A Novel Switching Mode for High Power Factor Correction and Low THD

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ABSTRACT

A new switching mode has been proposed to obtain high power factor and low THD in single stage AC-DC converter. The conventional voltage mode control in critical conduction mode distorts input current shape with poor THD in flyback topology. Once TRIAC dimmer is connected, visible flicker in the LED lamp is easily detected due to a lack of TRAIC holding current near the input voltage zero cross. The newly proposed method can shape the input current by providing a desired reference voltage so that low THD is obtained by ideal sinusoidal input current in case of no dimmer connection and flat input current performs good TRIAC dimmer compatibility in phase-cut dimming condition. To confirm the validity of the proposed method, theoretical analysis and experimental result from 8W dimmable LED lighting system are presented.

1. Introduction

In the LED driver using phase cut dimming, the key technical issue is a TRIAC holding current maintenance. Flicker is easily detected by premature TRIAC turn-off event when TRIAC conduction current is less than its holding current [1].

Conventional methods have attempted to flatten the input current of the LED driver above the holding current to improve LED flicker, but the input current is not exactly constant due to compensation error. When the dimmer isn't connect to LED driver, it changes the operating mode for better power factor (PF) and THD. However, PF is worse due to additional bleeder capacitor [2-3]. There have been many approaches to improve PF [4-8], but there was no method to improve PF and THD in all conduction modes such as CCM, BCM and DCM.

To improve keeping constant input current for TRIAC dimmer, we propose a new switching method. The proposed method also improves PF and THD in any conduction mode. In this paper, proposed method is explained theoretically and is verified through a 8-W LED project.

2. The concept of the proposed switching mode

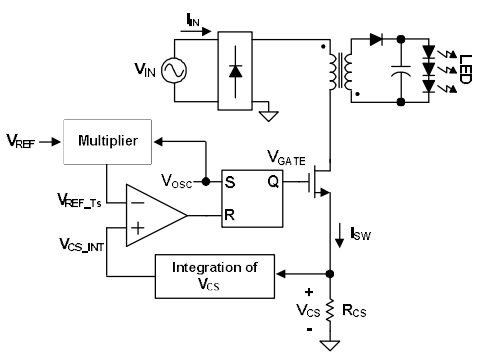

Fig. 1 Block diagram of proposed switching mode

A proposed switching mode by integration of the input current determines switch turn on time based on an averaged switching current to implement accurate input current control. Fig.1 shows a block diagram for the proposed method. The input current is same as the averaged switching current and it is proportional to an averaged current sensing voltage, which is given as

$$I_{IN} = I_{SW\_AVG} = \frac{1}{T_S}\int_0^{T_{ON}} i_{SW}(t)dt = \frac{1}{T_S}\int_0^{T_{ON}} \frac{v_{CS}(t)}{R_{CS}}dt \quad (1)$$

The switch turn on time is determined by comparing V_{REF_Ts} and V_{CS_INT}. V_{REF} is given as

$$\frac{1}{T_S}\int_0^{T_{ON}} v_{CS}(t)dt = k \cdot V_{REF} \quad (2)$$

$$I_{IN} = \frac{k \cdot V_{REF}}{R_{CS}} \quad (3)$$

where k is the multiplication of coefficient.

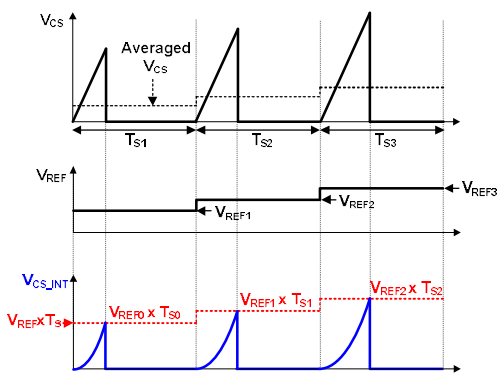

Fig. 2 Switching block waveforms

Fig. 2 shows the proposed switching mode sequence. V_{GATE} is turned off when V_{CS_INT} reaches to V_{REF_TS} which is the multiplication result from previous switching cycle. So, the input current follows V_{REF} in one switching delay which can be ignored in the line frequency. The novel switching mode provides excellent input current control by simply applying V_{REF} and R_{CS}.

3. Constant TRIAC conduction current

The main problem with phase cut dimming is a visible flicker due to unstable TRIAC conduction when the LED current is small. As shown Fig. 3, when the input current smaller than the TRIAC holding current, there may be variation in the TRIAC turn off time. With this, the input voltage applied to the LED driver is slightly changed,

resulting in a visible flicker. To overcome this limitation, Fig. 4 shows how the proposed method conducts the input current higher than the holding current of a TRIAC. Once the input current is maintained, the TRIAC conduction can be still maintained at the input voltage zero crossing and eliminates the fluctuation of TRIAC turn off time, so there is no visible flicker.

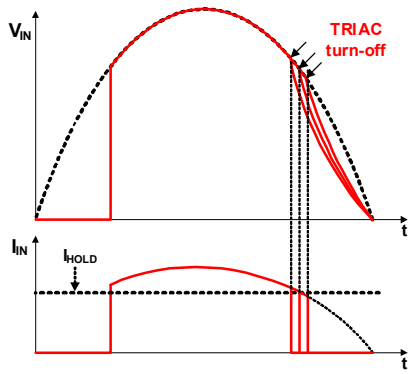

Fig. 3 The input current of conventional phase cut dimming

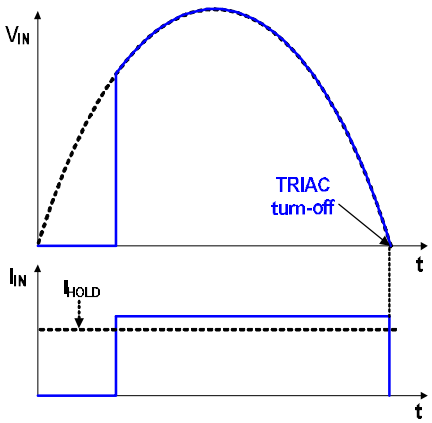

Fig. 4 The input current of proposed method

In the conventional peak current control mode, it is difficult to maintain the input current at a constant value because the peak current does not represent the input current. However, in proposed method, since the input current is the same as the averaged switching current, it can be utilized to control the TRIAC conduction current as Fig. 5. In the phase cut dimming condition, V_{REF_DIM} is the reference for LED current and V_{ILED} is sensed the LED current. V_{REF} is the output of feedback loop.

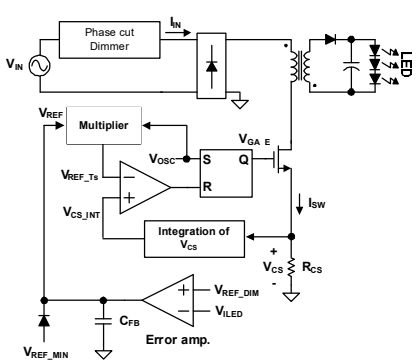

Fig. 5 Control block for the constant input current

When the phase angle decreases, V_{REF_DIM} is decreased to regulate the smaller LED current corresponding to the phase angle. To ensure the TRIAC conduction current at low phase angle, V_{REF_MIN} is required so that the input current is higher than the TRIAC holding current.

4. The simulation result

Fig. 6 shows the simulation result of input current controlled by the proposed switching mode. The input current is maintained as the sinusoidal waveform in conduction mode such as DCM, BCM and CCM.

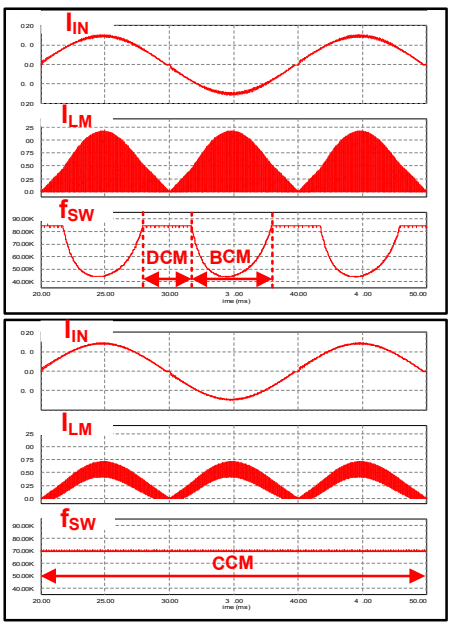

Fig. 6 the simulation result

5. The experiment result

The proposed method is verified in 8-W phase cut dimming LED driver. Fig. 7 shows the constant TRIAC conduction current based on the control block in Fig. 5. As shown Fig. 7, the input current is flat to maintain the TRIAC conduction current higher than the holding current till the line voltage zero crossing.

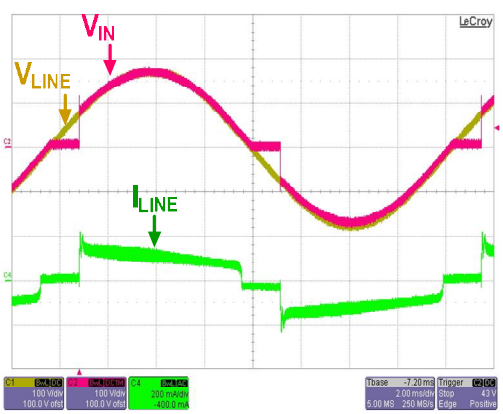

Fig. 7 The constant TRIAC conduction current at dimming mode

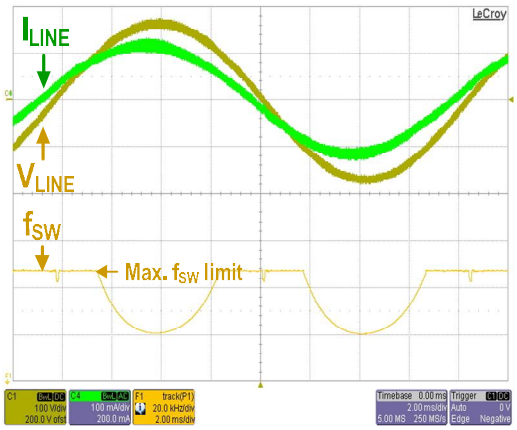

Fig. 8 The sinusoidal input current at non-dimming mode

And Fig. 8 shows the input current of the proposed method when there is no phase cut dimmer. The operation mode is BCM with maximum frequency limit so that the test result shows BCM at the peak of line voltage and DCM at the zero crossing. The proposed method shows the same input current shape as the sinusoidal waveform regardless of whether the switching frequency is variable or not. Fig. 9 and 10 show PF and THD comparisons between the conventional voltage mode and the proposed method. Particularly in THD result, the proposed method significantly improves THD lower than 3% over the entire input voltage.

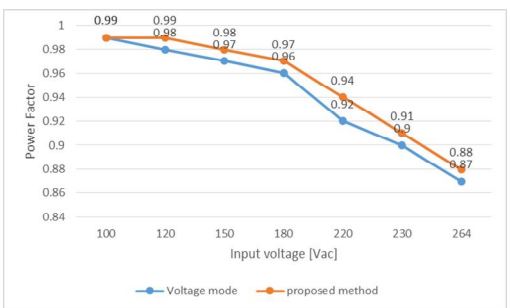

Fig. 9 PF performance comparison

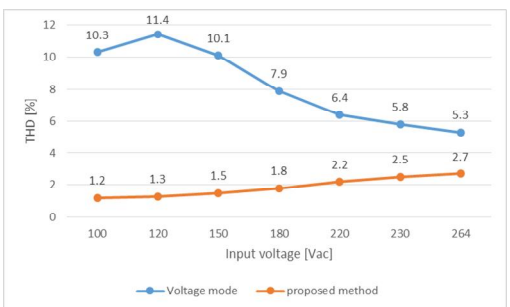

Fig. 10 THD performance comparison

6. Conclusion

A novel switching method for high PF and low THD has been proposed and verified by a 8-W LED driver system. The input current is controlled to maintain a sinusoidal waveform to achieve high PF and low THD in all conduction modes such as DCM, BCM and CCM. The proposed method maintains the input current higher than the holding current to improve the visible flicker due to the phase cut dimmer when the input current lower than the TRIAC holding current.

The proposed switching method shows significant improvement of PF, THD and high TRIAC dimmer compatibility performance.

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