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ORIGINAL ARTICLE

A current sensorless power factor correction control for LED lamp driver

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ADC;
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Abstract This paper proposes a new control technique to achieve a unity power factor at the input AC supply for light-emitting diode (LED) lamps controlled by AC–DC converter, without using a current sensor. Only two analog to digital converters (ADCs) for measuring the input and output voltages are used. This technique achieves isolation between power circuit and controller; it can be implemented by using a zero-crossing processing, which has a greater accuracy than other techniques. Simulation and experimental results illustrate the effectiveness and feasibility of the proposed control technique, which achieves low harmonic contents in the supply current, a near unity power factor (PF), a sinusoidal current waveform, and a fast dynamic response under transient operation.

1. Introduction

Today artificial lighting is a critical part of modern life. However, traditional methods of lighting such as fuel-based and incandescent lighting are highly inefficient. Therefore, the use of these products is being phased out across the industrialized world as in the European union [1]. Energy saving is becoming increasingly important, given that easily accessible energy resources are becoming scarce. Fluorescent tubes and compact fluorescent tubes (CFLs) have decreased the energy demand for lighting. Technology has yielded a surprising new lighting source which is LED lamps that are different from the traditional incandescent lamps, which use filaments to generate heat radiation, and fluorescent lamps, which use gaseous discharging. LED lamps present an effective and robust solution to replace the traditional lighting sources due to their advantages such as [2–4]:

- High luminous efficiency.
- Extremely long life, c.100,000 h.
- Extreme robustness because there are no glass components or filaments.
- No external reflector.

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Nomenclature

L	boost inductor	V_{ref}	reference voltage
D	diode	$v_{control}$	the controlled scaling factor of the rectified voltage
S	MOSFET (Switch)	V_{rms}	RMS value of the input voltage
V_s	supply voltage	V_o	load voltage
i_s	supply current	$V_{o(mean)}$	mean load voltage
$V_{in}(t)$	the rectified voltage	I_o	load current
i_l	inductor (rectified) current	t_k	sampling time
$\hat{i}_l(t)$	the estimated inductor current	ω_{line}	angular line frequency
i_{ref}	reference current		

- LED lamp module is composed of many LEDs; when one LED fails, there are many more for back-up.
- Can be very easily dimmed either by pulse-width modulation or lowering the forward current.
- No ultra-violet (UV) or infra-red (IR) output.

LEDs have many superior characteristics and effective applications in background lighting, displays, street lighting, and so on. Today, LEDs are available in various colours and are also suitable for white illumination.

The LED driven by the AC source has the same flicker problem as that of the traditional lamp to which the human being is negligibly sensitive. Furthermore, if all LEDs are packaged into a single chip, the brightness is more focused and the flicker problem will be more reduced than ever [5,6].

LEDs can be operated from a low-voltage DC supply. In general, lighting applications, the LED lamps have to operate from a universal AC input. Therefore, an AC–DC converter is needed to drive the LED lamp [6]. The LED brightness is strongly dependent on its current, so an efficient control is needed to regulate the LED current. The efficient driver not only performs unity PF, but also regulates the LED current [7]. There are various LED driving circuits with AC–DC converters, which are discussed in Refs. [8,9].

Most of the applications that require AC–DC power conversion need the output DC voltage to be well regulated with good steady-state and transient performances. The rectifier with a filter capacitor is cost effective, but it severely degrades the quality of the supply, thereby affecting the performance of other loads connected to it besides causing other problems. Although, a large electrolytic capacitor suppresses the ripple from the output voltage, it introduces distortions to the input current and draws inrush current from supply [10]. This introduces several problems, including a reduction of available power; the line current becomes non-sinusoidal which increases THD, and increases losses. This results in poor power quality, voltage distortion, and poor PF at input AC mains [11].

With the deployment of non-linear loads, such as switched mode power converters, standards agencies around the world are developing requirements for harmonic contents of electronic power conversion systems to reduce the overall distortion on main supply lines. Input current can be reshaped to be a sinusoidal waveform which can be in phase with the line voltage; the losses can be decreased and hence, a nearly unity PF can be achieved. For all lighting products and input power higher than 25 W, AC–DC LED drivers must comply with the line-current harmonic limits set by IEC61000-3-2 class C [12] as illustrated in Table 1.

Table 1

Harmonic order (n)	Maximum permissible harmonic current expressed as a percentage of the input current at the fundamental frequency (%)
2	2
3	30 * circuit power factor
5	10
7	7
9	5
$11 \leqslant n \leqslant 39$	3

Single-phase PFC is an active research topic in power electronics because of the high power quality requirement, and significant efforts have been made on the developments of PFC converters. In these converters, the main effort is devoted to the quality of the input current waveform while, simple single switch topologies like boost converter as used in the proposed work, the dynamic response of the output voltage is sacrificed [13]. The inductor is assumed to enter the continuous conduction mode (CCM) operation which is implemented using hysteresis current control method. Operation is possible throughout the line-cycle, so the input current does not have harmonic distortions [14,15].

Classic PFC techniques usually need to sense the input and output voltages, and the input current. Sensing the input current is not a trivial issue. It is a common practice to utilize a resistive sensor, but it is the most problematic and expensive of the three usual sensors because it generates power losses, and heat must be evacuated. Besides, in the case of digital control, the voltage through the resistor should be digitized with an ADC and the input current frequency is equal to the switching frequency. Hence, this ADC used for sensing the input current should have been higher sampling frequency than the ADCs used for the input and output voltages, which change at the line frequency and can be low cost ADCs. There are various PFC control algorithms using a current sensorless approach. Current prediction is proposed to enhance the power section performance in Refs. [16,17]. In Ref. [18], a power factor correction without current sensor based on digital current rebuilding has a complicated mathematical calculation and the