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Development of constant-power driving control for light-emitting-diode (LED) luminaire

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HIGHLIGHTS

► A constant-power driving technique is proposed for LED luminaire.
► A linear system dynamics model of LED luminaire is used in the control system design.
► The test shows that the feedback system accurately controls the input power.
► The LED illumination varies slightly (−1.7%) for constant-power driving.

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ABSTRACT

The illumination of an LED may be affected by operating temperature even under constant-current condition. A constant-power driving technique is proposed in the present study for LED luminaire. A linear system dynamics model of LED luminaire is first derived and used in the design of the feedback control system. The PI controller was designed and tuned taking into account the control accuracy and robust properties with respect to plant uncertainty and variation of operating conditions. The control system was implemented on a microprocessor and used to control a 150W LED luminaire. The test result shows that the feedback system accurately controls the input power of LED luminaire to within 1.3 per cent error. As the ambient temperature changes from 0 to 40 °C, the LED illumination varies slightly (−1.7%) for constant-power driving, as compared to that of constant-current driving (−12%) and constant-voltage driving (+50%). The constant-power driving has revealed advantage in stabilizing the illumination of LED under large temperature variation.

1. Introduction

High-power LED (light-emitting diode) lighting is considered to be the next-generation lighting technology with high efficiency, long life, and environmentally friendly [1–3]. The application is getting popular in street and indoor lighting after the heat dissipation problem has been solved [4–6] and the lighting efficiency of LED is improved rapidly [7].

The I–V curve of an LED lamp is sensitive in voltage, as shown in Fig. 1. A slight variation of input voltage may cause abrupt change of current which may damage the LED. The constant-voltage driver was thus not recommended for LED driving. Instead, the constant-current driving is usually used in commercial products, for example the product of Zetex (2008) [8].

The electrical performance of LED behaves like a kind of negative-temperature resistance. The electrical resistance of LED decreases with increasing temperature. The driving voltage as well as the input power for a constant-current driven LED may change due to variation of LED junction temperature. An illumination test of a 150W LED luminaire was carried out in the present study and we found that the constant-current driven LED causes an illumination decrease about 12%, and about 50% increase for constant-voltage driving, for a temperature rise of 40 °C (Fig. 2).

The test result of Fig. 2(b) has shown that the amount of light emission of an LED is affected by operating temperature even under constant-current condition. This is probably caused by the effect of electron noise inside the diode which results in the decrease of illumination at higher temperature.

In the present study, we intend to develop a constant-power driving technique to provide a constant-power input to the LED. The constant-power driver will balance the current supply as well as the light emission at variable operating temperatures. That is, the light emission can be balanced if the current is increased at higher operating temperature.

The control system design of a constant-power driver of LED is quite complicated since the LED is a diode performing like

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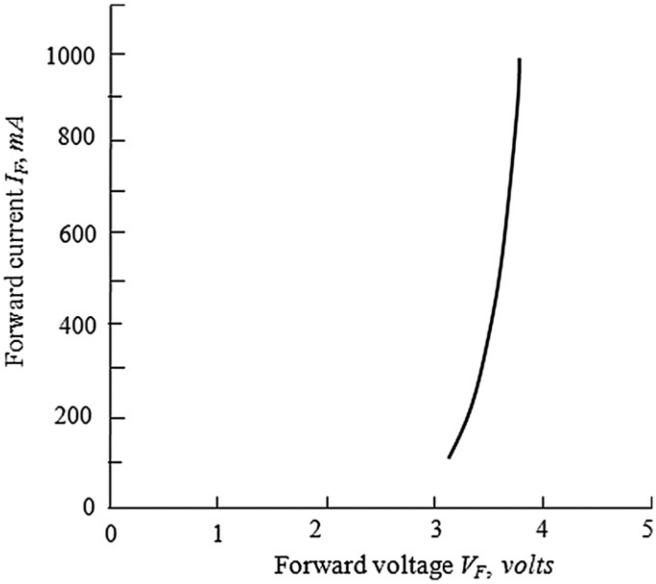

Fig. 1. *I–V* curve of an LED.

a negative-temperature resistor which results in a nonlinear behavior in feedback control system. A linear feedback control system to provide a constant-power input to the LED luminaire will be developed in the present study. The linear system dynamics model of the LED luminaire is first derived and used in the design of the feedback control system.

2. System dynamics model of LED luminaire

2.1. Derivation of system dynamics model of LED luminaire

The system dynamics model of LED luminaire developed by Huang et al. [9] is adopted in the present study. The LED lighting luminaire as shown in Fig. 3 [6] consists of three major components: LED lighting module, heat conducting block, and heat sink. The lighting module includes the light sources (i.e. LED lamps) and secondary optics component. LED lamps are attached to a metallic board for electrical connection. The secondary optics component is added on LED lamps to yield the desired illumination distribution. The heat conducting block acts as a thermal connector to the heat sink which is used to dissipate the heat to ambient. The heat sink was designed using loop heat pipe (LHP) attached on the fixture housing.

For a high-power luminaire, the heat conducting block and the heat sink are usually heavy (2–10 kg) compared to the LED lighting module. Hence, the thermal response of the whole luminaire is dominated by the heat conducting body and the heat sink.

Since LED lamp is made from semiconductor, its electrical phenomena is similar to a resistor but with a nonlinear voltage–current relation as shown in Fig. 1. The system dynamics of an LED luminaire thus can be treated as a multiple-input-multiple-output (MIMO) system with two inputs (voltage V and ambient temperature T_a) and two outputs (forward current I and body temperature T_b) [9]. Since the system dynamics model is nonlinear, the following linear-perturbation model in Laplace transform was derived [9]:

$$\begin{bmatrix} \tilde{T}_b(s) \\ \tilde{I}(s) \end{bmatrix} = \begin{bmatrix} G_{vb}(s) & G_{ab}(s) \\ G_{vi}(s) & G_{ai}(s) \end{bmatrix} \begin{bmatrix} \tilde{V}(s) \\ \tilde{T}_a(s) \end{bmatrix} \tag{1}$$

where the perturbed variables in time domain from the equilibrium state are defined as follows:

$$\tilde{V}(t) = V(t) - \overline{V} \tag{2}$$

$$\tilde{T}_a(t) = T_a(t) - \overline{T}_a \tag{3}$$

$$\tilde{T}_b(t) = T_b(t) - \overline{T}_b \tag{4}$$

$$\tilde{I}(t) = I(t) - \overline{I} \tag{5}$$

Eq. (1) indicates that both T_b and I are affected by ambient temperature T_a and applied voltage V which can be written as, in transfer-function form:

$$\tilde{T}_b(s) = G_{vb}(s) \times \tilde{V}(s) + G_{ab}(s) \times \tilde{T}_a(s) \tag{6}$$

$$\tilde{I}(s) = G_{vi}(s) \times \tilde{V}(s) + G_{ai}(s) \times \tilde{T}_a(s) \tag{7}$$

Fig. 4 shows the MIMO system block diagram.

The LED lighting luminaire is a 2 × 2 system with two inputs (V and T_a) and two outputs (I and T_b). The dynamic model consists of four components, $G_{vb}(s)$, $G_{vi}(s)$, $G_{ab}(s)$, and $G_{ai}(s)$.

The model components $G_{vb}(s)$ and $G_{ab}(s)$ are related to the response of heat conducting block temperature T_b due to the change of the applied voltage V and the ambient temperature (T_a).

Since the purpose of the present study is to develop a constant-power control system for a high-power LED luminaire, the simplified dynamics model as shown in Fig. 5 can be used which consists of the current model $G_{vi}(s)$ and the temperature disturbance model $G_{ai}(s)$ [9].

For constant-power driving control, the system dynamics model has to be modified to include input power of the LED luminaire as one of the outputs. The instantaneous power input to the LED luminaire $P(t)$ can be expressed as Eq. (8):

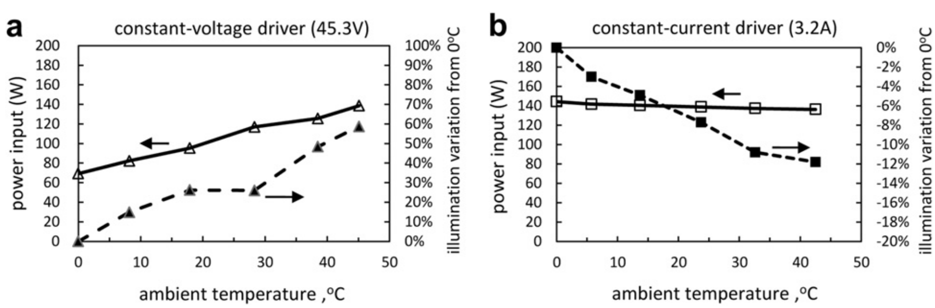

Fig. 2. Variation of LED illumination with temperature for different driver.