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Direct battery-driven solar LED lighting using constant-power control

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Abstract

A direct battery-driven LED lighting technique using constant-power control is proposed in the present study. A system dynamics model of LED luminaire was derived and used in the design of the feedback constant-power control system. The test result has shown that the power of 18 W and 100 W LED luminaires can be controlled accurately with error at 2–5%. A solar LED street lighting system using constant-power and dimming control was designed and built for field test in a remote area. The long-term performance was satisfactory and no any failure since the installation. Since no high-power capacitor is used in the present constant-power control circuit, a longer lifetime is expected.

Keywords: LED driving; Stand-alone solar LED lighting; Solar LED lighting; Solar energy; LED; Solar lighting

1. Introduction

Application of stand-alone solar PV system in remote areas where the grid power cannot reach has been proved economically feasible. However, the reliability and continuous service time in a continuous bad weather are the two key factors influencing the acceptability of this technology.

A high-performance stand-alone solar LED lighting system was developed by Huang et al. (2010a) for LED lighting. The system adopts the near-maximum-power-point operation (nMPPO) concept for the design of photovoltaic power generation system (Huang et al., 2006) to get rid of the maximum-power-point-tracking controller (MPPT) just by properly matching the PV module specification with the battery voltage to obtain a similar performance of MPPT. The additional cost, reliability problem, and energy loss of the MPPT is thus avoided.

To charge the battery in its full storage capacity, a 3-phase battery charge using pulse-width modulation (PWM) and feedback control technique was developed by Huang et al. (2010b).

Since the *I*–*V* curve of a LED lamp is sensitive in voltage, as shown in Fig. 1. A slight variation of applied voltage may cause abrupt change of current which may damage the LED. The constant-voltage driver was thus not recommended for LED. Instead, the constant-current driving is widely used in commercial products. A DC/DC converter with constant-current output for LED is thus needed in solar LED lighting system. This creates the problems of energy loss in the control circuit of the converter, decreasing solar system reliability, and increasing cost.

A lot of commercial DC/DC constant-current driver products for LED illumination are available. However, the energy conversion loss for high-power LED is high (>14%) at partial load condition, for example, the product of Zetex Semiconductors Plc. (2008). This happens when a dimming control of LED is employed. The cost of a DC/DC constant-current driver for 30–200 W LED is around 30–50 USD. Moreover, the lifetime of high-power DC/DC converter is expected to be around 3 years due to the capacitor failure in the circuit.

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Nomenclatures

D_T	PWM signal duty cycle, dimensionless
e	error signal from a comparator, $P_{set} - P_{ave}$ (W)
$G_c(s)$	transfer function of controller in feedback system, Eq. (6)
G_{vi}	transfer function from LED voltage V_{bat} to current I_{LED}, Eq. (5)
I	current to LED lamp, Eq. (1) (A)
I_{ave}	average current of LED, (A)
I_{LED}	current through the LED luminaire (A)
$T_{CL}(s)$	transfer function of the feedback control system, from setting power P_{set} to average power P_{ave}, Eq. (7)
T_I	integral constant of PI controller
K_p	proportional constant of PI controller
K_{vi}	gain of LED model $G_{vi}(s)$, Eq. (5)
LED_e	electric model of LED luminaire
LED_{ph}	photo-electrical model of LED luminaire
P_{ave}	average power to LED luminaire (W)
P_{set}	setting of input power (W)
$S^I(s)$	sensitivity function for variation of operating current, Eq. (8)
$S^V(s)$	sensitivity function for variation of operating voltage, Eq. (9)
T_j	different junction temperature (°C)
V	voltage of LED (V)
V_{bat}	battery voltage to LED luminaire (V)

To eliminate the DC/DC converter for LED lighting, Huang et al. (2010a) developed a special technology to drive LED directly by battery voltage using a PWM technique with constant average current control. A reliability test for the illumination of LED lamps was performed continuously for 13,200 h and shows that the light decay of PWM-driven LED is the same as that of constant-current driven LED.

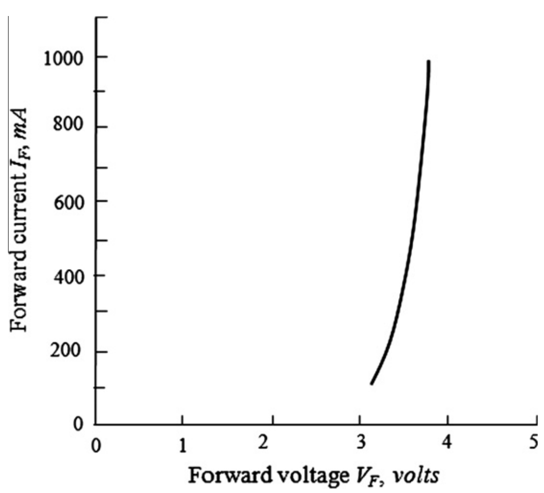

Fig. 1. I–V curve of a LED at junction temperature 25 °C.

The electrical performance of LED behaves like a negative-temperature resistance. The electrical resistance of LED decreases with increasing temperature. The driving voltage as well as the input power of a constant-current driven LED may change due to variation of LED junction temperature. An illumination test of a LED luminaire carried out in the present study shows 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).

Huang et al. (2012) developed a constant-power LED driver using ac power input to balance the LED current supply as well as the light emission at variable operating temperatures. A linear feedback control technique was used in the design of constant-power LED driver. The test result shows that the feedback control 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%).

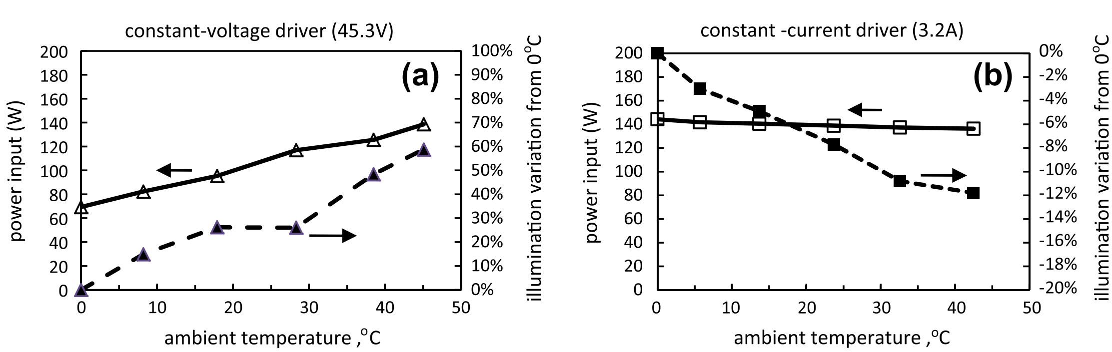

Fig. 2. Variation of LED illumination with ambient temperature for different driver.