Time-Delay Effects on DC Characteristics of Peak Current Controlled Power LED Drivers

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Abstract

New discrete time domain models for the peak current controlled (PCC) power LED drivers in continuous conduction mode include for the first time the effects of time delay in the pulse-width-modulator. Realistic amounts of time delay are found to have significant effects on the average output LED current and on the critical inductor value at the boundary between two conduction modes. Especially, the time delay can provide an accurate LED current for the PCC buck converter with a wide input voltage. The models can also predict the critical inductor values at the mode boundary as functions of the input voltage and the time delay.

1. Introduction

In the past few years, light-emitting diode (LED) technology has emerged as a promising technology for residential, automotive, decorative and medical applications. This is mainly caused by the enhanced efficiency, energy savings and flexibility, and the long lifetime of up to 100,000 hours. Today, LEDs are available for various colors and they are suitable for white illumination [1].

The luminous flux of LEDs is mostly determined by the LED forward current. Controlling the current accurately is a challenge when each LED has a large manufacturing tolerance in its forward voltage as shown in Table 1 [2]. Furthermore, the forward voltage V_F is varies over temperature with negative temperature coefficient. Therefore, current mode control is needed to achieve constant brightness of LEDs [3]-[4].

Table 1 Example of LED forward voltage variations

Z- power LED	V_F @ $25^\circ C$, I_F = 350 mA			V_F
	Min	*Typ*	*Max*	*deviation*
White, Green, Blue	2.9	3.25	3.8	*14.1 %*
Red	2.0	2.3	3.0	*23.4 %*

2. Discrete time domain modeling for PCC power LED drivers

The relationship is determined at the comparator input, whose detailed waveforms are shown in Fig. 2.

From the figure, discrete time domain equation for the converter can be represented as

$$i_{k+1} = i_k + m_1 T_s d_k - m_2 T_s (1 - d_k) \qquad (1)$$

If there is a time delay at turn off in the control circuit, the switch does not turn off when the inductor current reaches the control input V_c / R_s, rather it turns off after some time delay. Due to this delay, the inductor current has an overshoot of $m_1 t_{df}$ over V_c / R_s. The peak inductor current is altered only by the turn-off delay t_{df}. When the control circuit has a time delay at turn off , the switching control law [5] can be written by

$$i_k + m_1 T_s d_k = \frac{V_c}{R_s} + m_1 t_{df} \qquad (2)$$

where t_{df} is a time delay at turn off.

In the steady-state, setting $i_{k+1} = i_k = I$, $m_1 = M_1$, $m_2 = M_2$, $d_k = D$, and $t_{df} = T_{df}$, (2) and (3) can be written as

$$\begin{aligned} &M_1 T_s D = M_2 T_s (1 - D) \\ &I + M_1 T_s D = \frac{V_c}{R_s} + M_1 T_{df} \end{aligned} \qquad (3)$$

The steady-state average inductor current is given by

$$I_{avg} = I + \frac{M_1 T_s D}{2} = \frac{V_c}{R_s} + M_1 T_{df} - \frac{M_1 T_s D}{2} \qquad (4)$$

All the above equations apply to any converter. Using (4), Figs. 3-4 are plotted for the basic converters.

The boundary condition between the continuous and discontinuous conduction modes can be determined by setting $I = 0$ in (3) as follows.

$$T_s = \left(\frac{1}{M_1} + \frac{1}{M_2}\right)\left(\frac{V_c}{R_s} + M_1 T_{df}\right) . \qquad (5)$$

Using (5), Figs. 5-6 are plotted for the PWM converters.

3. Conclusion

This proposed discrete time domain modeling describes for the first time the effects of PWM delay on the average output current and the critical inductor value at the boundary between the two conduction modes in the PCC power LED drivers. When the time delay increases, the average output current increases and the critical inductor value at the mode boundary decreases.

When the input voltage varies, the average output current of the boost and buck-boost converters varies over a wide range. On the other hand, the average output current of the PCC buck converter is maintained at constant level. Thus the PCC buck converter is most suitable for the power LED drivers, especially in wide input voltage applications.

References

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[3] O. Ronat, P. Green and S. Ragona, “ Accurate current control to drive high power LED strings, “ IEEE APEC, 2006, pp. 376-380.

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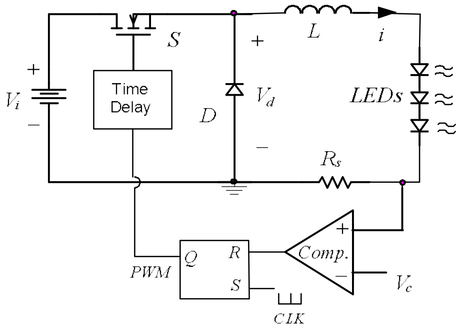


Fig. 1 Peak current controlled buck LED driver with constant-frequency controller.

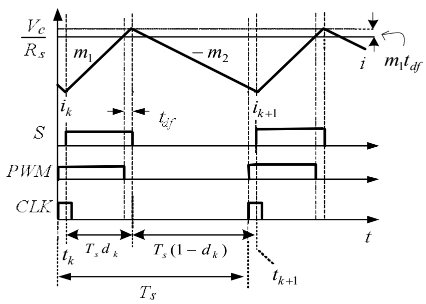


Fig. 2 Key theoretical waveforms with simple peak current control.

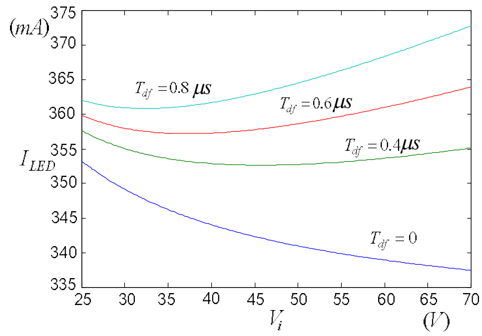
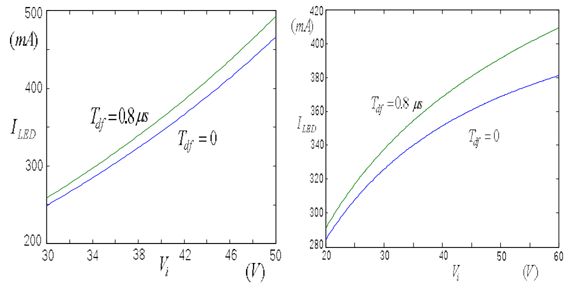


Fig. 3 Average output current of peak current controlled buck converter (V_o = 10 V, V_c / R_s = 390 mA)



(a) Boost (b)Buck-boost

Fig. 4 Average output current of the PCC boost and buck-boost converters

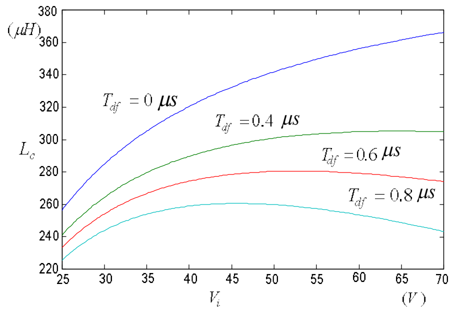
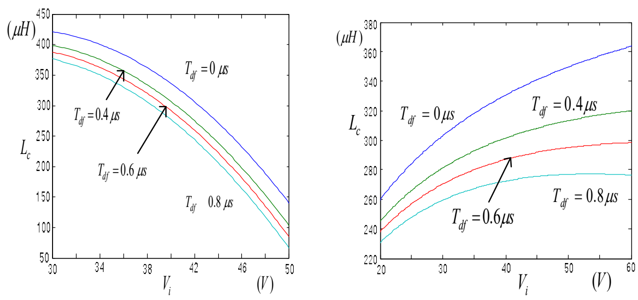


Fig. 5 Critical inductor value curve of peak current controlled buck converter ($V_o = 10\ V, V_c / R_s = 390\ mA$)



(a) Boost (b) Buck-boost

Fig. 6 Critical inductor value curve of the PCC boost and buck-boost converters.