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Research Note

Modulation Scheme for Dimming High-Brightness LED Lamps

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ABSTRACT

This paper presents a phase-controlled two-phase resonant converter as a highly flexible platform for evaluating different modulation patterns of the operating current for high-brightness light emitting diode (LED) lamps. This control flexibility arises from the wide bandwidth of the resonant converter ensuring an operation free of instabilities and flicker effects. The control parameter is the phase-shift, Ψ, between the drive signals of each inverter leg. The proposed driver is designed as a current source able to set different patterns of amplitude modulated (AM) output current to implement light dimming controls. A 120 W prototype has been built to validate the design proposal.

KEYWORDS: LED driver, dimming control, resonant converter

1. Introduction

The driver circuit is based on the phase-controlled LCsCp resonant converter[1], shown in Figure 1.

A digital circuit generates the control signals, M1–4, shown in Figure 2.

The output current, I_0, is precisely adjusted, at constant switching frequency, through the phase-shift modulation (PSM) of the control signals M1,4 to M2,3. The converter bandwidth[2] enables the implementation of different PSM patterns at a frequency well above the frequency range where flicker is perceived by the human eye. The required PSM is implemented varying the eight-bits command signal, m[7..0], according to a given control law.

The study of different modulations for dimming LED lamps is an interesting design issue. For example, an increment of the lm/W rendering has recently been reported using a bi-level modulation pattern of the lamp current[3] in comparison to PWM control. In this paper, different modulation patterns of the lamp current are evaluated seeking to minimize the harmonic content of the resulting waveform as well as to reduce the LED current stress and increase the luminous rendering.

2. Experimental results

The experimental prototype was designed[4] to drive four Bridgelux BXRA-C2000 matrixes in series connection to obtain a total output power P_0=120 W. The DC supply voltage is V_{dc}=400 V, the output current, I_0=1.75 A, the transformer turn ratio is n=2, the switching frequency is $\omega_0 = 2\pi(100\ \text{kHz})$, the nominal value of the control angle is Ψ_o=45° and the reactive components are L=700 μH, C_s=75 nF and C_p=7.5 nF. The output current under nominal conditions, i.e. Ψ_0=45°, is shown in Figure 3(a). The efficiency of the experimental prototype was η=92% and the measured illuminance

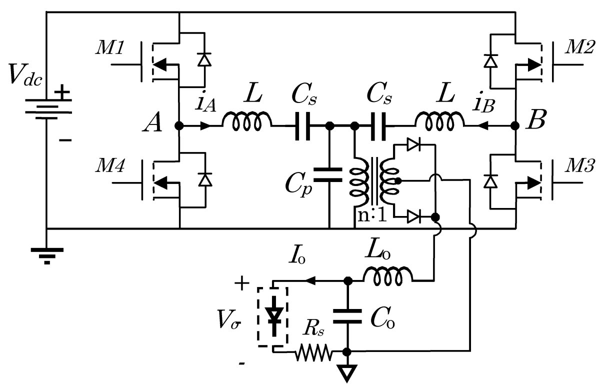


Figure 1 PSM-controlled LCsCp resonant converter

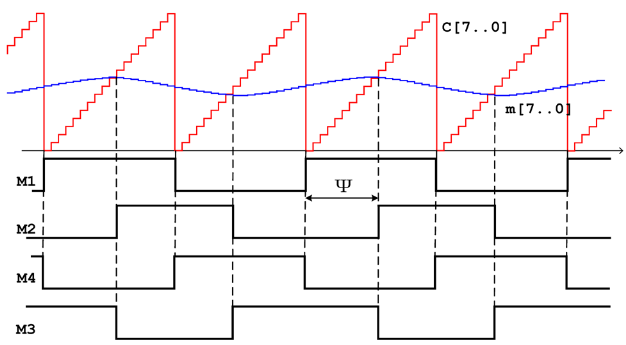
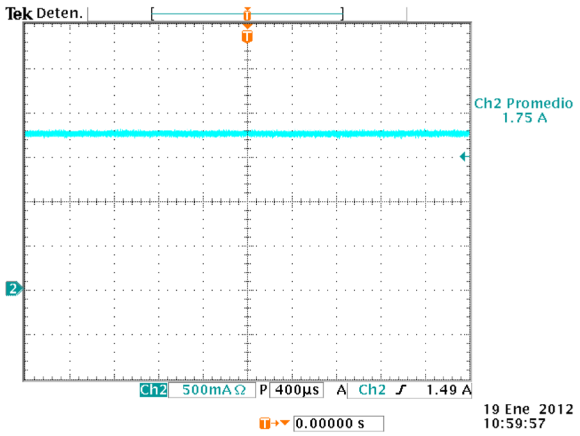
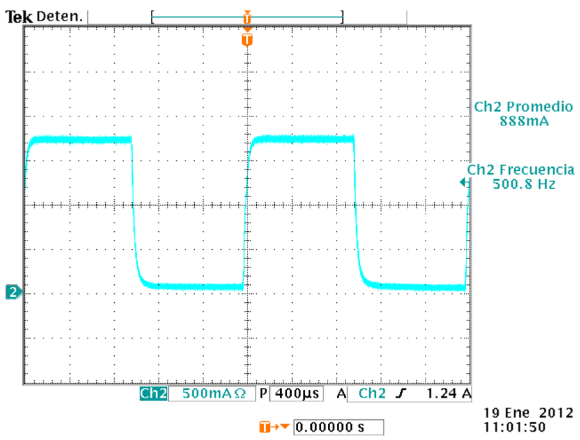


Figure 2 Digital waveforms of the PSM control

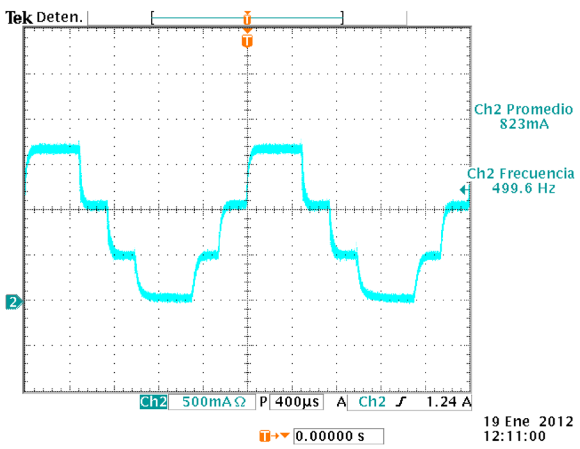
was 20.7 klux. The PSM directly modifies the nominal LED current enabling the dimming control. In order to prevent degradation of the light quality parameters, in[3] it is recommended to operate the LEDs at their nominal



(a)



(b)



(c)

Figure 3 (a) Output current at nominal conditions (b) PWM control (c) PSM modulation with a low-resolution sinusoidal pattern

current. For this reason, the dimming is generally implemented turning on/off the nominal LED current, following a pulse width modulation (PWM) pattern, which modifies the average current while preserving its amplitude. In order to implement the PWM modulation, the proposed driver cancels the LED current by imposing $\Psi=180^\circ$ when the phase command, m[7..0], saturates at the maximum value of the carrier signal, c[7..0]. The dynamic performance of the resonant converter is limited by the rectifier stage. Considering that the experimental dynamic resistance of the LED lamp is $r_d=5.5\,\Omega$, the output capacitance $C_0=3.3\,\mu F$ and the shunt resistance $R_s=1\,\Omega$, the converter bandwidth, ω_H, is calculated as $\omega_H=1/(r_d+R_s)C_0=2\pi(7.41\text{ kHz})$. Making the most of the converter bandwidth, the modulation frequency is chosen as $f_m=500$ Hz, well above the zone where the human eye perceives the flicker effect. The resulting output current for 50% duty cycle is shown in Figure 3(b). The measured efficiency and illuminance were 78% and 10.6 klux, respectively.

Leveraging the flexibility of the proposed driver, the luminous flux and efficiency achieved by the PWM control is improved using different PSM strategies. For example, the same dimming ratio of 50% is achieved with minimum harmonic content if a sinusoidal pattern modulates the lamp current. The sine function is approximated by setting up four different values of Ψ. The resulting current waveform is shown in Figure 3(c). The prototype efficiency under this condition was 83% and the measured illuminance was 11.4 klux. Further efficiency improvements can be achieved by using synchronous rectification.

3. Conclusions

The resonant converters are suitable to drive high-brightness LED lamps for outdoor-lighting applications. The proposed driver achieves high reliability due to the insulation transformer and the avoidance of electrolytic capacitors. Experimental results have demonstrated the high flexibility of the proposed driver to implement different modulation patterns to dim the LED lamp. The fast dynamics of the resonant stage ensure an operation free of instabilities and flicker effects. Parameters such as efficiency, LED current stress and measured illuminance can be improved by applying different modulation pattern to PWM.

Acknowledgement

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