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.

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

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

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

The constant-power driver has revealed advantage in stabilizing the illumination of LED under large temperature variation. This is important in practical application. In addition, the constant-power driver can provide an accurate power consumption control through dimming of the LED during the night in solar LED lighting.

However, for solar LED lighting, the power source comes directly from a battery whose voltage will vary during discharge. The required constant-power control is thus different from the constant-power driver using ac power source developed by Huang et al. (2012). Besides, the conventional DC/DC driver uses high-power capacitor in circuit which may cause failure in about 3 years. The constant-power driving in solar LED lighting doesn't use high-power capacitor in circuit and will have longer lifetime.

In the present study, we intend to develop a constant-power control system for LED which is directly driven by battery in solar-powered lighting system. A solar LED lighting system using the constant-power and dimming control for LED lighting at night was designed, built, and tested in a remote area to verify this technology.

2. Constant-power feedback control for LED driven by battery

2.1. Feedback structure of constant-power control for LED driven by battery

The feedback structure of the LED constant-power control system driven directly by battery is shown in Fig. 3. It is seen that no high-power capacitor is used in the circuit like conventional DC/DC driver. Hence, longer lifetime is expected for the constant-power driver.

The electric model of LED luminaire (LED_e), G_{vi} , receives the battery voltage as the input and creates the current through the LED luminaire $I_{LED} (=G_{vi} \times V_{bat})$. The MOSFET switching device then receives a PWM signal

from the controller with specific duty cycle to create a PWM current input to the LED luminaire which will generate light output due to photo-electrical effect (LED_{ph}). The PWM current is measured and averaged using an average current measuring device to obtain the average current signal I_{ave} which will merge with the battery voltage signal in a multiplier device to obtain the average power P_{ave} . The comparator will compare P_{ave} with the set value P_{set} and generate an error signal $e (=P_{set} - P_{ave})$ to the controller $G_c(s)$ which will output a PWM signal to MOSFET from the calculation in the controller. The controller $G_c(s)$ can be designed based on a known LED luminaire dynamics model G_{vi} according to the desired system response and disturbance rejection etc.

2.2. Derivation of system dynamic model of LED luminaire for control system design

The current response I_{LED} caused by the voltage input V_{bat} is much shorter than 1 ms in LED and can be approximated as an instantaneous process, as compared to the thermal response (Abdelkader et al., 1992). Hence, the voltage to current model $G_{vi}(s)$ can be treated as a quasi-steady system with a constant gain K_{vi} .

Actually, the gain of K_{vi} is the slope of the I - V curve of LED luminaire, i.e. electrical conductance. K_{vi} can then be derived from a steady-state measurement of current-to-voltage relation (I - V curve).

The I - V curve of LED luminaire can be derived from the I - V curve of a single LED lamp using network analysis. The single LED lamp is driven by a constant-voltage power supply and the current under different voltages are measured at fixed junction temperature.

Since the I - V curve varies with LED junction temperature, a cooling device made from a thermoelectric cooler with a control system was developed to control the LED junction temperature during the experiment. The measurement of LED junction temperature uses the pulse method

Fig. 3. Feedback structure of LED constant-power control system.

Fig. 4. I - V curves of a LED lamp at different junction temperatures.

developed by Huang et al. (2009). A low current pulse (1 mA) with short time duration (50 μ s) was applied to the LED lamp when the junction temperature is in equilibrium with a test chamber holding the test section. The voltage was then measured and the junction temperature was determined using the predetermined V - T_j relation at low current (1 mA). The experiment was conducted using a LED lamp ez-1000 (made by Cree) at $T_j = 25, 50, 75$ °C. The measurement result of I - V relation of the LED lamp is shown in Fig. 4.

A quadratic function can be derived to fit the I - V curve of Fig. 4:

$$I = a_o V^2 - a_1 V + a_2 \quad (1)$$

where a_o, a_1, a_2 are the fitted parameters for different junction temperature T_j . Applying the perturbation relations,

$$\tilde{V}(t) = V(t) - \bar{V} \quad (2)$$

$$\tilde{I}(t) = I(t) - \bar{I} \quad (3)$$

to Eq. (1) and neglecting the second-order term, $\tilde{V}\tilde{V}$, we obtain the following relation:

$$\tilde{I} = (2a_o \bar{V} - a_1) \tilde{V} \quad (4)$$

Taking the Laplace transform of Eq. (4), the dynamics model for a single LED lamp can be expressed:

$$G_{vi}(s) = \frac{\tilde{I}}{\tilde{V}} = 2a_o \bar{V} - a_1 \equiv K_{vi} \quad (5)$$

Two kinds of LED luminaire, 100 W and 18 W, was selected for experiment in the present study. The 100 W luminaire consists of 84 LED lamps with 7 in series and 12 in parallel and the 18 W luminaire consists of 15 LED lamps with 3 in series and 5 in parallel. The dynamics model of the luminaire can be easily derived using electrical network principle. Table 1 shows the derived parameters a_o, a_1, a_2 and the model K_{vi} of a single LED lamp and the 18 W and 100 W LED luminaire.

The derived linear system dynamics model of the LED luminaire will be used in the design of the feedback control system.

Table 1

Determination of the model parameters and K_{vi} for a single LED lamp and the 18 W/100 W luminaire.

T_j , °C	a_o	a_1	a_2	K_{vi} (single LED)	K_{vi} (18 W/100 W luminaire)
25	0.2037	0.7955	0.6408	0.5298	0.8830/0.9082
50	0.3140	1.2322	1.0487	0.6746	1.1243/1.1565
75	0.4193	1.7481	1.7069	0.7456	1.2427/1.2782

2.3. Controller design

The PI (Proportional-Integral) algorithm was chosen as the controller of the LED constant-power feedback control system (Fig. 3):

$$G_c(s) = K_p \left(1 + \frac{1}{T_I s} \right) \quad (6)$$

From the feedback structure of Fig. 3 with PI controller, Eq. (6), the closed-loop system transfer function can be derived as:

$$T_{CL}(s) = \frac{P_{ave}(s)}{P_{set}(s)} = \frac{K_p T_I I_{ave} V_{bat} s + K_p I_{ave} V_{bat}}{T_I (1 + K_p I_{ave} V_{bat}) s + K_p I_{ave} V_{bat}} \quad (7)$$

where $I_{ave} = D_T K_{vi} V_{bat}$, D_T is the duty cycle of MOSFET, $K_{vi} = G_{vi}$ according to Eq. (5).

The design criterion for the present constant-power feedback control system of solar LED lighting is set as, according to the step response:

- (1) Rise time (the time of step response from 10% to 90% of the final steady value) < 0.5 s.
- (2) Settling time (the time of step response to reach 98% steady value) < 1 s.

The two parameters of the PI controller, K_p and T_I , can be determined from the control system simulation using Matlab/Simulink, as shown in Fig. 5 which includes the anti-windup loop for the saturation phenomenon in integral control.

The IAE (integral of absolute error) is used as the design criteria to determine the suitable controller parameters. A smaller IAE value represents smaller control error.

$$IAE = \int |P_{set} - P_{ave}(t)| dt \quad (8)$$

The proportional constant K_p of the PI controller was first tuned without the integral control. It was found that the system response maintains about the same at $K_p > 0.3$. But a higher value of K_p also easily causes saturation of the actuator. Therefore K_p is chosen as 0.3. The integral constant T_I is then tuned at $K_p = 0.3$. The results are shown in Table 2. It is seen that the rise time varies slowly at $T_I < 1/12$. IAE decreases with decreasing T_I . The step response for various T_I shown in Fig. 6 also reveals that $T_I = 1/12$ is good enough to meet the design criterion.

Fig. 5. Simulation block diagram with an anti-windup loop.

Table 2
Variation of step response parameters with T_I at $K_p = 0.3$.

T_I	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
	1/6	1/9	1/12	1/15	1/18	1/21
Rise time (s)	0.37	0.25	0.18	0.15	0.12	0.11
Settling time (s)	0.66	0.44	0.33	0.27	0.22	0.19
IAE value	0.361	0.290	0.255	0.235	0.225	0.217

Fig. 6. Simulation result of step response for $K_p = 0.3$, $T_I = 1/6$ – $1/21$.

The parameter tuning of PI controller described above is according to the step response of the given control command (constant power setting). It may not be robust with respect to the plant uncertainty and disturbance (Zhou

et al., 1996). For future application in solar LED lighting, the battery voltage as well as the LED driving current may vary with environment. The controller then should be able to reject the disturbances from environment. Here, we use a sensitivity function which is defined as the variation of closed-loop transfer function $T_{CL}(s)$, Eq. (7), with respect to the operating variables in $T_{CL}(s)$, that are I_{ave} and V_{bat} (Franklin et al., 1994). Therefore, the sensitivity functions $S^I(s)$ and $S^V(s)$ are defined and derived as:

$$S^I(s) = \frac{I_{ave}}{T_{CL}} \frac{\partial T_{CL}(s)}{\partial I_{ave}} = \frac{T_I s}{T_I (1 + K_p I_{ave} V_{bat}) s + K_p I_{ave} V_{bat}} \quad (9)$$

$$S^V(s) = \frac{V_{bat}}{T_{CL}} \frac{\partial T_{CL}(s)}{\partial V_{bat}} = \frac{T_I s}{T_I (1 + K_p I_{ave} V_{bat}) s + K_p I_{ave} V_{bat}} \quad (10)$$

It is seen that $S^I(s) = S^V(s)$. $S^I(s)$ or $S^V(s)$ represents the ratio of the closed-loop transfer function change rate with respect to the change rate of I_{ave} or V_{bat} . Lower sensitivity implies that the closed-loop gain is less sensitive to the variation of operating variable I_{ave} or V_{bat} . Substituting the design parameters of the PI controller, K_p , T_I , into the sensitivity functions, Eqs. (8) and (9), and calculate their frequency response. By examine the gain of the sensitivity function, we can check the robustness of the controller design.

Fig. 7. Frequency response of closed-loop sensitivity function $S^I(s) = S^V(s)$ at $I_{ave} = 8.4$ A, $V_{bat} = 25.4$ V.

Fig. 8. Frequency response of closed-loop sensitivity function $S^I(s) = S^V(s)$ at $K_p = 0.3$, $T_I = 1/12$, $V_{bat} = 25.4$ V.

Fig. 9. Control system simulation result of 100 W LED luminaire at $P_{set} = 70$ W under disturbance of V_{bat} .

It is seen from Fig. 7, that the gain of the sensitivity function, $S^I(j\omega) = S^V(j\omega)$, is less than -30 dB at different parameters of the PI controller. $K_p = 0.3$ and $T_I = 1/12$ seems suitable for the PI controller. Fig. 8 is the gain of sensitivity function at various I_{ave} for $V_{bat} = 25.4$ V and $K_p = 0.3$ and $T_I = 1/12$. The sensitivity is seen always less than -30 dB over a wide range of frequency and current I_{ave} (from 2.8A to 14A).

From the above discussion, the transfer function of the controller is chosen as

$$G_c(s) = 0.3 \left(1 + \frac{1}{12s} \right) \quad (11)$$

2.4. Control system simulation

To verify the above controller design, we carried out a time-domain simulation using Simulink to check the control accuracy under a disturbance of battery voltage.

Fig. 9 shows the simulation result of the 100 W LED with power setting at 70 W. It is seen that the LED power

Fig. 10. Control system simulation result of 18 W LED luminaire at $P_{set} = 18$ W under disturbance of V_{bat} .

Fig. 11. Implementation of LED constant-power control system.

P_{ave} remains steady at 70 W without any disturbance caused by a fast battery voltage change from 25.4 V to 23 V in 40 s.

The simulation of the 18 W LED luminaire using the same controller with battery voltage changes from 13.0 V to 11.5 V in 50 s was carried out and the result is shown in Fig. 10. The LED power P_{ave} remains steady and at the setting value 18 W without any disturbance.

2.5. Control system implementation and test

The present design of LED constant-power control system was implemented in a PIC microprocessor-based control system built in the laboratory (Fig. 11). No high-power capacitor is used in the circuit and longer lifetime is expected.

The instantaneous current through the LED luminaire was detected by the voltage across a standard resistor R_s which is small enough (0.003 ohm) to reduce energy loss. An OP (LM324) is used to amplify the voltage across the resistance R_s and the signal is sent to the microprocessor in which it is integrated and averaged to obtain I_{ave} .

The battery voltage V_{bat} was measured by the voltage across the sensing resistor R_2 for the microprocessor to read. The resistor R_1 is used to create a voltage drop from battery such that the voltage across R_2 is low enough to be measured by the microprocessor. The average power was calculated from the multiplication of average current I_{ave} and battery voltage V_{bat} . The controller software stored in the PIC then calculates the control signal (PWM signal, duty cycle D_T) using the PI algorithm described previously and actuates the MOSFET to output a PWM current to drive the LED luminaire.

We used a power supply with adjustable voltage to drive LED to test the control accuracy under battery voltage disturbance. Fig. 12 shows the test results for the 100 W LED luminaire whose power was set at 70 W. The voltage was changed from 25.9 V to 23 V (about 12%) during the test. The measured average LED power input P_{ave} is 69.9 W,

Fig. 12. Constant-power control system test result of 100 W LED luminaire.

Fig. 13. Constant-power control system test result of 18 W LED luminaire.

with standard deviation 0.38 W. The maximum deviation is 1.39 W, 2% of the setting value 70 W. Fig. 13 shows the result of the 18 W LED luminaire under the similar control system test with voltage change from 14.2 V to 11 V (about 22.5%). The measured average LED power input P_{ave} is 17.95 W, with standard deviation 0.35 W.

3. Field test of constant-power driving in solar street lighting

The constant-power control technology for LED lighting directly driven by battery was developed in the present study. The control accuracy of the LED input power under variable battery voltage disturbance was verified experimentally. A solar LED street lighting system was then designed and built for long-term field test in a remote area (Ali Tribe), which is located in the high mountain area of southern Taiwan. Fig. 14 shows the photo of the installation.

The constant-power LED driver has revealed advantage in stabilizing the illumination of LED under large

Fig. 14. Ali's 18 W solar LED street lighting system.

Based on the nMPPO concept (Huang et al., 2006), the solar LED lighting system consists of a 18 W LED (12 V), a 130 Wp solar PV module, and a 100 A h/12 V lead-acid battery. The net illumination of the 18 W LED luminaire is 1300 lumen at 18 W input. A microprocessor(PIC)-based solar charging/discharging controller was designed and built according to the constant-power control technique described above, for battery charging control according to the 3-phase charge control technique (Huang et al., 2010b), and for LED dimming control according to a desired schedule from the constant-power setting values (P_{set}) in the controller.

3.2. Field test of solar LED street lighting system

This solar street lighting system was installed and started to run in June, 2011. The control system was also designed with data acquisition function to record the long-term performance. Fig. 15 shows the field test result of LED dimming control at night. It is seen that the constant-power control performs satisfactory in tracking the dimming schedule. The control error of P_{ave} away from

Fig. 15. Field test result of control at LED dimming night.

Fig. 16. Long-term record of LED dimming performance.

Fig. 17. Long-term performance in battery charging and discharging (LED lighting).

the dimming schedule P_{set} is mainly due to the larger time step (6 min) used in the dimming time schedule. Another source of error may come from the measurement error of P_{ave} inside the control system. The total energy consumption of LED lighting was 125 Wh per night.

The solar street lighting system has been run for more than 14 months without any failure. Fig. 16 is the continuous record for 11 nights which shows good performance in LED dimming control.

Fig. 17 shows the long-term performance for battery charging at daytime and discharging (LED lighting) at night. The battery voltage higher than 14 V implies that the weather is clear with high solar irradiation so that the battery is charged over the overcharge point (14.1 V) and the PWM charging control (Phase 2) was activated (Huang et al., 2010b). The field test data shows that one clear-day charging can provide LED lighting for at least three consequent nights as can be seen from December 29, 2011.

4. Conclusion

A direct battery-driven LED lighting technology using constant-power control is proposed for LED luminaire in

the present study. A system dynamics model of LED luminaire was derived and used in the design of the feedback control system. The PI algorithm was adopted in the controller. The test result of the control system has shown that the power of 18 W and 100 W LED luminaires can be controlled accurately with error 2–5% at battery voltage change 12–22.5%.

A real solar LED street lighting system using the constant-power control technique was then designed and built for long-term field test in a remote area.

The design of the solar LED street lighting system has three unique features: (1) using the near-maximum-power-point operation (nMPPO) concept in the design of photovoltaic power generation system (Huang et al., 2006) to avoid the maximum-power-point-tracking controller (MPPT); (2) to charge the battery after the overcharge point using PWM control technique; (3) to drive LED for lighting directly from the battery using constant-power control technique developed in the present study.

A microprocessor(PIC)-based solar charging/discharging controller was designed and built for LED lighting control according to the constant-power control technique, for battery charging control according to the 3-phase charge control technique (Huang et al., 2010b), and for LED dimming control according to a desirable schedule using the time-variant constant-power setting values (P_{set}) in the controller.

The dimming schedule of LED was designed with four modes from 18 W in full load at beginning to 4.5 W before sunrise. It was shown that the constant-power control performs satisfactory in tracking the dimming schedule. The total energy consumption of LED lighting was 125 Wh per night.

The field test data shows that one clear-day charging can provide LED lighting for at least three consequent nights. The long-term performance for battery charging at daytime and discharging (LED lighting) at night was found satisfactory and no any failure since the installation. This verifies the technical feasibility of constant-power control for LED lighting and its application in solar lighting system.

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References

- Abdelkader, H.I., Hausien, H.H., Martin, J.D., 1992. Temperature rise and thermal rise time measurement of a semiconductor laser diode. *Review of Scientific Instruments* 63 (3), 2004–2007.
- Franklin, G.F., Powell, J.D., Emami-Naeini, A., 1994. *Feedback Control of Dynamic Systems*, third ed. Addison-Wesley (Chapter 4).
- Huang, B.J., Sun, F.S., Ho, R.W., 2006. Near-maximum-power-point-operation (nMPPO) design of photovoltaic power generation system. *Solar Energy* 80, 1003–1020.

- Huang, Bin-Juine, Tang, Chun-Wen, Wu, Min-Sheng, 2009. System dynamics model of high-power LED luminaire. *Applied Thermal Engineering* 29, 609–616.
- Huang, B.J., Wu, M.S., Hsu, P.C., Chen, J.W., Chen, K.Y., 2010a. Development of high-performance solar LED lighting system. *Energy Conversion and Management* 51, 1669–1675.
- Huang, B.J., Hsu, P.C., Wu, M.S., Ho, P.Y., 2010b. System dynamic model and charging control of lead-acid battery for stand-alone solar PV system. *Solar Energy* 84, 822–830.
- Huang, Bin-Juine, Chen, Chun-Wei, Ong, Chin-Dian, Du, Bo-Han, Hsu, Po-Chien, 2012. Development of constant-power driving control for LED luminaire. *Applied Thermal Engineering*, accepted for publication.
- Zetex Semiconductors Plc., 2008. ZXLD1320 Buck Mode DC–DC Converter for LED Driving with 1.5 A Output and Current Control. Issue 1 – January 2008 <<http://www.zetex.com>>.
- Zhou, K., Doyle, J.C., Glover, K., 1996. *Robust and Optimal Control*. Prentice-Hall, Upper Saddle River, NJ.