Operation of Stand-Alone Lighting System Powered by Energy Storage Device

Unchittha Prasatsap, Suwit Kiravittaya, and Jirawadee Polprasert

Abstract— *This paper presents (1) the discharging characteristics of battery via LED bulbs, (2) the difference between LED bulb and halogen bulb as they are loads for discharging battery via discharge controller and (3) the flow of electric power in the system. From this study, we observe a distinct difference between I-V characteristics of LED and halogen bulbs, which can be explained by the operation of LED driver circuit in the bulb. The dissipated power values are varied due to the bulb types as well as a voltage across battery. In addition, the power loss in discharge controller also depends on the power flowing in the system. From our study, LED light bulb is recommended for a stand-alone lighting system operated by using an energy storage device.*

Keywords— **Discharge controller, energy storage system, LED driver, lighting system.**

1. INTRODUCTION

The stand-alone photovoltaic system is alternative produce the electricity with villages. [1, 2] The most common method of energy storage utilizes batteries in stand-alone solar systems. The main reason of selecting a sealed lead acid battery or a valve regulated lead acid battery is its low cost and wide availability. In previous works [3, 4], researchers use a lead-acid battery in the application and development of renewable energy systems. Moreover, design methods for efficient solar chargers are developed [5, 6] in order to control the charge and discharge of a battery. It enhances efficiency and prolongs battery lifetime.

In lighting system, LED bulb is an interested light source in a lighting technology since LED bulb has many advantages such as energy efficiency, ecologically friendliness, and low voltage power supply and design flexibility. Recently, Li *et al*. study the power flow analysis. [7] Design of LED driver has been developed. [8] From above reasons, we investigate the usage of LED light bulb in this work. We focus on a stand-alone photovoltaic system. The power flowing via discharge controller and system performance are evaluated. Moreover, we study the different discharged characteristics of the LED bulb and halogen bulb powered by a sealed lead-acid battery as the energy storage device.

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This investigated system consists of a discharge controller, energy storage device, LED bulb and halogen bulb. The paper presents and discusses on different characteristics of LED bulb and halogen bulb, and the power flowing.

2. INVESTIGATED SYSTEM

Schematic of the investigated system is shown in Fig. 1. The system consists of a discharge controller controlled by a microcontroller (Microcontroller Unit, MCU), 12-V 7.5-AH lead-acid battery and load as a light bulb.

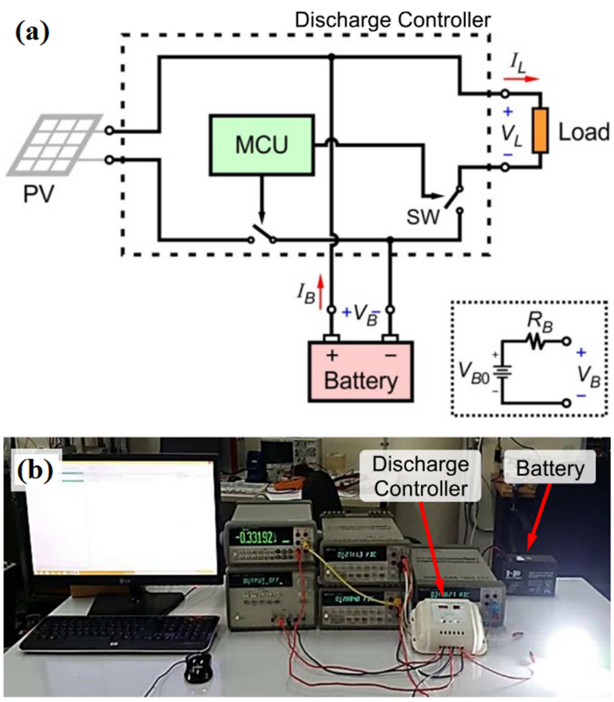

Fig. 1 (a) Block diagram of the investigated system consists of a discharge controller, battery and load. The lower right inset is the equivalent circuit of battery. (b) The photograph of the investigated system.

Various LED light bulbs (5 W, 10 W, 15 W, 20 W and 25 W) and a halogen lamp (20 W) are applied for this study.

The discharge of battery is done via the discharge controller. Electrical characteristics of the system is extracted by using 34450A Keysight multimeter and a computer. Battery voltage V_B, load voltage V_L, battery current I_B and load current I_L are continuously recorded. After that the data are analyzed for discharge characteristics of battery and power flowing in the system.

2.1 Discharge Controller

The discharge controller is a Suoer ST-G1210 model, which operated by controlling the transistor with a pulse width modulation. If the discharged battery voltage decreases until the discharge cut-off voltage (approximately 10.5 V [10]), the discharge controller sent order to the switch sw shown in Fig. 1(a). This operation can prevent an excessive discharge, which causes the battery lifetime shortening.

2.2 LED bulbs

This system uses the LED bulbs (brand LEDSTAR). Internal circuit of a LED bulb is an LED driver circuit, which includes a full wave bridge rectifier, PT4115, the buck converter circuit and LEDs. PT4115 is a continuous conduction mode of buck converter circuit. Internal structure of PT4115 includes the power switch and high-side output current sensing circuit. The buck converter circuit will help step down voltage to LEDs [8, 9].

3. RESULTS AND DISCUSSION

3.1 The discharge characteristics via 5-W LED bulb

The discharge of battery via LED can be divided into 3 phases as follows. For the first phase, the abrupt change of the battery current occurs while the voltage is gradually dropped. This is mainly due to the intrinsic battery characteristics [11].

In the second phase, a linear discharge characteristic is observed as shown in Fig. 2(a). For our experiment, the battery voltage decreases at the rate of about 1.4 mV/min, while the current increases at approximately 39.5 □A/min. The increase of battery current is due to the fact that the LED driver circuit attempts to draw a constant power. Dissipated power calculated via the current and voltage (P_B = I_BV_B) is quite constant as shown in Fig. 2(b).

The gradually decrease of a battery voltage during the discharge state is due to the slow ionization of the electrode. Concentration of electrolyte in the battery becomes less. This results in the increment of the battery resistance. The resistance value can be obtained from the measurement data when we consider the equivalent circuit of the battery as shown in the lower right inset of Fig. 1 (a). It can be written as

$$R_B(t) = \frac{V_{B0} - V_B(t)}{I_B(t)} = \frac{0.176 + 0.0014t}{0.322 + (3.95\times10^{-5})t} \quad (1)$$

where V_{B0} is the battery voltage at no load and the value is approximately 12.8±0.05 V for our experiment.

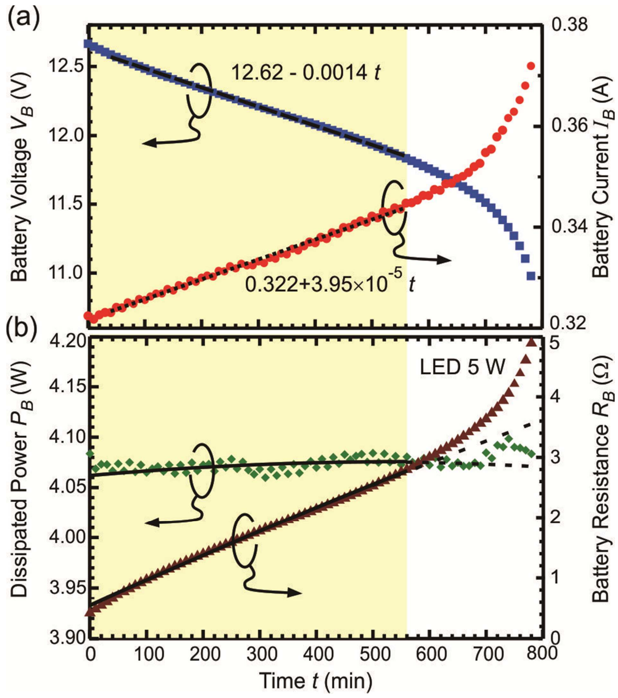

Fig. 2 (a) The battery voltage and battery current and (b) dissipated power and battery resistance during discharge of lead-acid battery via discharge controller. A 5-W LED bulb is used as a load.

In the last phase, a non-linear discharge behavior occurs. The battery can no longer supply power to the load. As observed in Fig. 2 (after ~ 560 minutes), the battery voltage decreases nonlinearly. The concentration of electrolyte decreases continuously until the lack of sulfate ions happens [12]. At this point, the resistance of the battery increases sharply. So the external battery voltage drops. In our experiment, the battery voltage decreases to 10.9 V and the discharge controller disconnects the load in order to prevent an over discharge event, which deteriorates the battery.

The lead-acid battery is discharged via discharge controller at different load sizes of LED bulb as shown in Fig. 3. The same trends of the voltage and current at different load size are observed. The battery voltage decreases while the current increases. The different sizes of the load affect the initial voltage, discharged current and discharged voltage values. If the size of the load is large, the initial discharged voltage will have a lower value. The discharging consumes more current. So the battery is empty faster. In addition, the current-voltage characteristics for each load type are shown in Fig. 3(c). At various types of 20-W light bulbs we observe the difference of discharge characteristics, which is described in the next section.

3.2 The difference of discharging characteristics between LED bulb and halogen bulb

For a direct experimental comparison between of various types of light bulb, we use LED bulbs and 20-W halogen bulb. An initial no load battery voltage is 12.8 V. The current-voltage characteristics for each light bulb type are shown in Fig. 3(c). We can be divided into 3 phases as follows.

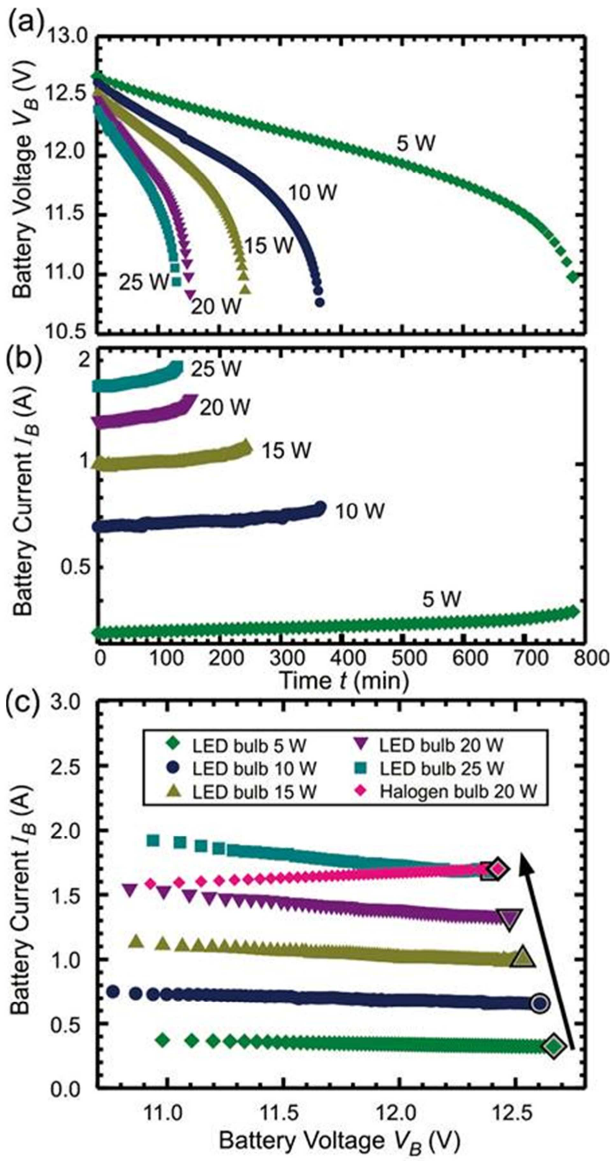

Fig. 3 (a) battery voltage and (b) battery current during discharge of a lead-acid battery at different load size of LED bulbs. (c) I-V characteristics of various types of light bulb.

In the first phase, when the load is connected in the system, the rapid changes of the battery current and voltage occur in a short time due to the load resistance. The current and voltage of LED bulb change more than halogen bulb because power electronics circuit is within LED bulb. LED bulb uses an initial current and voltage of less than the halogen bulb.

In the second phase, a linear discharge characteristic is observed as shown in Fig. 4(a). For a halogen bulb, the discharged voltage decreases linearly to approximately 7.4 mV/min while the discharged voltage of a LED bulb decreases less than approximately 6.8 mV/min. The halogen bulb typically uses more current than the LED bulb with the same consuming power rate. The battery voltage decreases faster and the discharging of battery is faster than in the case of LED bulbs. Halogen bulb shows a distinct different characteristic. Unlike the LED bulbs, when the voltage of the halogen bulb increases, the drawn current is also increased. LED driver circuit attempts to draw a constant power as shown in Fig. 4(b). The halogen bulb consumes more power at higher voltage level. Since the battery is not an ideal constant voltage source, the increment of the consuming power of the halogen bulbs is undesired. Therefore, we suggest the usage of LED bulb for a stand-alone lighting system operated by using an energy storage device.

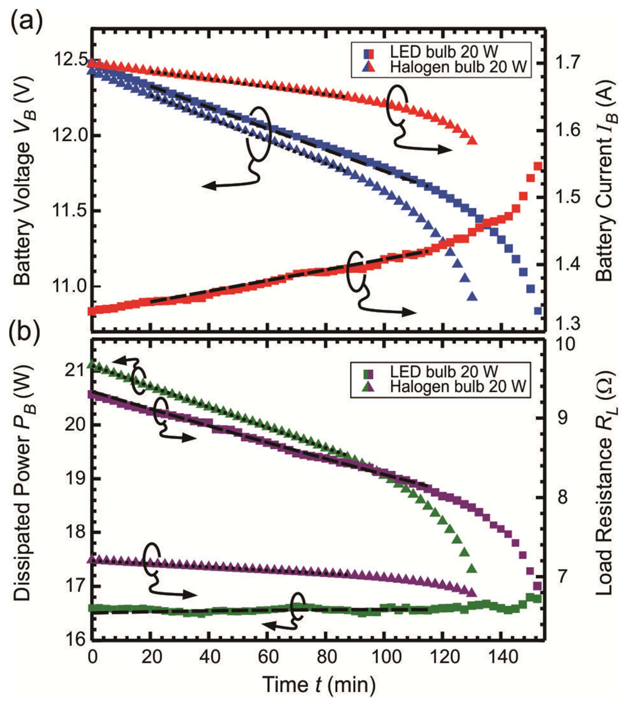

Fig. 4 (a) The battery voltage and battery current and (b) dissipated power and load resistance during discharge of lead-acid battery via discharge controller. A 20-W LED bulb and halogen bulb are used as a load.

In the final phase, a non-linear discharge behavior occurs. The battery can no longer supply power to the load. As observed the battery voltage of LED bulb and halogen bulb rapidly decreases to 10.8 V and 10.9 V respectively. Then the discharge controller disconnects the load. We observe that LED bulb can consume power from battery in a long time and LED bulb has less heat than halogen bulb. So LED has the better efficiency, saves energy cost.

3.3 The power flowing in the system

Power flowing in the investigated system is varied accordingly time, load size and load type. The calculated time-averaged power flow and loss in the investigated system are presented in the Table 1. The average efficiency of this system is approximately 96.92 %. The average loss in the discharge controller 3.08 %, which is defined as $\Delta P = P_B - P_L$ and $\eta = (P_L \div P_B)\times 100$ is observed. For an experimental comparison between different loads, we observed to the efficiency and loss of system which uses LED bulbs and halogen bulb. The efficiency and loss of system have approximately the same values.

Table 1. The calculated power flows and loss in the investigated system

	Load (W)	P_B (W)	P_L (W)	$P = P_B - P_L$ (W)	$\eta = (\frac{P_L}{P_B})\times 100$ (%)
LED Bulb	5	4.07	3.91	0.16	96.02
	10	8.20	7.98	0.23	97.26
	15	12.23	11.90	0.33	97.31
	20	16.58	16.12	0.46	97.20
	25	20.72	20.20	0.70	96.61
Halogen Bulb	20	19.72	19.16	0.56	97.15

4. CONCLUSION

In this study, an operation of stand-alone lighting system powered by a lead-acid battery is investigated Various LED and halogen bulbs are used as the load. The discharge characteristic of the battery via LED bulb is investigated and it can be divided into 3 phases. Consuming power of the LED bulb is nearly constant in a wide voltage range. The direct comparison of the electrical characteristics between LED and halogen load is performed. Advantage power consumption behaviour of LED bulbs over halogen bulb is emphasized. From this advantage, a stand-alone photovoltaic system could have better performance/efficiency when LED bulb is adapted.

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