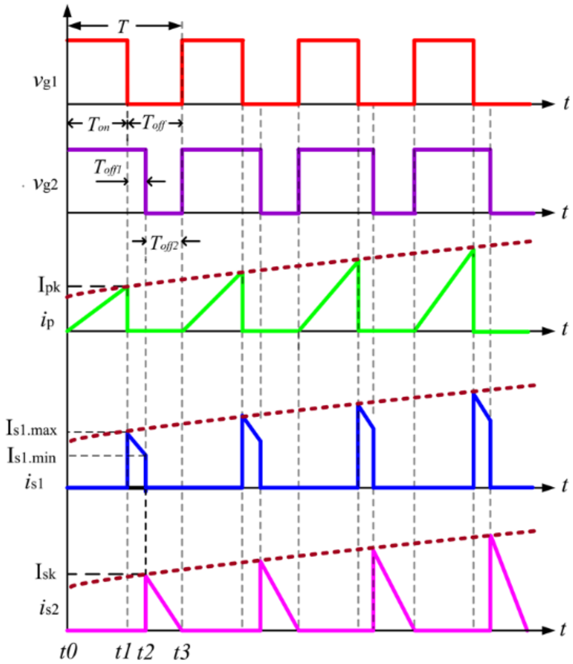


Fig.2 SSPR control mode I

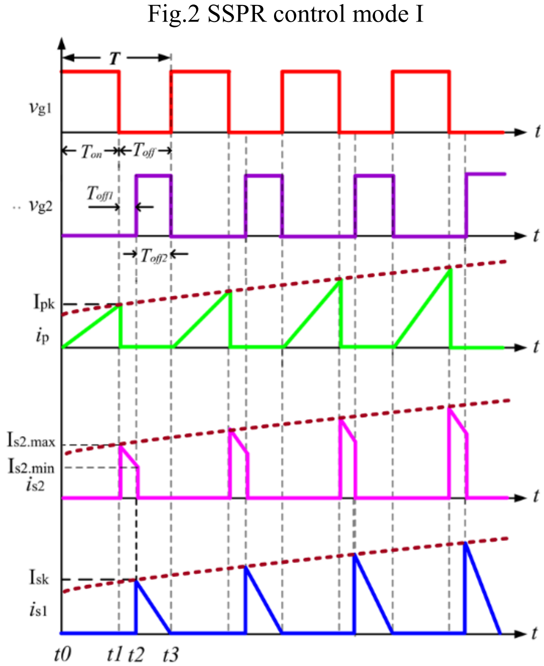


Fig.3 SSPR control mode II

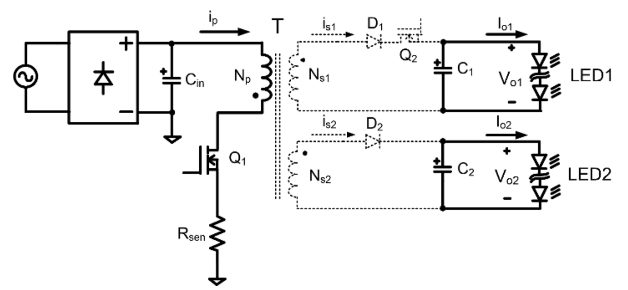
There are two control modes of the SSPR switch Q2, as shown in Fig.2 and Fig.3.

Under mode I, as shown in Fig.2, Q_2 is turned on right after the primary switch Q_1 is off. When Q_2 is on, D_1 freewheels the secondary current and D_2 is off. After Q_2 turns off, D_1 turns off and D_2 conducts to freewheel the secondary current. Under this mode, the following conditions must be met according to the principle of the "time-sharing multiplexing" [11]:

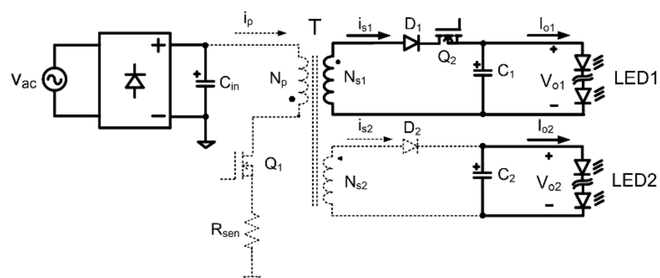
$$V_{o1}/N_{s1} < V_{o2}/N_{s2} \tag{1}$$

Under mode II, as shown in Fig.3, D_2 is turns on to freewheel the secondary current right after the primary switch Q_1 is off. When Q_2 is on, D_1 freewheels the secondary current and D_2 is off. Under this mode, (1) should also be met.

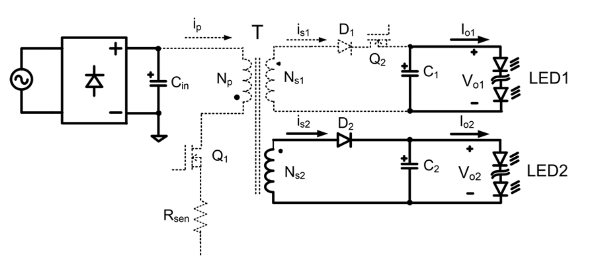
These two mode are similar. In this paper, only mode I is analyzed in detail. Depending on the on-off state of each switching element, there exist three working states of the circuit in a switching cycle. Fig.4 shows the equivalent circuit of the operation states.



(a) Equivalent circuit I



(b) Equivalent circuit II



(c) Equivalent circuit III

Fig.4 Equivalent circuits of the three operation stages

Stage.1 [t_0-t_1]: At t_0, primary switch Q_1 is turned on, the freewheeling diode D_1 and D_2 are off regardless of whatever the state of secondary switch Q_2 is. The equivalent circuit is shown in Fig.4a. The secondary current I_{s1} and I_{s2} are zero, the primary current rises linearly. LED loads are powered by output capacitors.

Stage.2 [t_1-t_2]: At t_1, primary switch Q_1 is off and secondary switch Q_2 is turned on, the freewheeling diode D_1 is conducted and D_2 is off. The equivalent circuit is shown in Fig.4b.The energy of the primary magnetizing inductance is transmitted by the transformer to the first channel. The secondary current i_{s1} decreases linearly until switch Q_2 is off.

Stage.3 [t_2-t_3]: At t_2, switch Q_2 is turned off. D_1 is off and D_2 is conducted. The freewheeling current flows through D2. The equivalent circuit mode is shown in Fig.4c. The secondary current I_{s2} linearly decreases to zero.

PSR control for high power factor flyback LED driver have been well studied and many semiconductor companies have released PSR controlled PFC ICs for flyback LED driver in recent years. To save the contents, theory of PSR is not introduced in detail here.

Suppose the equivalent total output current I_o can be well regulated by PSR control,

$$I_o = \frac{1}{\pi}\int_0^{\pi} n \cdot I_{pk} \cdot \frac{T_{off}(\theta)}{T} dt = I_{ref} \tag{2}$$

Where, n is transformer turns-ratio, and I_{ref} is the current reference set by the PSR control IC. As shown in Fig.2, the following equations can be obtained in a switching cycle.

$$I_{pk} \cdot N_p = I_{s1.\max} \cdot N_{s1} \tag{3}$$

$$I_{s1.\min} \cdot N_{s1} = I_{s2p} \cdot N_{s2} \tag{4}$$

$$I_{o1} = (I_{s1.\min} + I_{s1.\max}) \cdot T_{off1} / 2T \tag{5}$$

$$I_{o2} = I_{s2p} \cdot T_{off2} / 2T \tag{6}$$

$$T_{off2} / T_{off} = I_{s1.\min} / I_{s1.\max} \tag{7}$$

Define $n_1 = N_{s1} / N_{s2}$, $k = T_{off2} / T_{off}$, from (3)~(7), it can be concluded,

$$I_{o1} = I_{o2}(k^2 - 1) / n_1 k \tag{8}$$

So when n_1 is determined and k is keep constant, I_{o1} and I_{o2} are constant also. Adjusting the value of k, different I_{o1} and I_{o2} can be obtained.

According to the analysis above, an open-looped SSPR controller can be realized with simple logic circuit show in Fig.5. Fig.5 shows the key waveforms. The value of k can be changed by adjusting the value of R_1 or R_2.

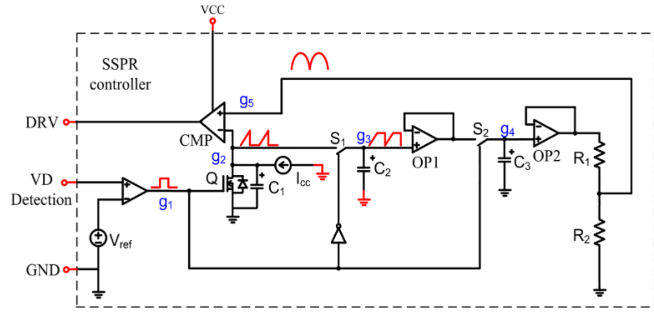


Fig.5 Schematic of the proposed open-looped SSPR control

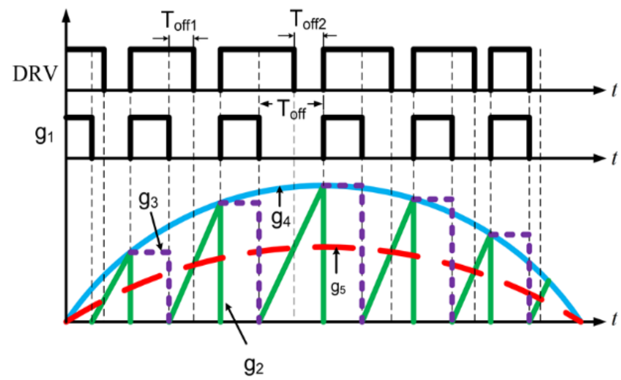


Fig.6 Key waveforms in the proposed open-looped SSPR controller

III. Experimental Results

An 18 W lab-made LED driver prototype with universal input and two 30Vdc/0.3A outputs is built up to verify the proposed method. Components parameters are labelled in the circuit schematic of the prototype, as shown in Fig.7.

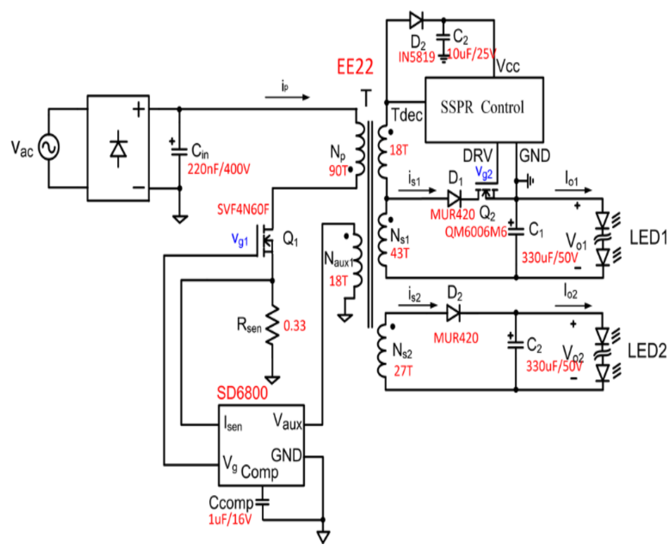


Fig.7 circuit schematic of the laboratory prototype

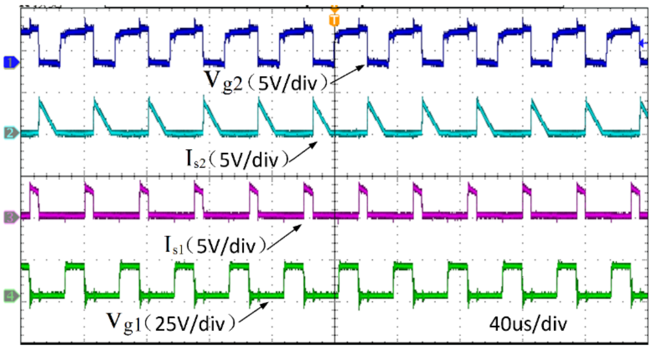


Fig.8 Key waveforms of the flyback converter

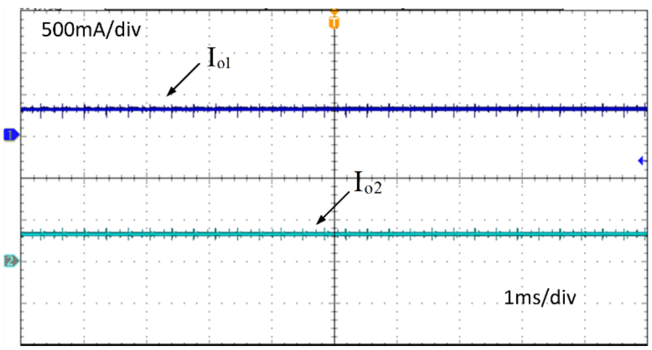


Fig.9 Measured output currents waveforms of two channels @90V AC input

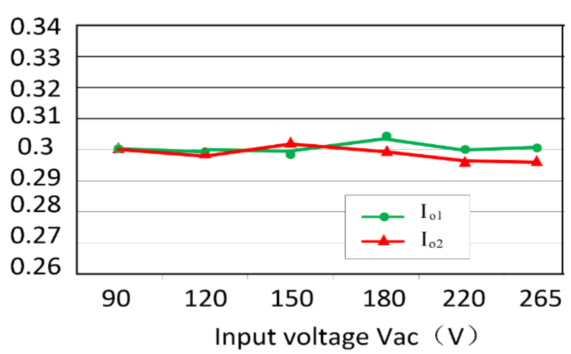


Fig.10 Measured output current at different input voltage with full load

Fig.8 shows the measured key waveforms of the flyback converter. Measured output currents waveforms of two channels at 90V AC input are shown in Fig.9. Measured output current under different input voltage is shown in Fig.10. It can be seen that the output currents of both channels are almost constant. The maximum current sharing error is about 1%, which occurred under high input voltage and caused by control delay of the control circuit.

IV. Conclusion

A new control strategy for two-channel PSR flyback LED driver is proposed in this paper. Current sharing technology is realized with open-looped SSPR control. The control circuit is simple and easy to realize, which can be integrated into a chip with four pins. The principles of constant output current control and output current sharing control are analyzed. Theoretical analyses are verified by an 18W experimental prototype.

In conclusion, this proposed control is very suitable for industrial applications.

Reference

[1] B. T. Irving, "Analysis and design optimization of magnetic-feedback control using amplitude modulation", IEEE Trans. Power Electron., vol. 24, no.2, 2009. pp.426-433.

[2] J. Z. Hulong zheng, Lianghui Xu and Z. Qian, "A Primary side controlled WLED Driver compatible with triac Dimmer", APEC 2011, Twenty-sixth Annual IEEE, 2011. pp.699-704.

[3] R. Nalepa, N. Barry, and P. Meaney, "Primary side control circuit of a flyback converter", in Proc.IEEE Applied Power Electronics Conference and Exposition, 2001. pp.542-547.

[4] J.-J. Shen, T. Liu, Y. Q. Wu, etal, "Constant current LED driver based on flyback structure with primary side control", in Power Engineering and Automation Conference (PEAM), 2001. pp.260-263.

[5] C.L. Chiu, K.H. Chen, "A high accuracy current-balanced control technique for LED backlight", in Proc. IEEE Power Electronics Specialists Conf., 2008. pp.4202-4206.

[6] J. Jacobs, Jie Shen, D. Hente, "A Simple Digital Current Controller for Solid-State Lighting", in Proc. IEEE Power Electronics Specialists Conf., 2008. pp.2417-2422.

[7] K.I. Hwu, S.C. Chou, "A Simple Current-Balancing Converter for LED Lighting", in Proc. IEEE Applied Power Electronics Conference, 2009. pp.587-590.

[8] Yuequan Hu, Jovanović, M.M., "A New Current-Balancing Method for Paralleled LED strings", in Proc. IEEE Applied Power Electronics Conf., 2011. pp.705-712.

[9] J. Zhang, J. Wang, etal, "A Capacitor-Isolated LED Driver with Inherent Current Balance Capability", IEEE Trans. Ind. Electron., vol.59, no.4, 2012. pp.1708-1716.

[10] J. Zhang, L. Xu, X. Wu, and Z. Qian, "A precise passive current balancing method for multi-output LED drivers", IEEE Trans. Power Electron, 2011. pp.2149-2159.

[11] Wen C C, Chen C L, Chen W, etal. "MagamP Post regulation for flyback converter", Power Electronics Specialists Conference, 2011. pp.333-338