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RESEARCH ARTICLE

ADAPTIVE FEEDBACK CONTROL BASED LED DRIVER FOR LOW-POWER LIGHTING APPLICATIONS

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ABSTRACT

It is proposed to develop a dimmable LED driver circuit with adaptive feedback control for regulating the LED current and brightness. By using universal input voltage operation, high efficiency and high power factor can be achieved by a coupled inductor single ended primary inductance converter power factor correction (PFC) converter with a simple commercial transition-mode PFC controller. The operation principles and design considerations of the studied LED driver can be analyzed. Matlab simulink can be used to demonstrate the operation of the adaptive feedback control system, LED lamp current and voltage waveforms.

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INTRODUCTION

Light-emitting diode (LED) gradually becomes a commonly used solid-state light source in general lighting applications. It has longer lifetime and has no poison mercury content compared with the conventional fluorescent lamp. Multiple LED lamps are usually connected in parallel for obtaining enough lighting levels. In addition, dimming control is often needed to regulate lighting levels for human needs as well as to achieve energy saving. A conventional linear current-regulator method, has simple circuit configuration. It is widely used for dimming applications by modulating the current amplitude of the parallel-connected LED lamps. However, linear dimming is not recommended at currents lower than the test conditions because it may produce unpredictable results and may be subjected to variation in performance. A pulse width modulation (PWM) dimming method can be used to dim the LED lamp by modulating its pulse current width. The corresponding PWM controller series connected with every LED lamp raises the circuit complexity and cost. Furthermore, the uncontrollable current amplitude will shorten the lifetime of the LED lamp.

A novel LED driver with self-adaptive drive voltage. An adaptive voltage adjustment by sensing the gate-source voltage VGS of the dimming transistors. The studied LED driver is a current-mode controlled single-ended primary inductance converter (SEPIC) with 20-30-V dc input voltage. A sequential phase-shifted PWM dimming scheme is also used to adjust LED string brightness individually for reducing the input/output current ripple. Every LED string has an individual PWM controller. In general lighting applications, ac input current harmonics have to also meet IEC 61000-3-2 Class C regulations for output power over 25

W.

Literature Survey

There are two types of dimming methods available currently which are related to the type of the input given

- DC Dimming Methods
- AC Dimming Methods

Dimming

Dimming is the process of controlling the amount of electrical power supplied to a light source. The four most popular methods for dimming LED lights are described below and cover 0-10V dimming. PWM (Pulse Width Modulation) dimming. Forward Phase Dimming (sometimes referred to as 'TRIC' or incandescent Dimming) and Reverse-Phase dimming (sometimes referred to as an ELV or Electronic Low Voltage Dimming)

1) 0 – 10 V Dimming: This method can use a number of devices to control the dimming. This requires additional low voltage wiring, but is more accurate than AC phase dimming. Dimmer Types:

- 0 - 10 V controller outputs 0 - 10 V using a computerized control device.
- 0 - 10 V wall dimmer uses a passive current sinking dimmer to sink 5mA off a 0 - 10 V input
- Potentiometer 50 k with 2 terminal is recommended.
- Fixed register - A Fixed resistor can be used to tune the drivers output.

PWM (Pulse Width Modulation): This method can use a number of devices to control dimming. This requires additional low voltage wiring but is more accurate than AC dimming. PWD dimmable LED Drivers use CCR (Constant Current Reduction) based on the duty cycle of the PWM input signal to achieve dimming.

AC Line Dimmers

Requires a leading edge (TRIAC) or trailing to change input voltage via phase cut. the resulting chopped wave has less energy than the AC line. Since these types of dimmers connect directly between AC source and AC input of the power source, they are very popular and easy to use. They typically require no additional wiring so are good for retrofit and residential applications.

Leading Edge: Also commonly known as

'TRIC Dimming', 'SCR Dimming' and forward Phase dimming control is the most common form of phase dimming. It uses a silicon device usually an SCR or TRIC to turn the mains waveform on part way through its cycle. By varying the point at which the waveform turns on we can alter the amount of power delivered to the load.

The first solid state phase control dimmers employed CRs and Tric for switching. The electrical characteristics of these devices require that the unwanted power be cut off from the start or leading edge of each half power cycle. The very rapid switch-on time of SCRs and Tric produces very low losses. However the rapid current increase produces unwanted Electromagnetic Interference (EMI) radiated from the load circuits and harmonics distortions in the supply mains. To produce these problems, a substantial inductor is incorporated into the dimmer circuit to slow the rate of current increase.

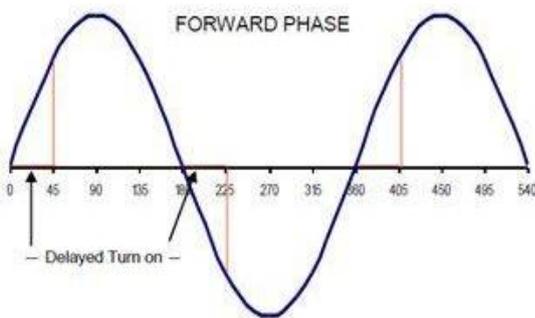


Fig. 1 Firing of Silicon Device

Trailing Edge

A trailing edge dimmer is a reverse dimmer with a more complex circuit than a forward phase dimmer. The simple leading edge circuit can no longer be used, because most Tric can not be turned off until the wave crosses zero volts.(Gate turn-off(GTO) Tric's exist, but are far more expensive and less common). To implement a trailing edge dimmer, the switching device turns on as the AC waveform passes through zero. Called zero crossing detector circuit. After a predetermined time set by the control, the switching

device is turned off and the remaining part of the waveform is not used by the load. Trailing edge dimmers commonly use MOSFET as these require almost no control current and are rugged and reliable.

They are also inexpensive and readily available at voltage ratings suitable for mains operation. Another option is IGBT (insulated Gate Bipolar Tra- sistor), which combines the advantages of both MOSFET and bipolar transistor. These are generally more expensive than MOSFETs. Reverse phase control dimmer employ MOSFET or IGBTs to remove power from the end of each cycle. The general thought was that a reverse phase control dimmer will produce less EMI and mains distortion than a forward phase dimmer. Using IGBT and MOSFET to achieve slow turn-on times has enable the production of phase control dimmer with accept- able EMI and harmonic distortion, without need for big , heavy inductors. The drawback is higher heat dissipated in the switching devices necessitating thermal control measures, such as heat sinks.

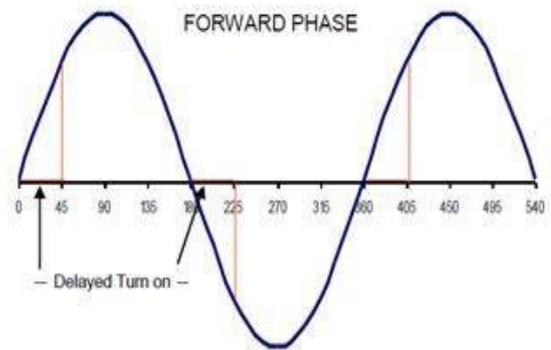


Fig. 2 Typical trailing edge performance waveform

Problem Definition

The LED driver consists of a coupled inductor SEPIC PFC converter, an improved PWM Dimming circuit, and an adaptive feedback controller. The input current can be operated at CCM condition by using a commercial low-cost TM PFC control IC. High power factor can be achieved without an additional input filter for eliminating high frequency current ripple. The output voltage of the coupled inductor SEPIC PFC converter can be adjusted by the studied adaptive feedback controller to minimize the power losses on the dimming transistors. Com- pared with the conventional PWM dimming scheme that the pulse width of every LED lamp current is modulated by the individual PWM controller, the studied dimming circuit uses only one simple PWM controller to modulate all of the LED lamps' pulse width..

Previous Methods

A conventional linear current-regulator method, as shown in Fig. 1(a), has simple circuit configu- ration. It is widely used for dimming applications by modulating the current amplitude of the parallel- connected LED lamps. However, linear dimming is not recom- mended at currents lower than the test conditions because it may produce unpredictable results and may be subjected to variation in per- formance.

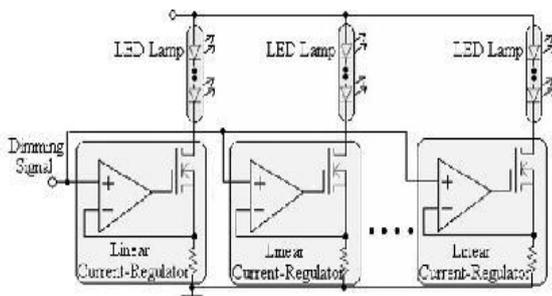


Fig. 3 Conventional Linear Current-Regulator Circuit

Analog Dimming

Analog dimming can use a simpler circuit, but the variable current supplied to the LED means that the regulator supplying the current to the LED must soak up any power not supplied to the LED. This additional power arises from the difference between the raw supply voltage powering the LED/regulator subsystem and the voltage across the LED. That power is wasted as heat. In addition, analog dimming may be inappropriate for applications that require a constant color temperature. An LED’s color will change depending on the current driven through the device

TRIAC Dimming

TI’s LM3445 In general lighting situations, especially where LEDs are replacing incandescent bulbs, there is a need to permit the use of TRIAC controls, because TRIAC dimming controls have become commonplace over the last few decades. Here, the TRIAC dimmer supplies time-sliced sections of sinusoidal AC voltage to the LED driver. The driver must then translate this chopped AC power into something the LED can use. Texas Instruments’

LM3445 TRIAC-dimmable LED drivers offer 100:1 full range dimming capability, going from nearly imperceptible light to full on in a continuous range. TI’s LM3445 maintains a constant current to large strings of LEDs driven in series off of a standard line voltage. TI’s TRIAC dimmable LED driver allows master-slave operation control in multi-chip solutions, which enables a single TRIAC dimmer to control multiple strings of LEDs with smooth, consistent, flicker-free LED dimming. This method dims the output illuminance through cutting the phase of the AC current, which will decrease the power input to the light. There are mainly four types of phase-cut dimming methods:

Leading Edge Dimming: This can altern-

tively be called as “triac dimming” or “incandescent dimming”. It turns off the sinusoidal signal of the electrical current at the front of the AC input. It fits the traditional incandescent lamps or magnetic low voltage transformer. Nevertheless, it can cause buzzing noise when dimmed, and when it is used for an LED lamp, it can produce a high inrush current to its electronic component, and eventually the entire luminaire will be damaged.

Trailing Edge Dimming:: This is also called “electronic dimming”, which can be considered as a reverse form of

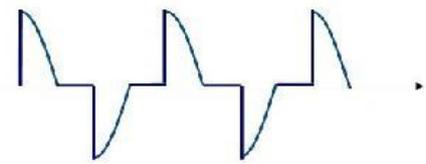


Fig. 4 Leading Edge Dimming Waveform

leading edge dimming, as it turns off the end of the AC input waveform. It can be used for electronic driver and low voltage transformers. In comparison to leading edge dimming, it will not exert high inrush current, while not causing buzzing sound when dimmed.

The Proposed Mechanism

Adaptive Feedback

A simple PFC control is used for achieving high power factor input and output voltage regulation of the LED driver.

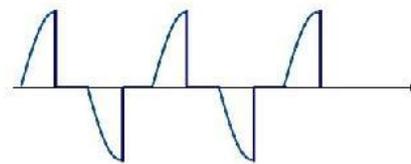


Fig. 5 Leading Edge Dimming Waveform

The band gap and the forward voltage of the LED may decrease in accordance with increasing operation time because the junction temperature changes with power dissipation and ambient temperature as well as device aging. A constant output voltage design for the LED driver circuit will cause serious power dissipations on dimming circuit under dimming operation. Thus, an adaptive feedback control, is designed to minimize the power losses on the dimming transistors. The drain voltage of the dimming transistors is sensed to determine the proper reference voltage V_{ref} in the voltage feedback control loop. The output voltage of the LED driver can be adjusted so that the dimming transistors are operated with a minimum voltage drop.

Dimming Circuit

The PWM dimming signal is generated by a commercial low-cost PWM control IC (TL494) and is then voltage divided by the resistors R3 and R4 to a specific modulating voltage V_m . The current pulse width of the parallel-connected LED lamps can be adjusted by the PWM dimming signal. The dimming frequency is usually higher than 70 Hz, making them perceivable to the human eye. Considering the switching loss for the dimming transistors, the dimming frequency in this paper is designed at 400 Hz. During on-time interval of the PWM dimming, the amplitude of LED lamp current is regulated by a linear current regulator to be operated at a specific condition suggested by the LED’s datasheet. The linear current regulator consists of an operational amplifier LM358, a dimming transistor

2N6660, and a dimming resistor R_d . In this paper, the used LED lamp is composed of 13 pieces of series connected LUMILEDS emitter-type LEDs.

This LUMILEDS diode is a 1.2-W high-luminance LED with a nominal voltage of 3.42 V at a rated current of 350 mA.

SEPIC

Single-ended primary-inductor converter (SEPIC) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input; the output of the SEPIC is controlled by the duty cycle of the control transistor. A SEPIC is essentially a boost converter followed by a buck-boost converter, therefore it is similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input), using a series capacitor to couple energy from the input to the output (and thus can respond more gracefully to a short-circuit output), and being capable of true shutdown: when the switch is turned off, its output drops to 0 V, following a fairly hefty transient dump of charge. SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output. For example, a single lithium ion battery typically discharges from 4.2 volts to 3 volts; if other components require 3.3 volts, then the SEPIC would be effective.

Methodology Used

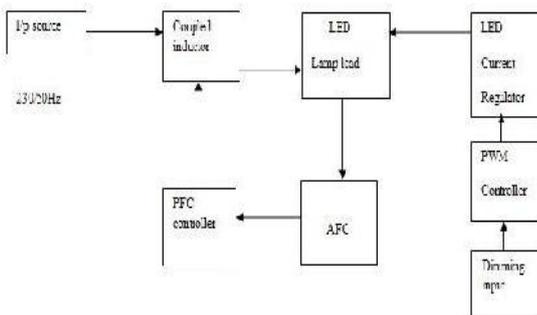


Fig. 6 Block Diagram Of LED Dimming Circuit

PFC Controller: Phase-fired control is often used to control the amount of voltage, current or power that a power supply feeds to its load. It does this in much the same way that a pulse-width modulated (PWM) supply would pulse on and off to create an average value at its output. If the supply has a DC output, its time base is of no importance in deciding when to pulse the supply on or off, as the value that will be pulsed on and off is continuous. PFC differs from PWM in that it addresses supplies that output a modulated waveform, such as the sinusoidal AC waveform that the national grid outputs. Here, it becomes important for the supply to pulse on and off at the correct position in the modulation cycle for a known value to be achieved; for example, the controller could turn on at the peak of a waveform or at its base if the cycle's time base were not taken into consideration. Phase-fired controllers take their name from that fact that they trigger a pulse of output at a certain phase of the input's modulation cycle. In essence, a PFC is a PWM controller that can synchronizes itself with the modulation present at the input. Most phase-fired controllers use thyristors or other solid state switching

devices as their control elements.

Dimming Input: Dimming input is the user input given to the PWM controller for the regulation of the voltage.

PWM controller: It's a Pulse Width Modulation controller with changes according to the input of the given to the controller. The PWM controller output is used for the LED current regulator which regulates the LED current.

AFC: The band gap and the forward voltage of the LED may decrease in accordance with increasing operation time because the junction temperature changes with power dissipation and ambient temperature as well as device aging. A constant output voltage design for the LED driver circuit will cause serious power dissipations on dimming circuit under dimming operation. Thus, an adaptive feedback control, as shown in Fig. 8, is designed to minimize the power losses on the dimming transistors. The drain voltage of the dimming transistors is sensed to determine the proper reference voltage V_{ref} in the voltage feedback control loop. The output voltage of the LED driver can be adjusted so that the dimming transistors are operated with a minimum voltage drop.

EXPERIMENTAL RESULTS

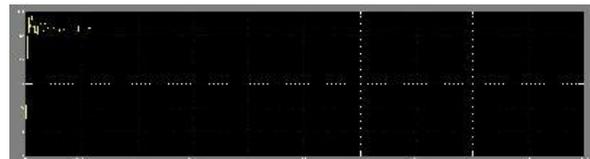


Fig. 7 Load Voltage for Input = 230 V PF = 0.3

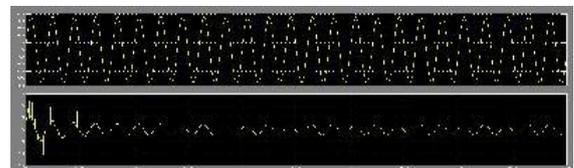


Fig. 8 Input Voltage & Current for Input = 230 V PF = 0.3

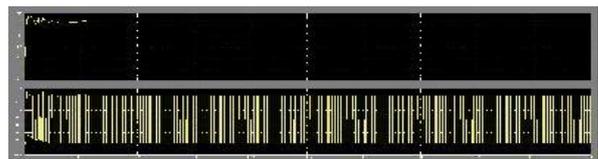


Fig. 9 Load Voltage & Current for Input = 230 V PF = 0.3



Fig. 10 Efficiency for Input = 230 V PF = 0.3

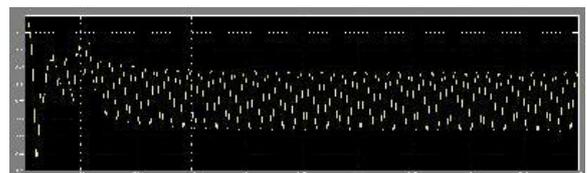


Fig. 11 Power Factor for Input = 230 V PF = 0.3



Fig. 12 Rectifier Output for Input = 230 V PF = 0.3

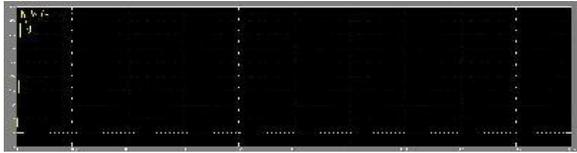


Fig. 13 Load Voltage for Input = 100 V PF = 1



Fig. 14 Input Voltage & Current for Input = 100 V PF = 1



Fig. 15 Load Voltage & Current for Input = 100 V PF = 1



Fig. 16 Efficiency for Input = 100 V PF = 1

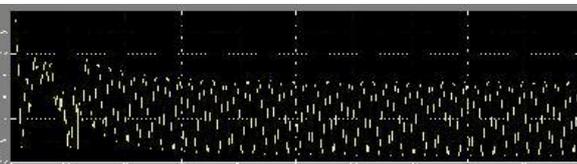


Fig. 17 Power Factor for Input = 100 V PF = 1



Fig. 18 Rectifier Output for Input = 100 V PF = 1

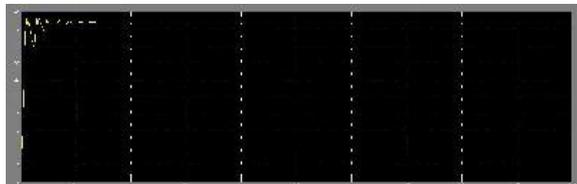


Fig. 19 Load Voltage for Input = 100 V PF = 0.7

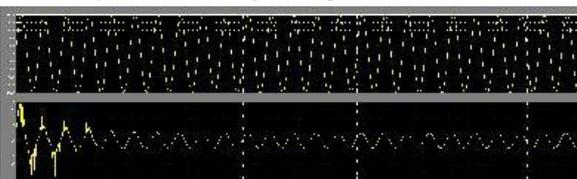


Fig. 20 Input Voltage & Current for Input = 100 V PF = 0.7

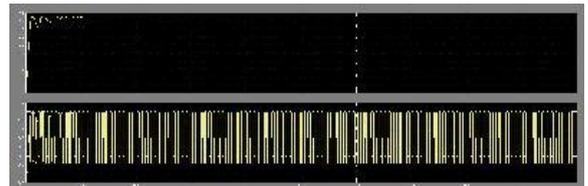


Fig. 21 Load Voltage & Current for Input = 100 V PF = 0.7

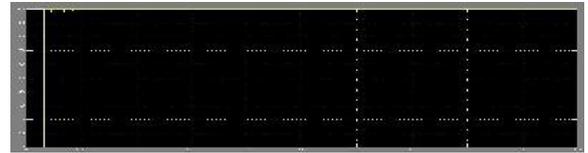


Fig. 22 Efficiency for Input = 100 V PF = 0.7

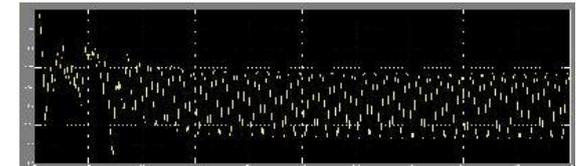


Fig. 23 Power Factor for Input = 100 V PF = 0.7

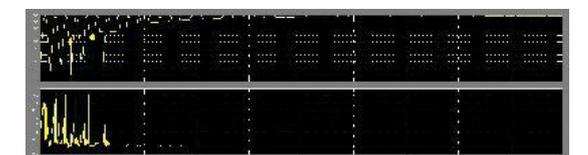


Fig. 24 Rectifier Output for Input = 100 V PF = 0.7



Fig. 25 Load Voltage for Input = 100 V PF = 0.3

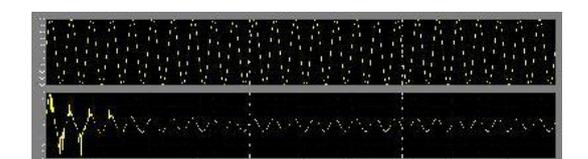


Fig. 26 Input Voltage & Current for Input = 100 V PF = 0.3

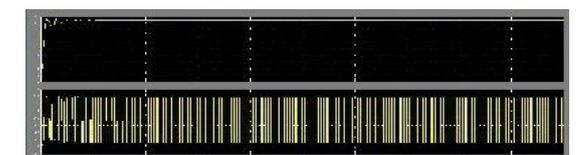


Fig. 27 Load Voltage & Current for Input = 100 V PF = 0.3

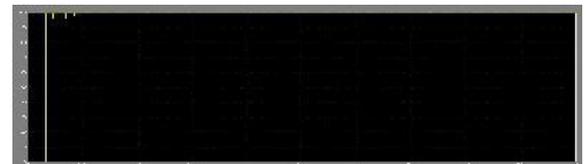


Fig. 28 Efficiency for Input = 100 V PF = 0.3



Fig. 29 Power Factor for Input = 100 V PF = 0.3



Fig. 30 Rectifier Output for Input = 100 V PF = 0.3

CONCLUSION

In this paper, we have presented a dimmable LED driver for low-power lighting applications. Under universal input voltage operation, high efficiency and high power factor can be achieved by a coupled inductor SEPIC PFC converter with an adaptive feedback control design. An improved PWM dimming technique was also studied for regulating the LED current and brightness. Current amplitude of LED lamps can be regulated at a specific condition suggested by the LEDs datasheet. A laboratory prototype was built and tested. The experimental waveforms of the laboratory prototype were shown to verify the feasibility of the proposed scheme.

After comparing leading edge and trailing edge Phase-cut dimming methodologies, it is clear that for most LED lamps, trailing edge dimming is a better option comparing to leading edge dimming. However, because LED retrofits are mostly for the existing incandescent or halogen fixtures, which makes many manufacturers designed their LED lamps to be suitable for leading edge dimmers. So when you choosing a dimmable LED, it is better to clarify the capable dimming method for the product before getting a dimmer for it, or you can use a "Universal" dimmer, as it is suitable for both leading edge and trailing edge dimming.

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