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Development of Current Control System for Solar LED Street Light System

Byun Gon Kim[†], Kwan Woong Kim[††], Tae Su Jang[†††], Jun Myung Lee[†††] and Yong Kab Kim[*]

[†]Dept. of Electronic and Information Engineering, Kunsan National University, Korea
[††]Thunder Technology, Director in Digital Signer Processing Team, Chonju Korea
[†††]Dept. of Electrical and Information Communication Engineering, Wonkwang University, Korea
[*]Dept. of Electrical and Information Communication Engineering, Wonkwang University, Korea

Abstract

As inexhaustible clean energy, solar energy will be the most ideal green energy in the 21st century. The effective method to convert solar energy into electrical energy is by solar photovoltaic power generation technologies. LED Emitting Diode is a kind of component which can transform electricity into visible light. As the smart current control system for photovoltaic street lights, the proposed system has improved the battery charging and discharging mechanism to extend the lifespan and effectively controls the LED discharge current according to battery charge state and lighting.

Keywords: Maximum Power Point Tracking, Pulse Width Modulation, Light Emitting Diode

1. INTRODUCTION

Due to the recent times of high oil prices and global warming, greater attention has increased towards the new renewable energy enabled to replace the fossil fuel. Since the new renewable energies, such as solar rays, wind power, terrestrial heat and hydrogen energy, can be reproduced by Mother Nature, it is possible to carry out low-carbon green growth while saving the global environment.

As the independent LED street light system using solar battery, the system proposed in this study is only enabled to receive the solar energy and therefore, must be designed and operated with maximum efficiency. Thus, the goal of this study is to design a system that maintains performance and effectively controls in cold winters with the longest lighting periods, least amount of sunlight and low temperatures. For the photovoltaic LED light system to operate in effective and stable conditions, factors like effective charge/discharge, battery status management and LED discharge current control greatly influence the performance of the system.

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[†]CorrespondingAuthor:ykim@wku.ac.kr
Tel: +82-63-850-6695,Fax: +82-63-850-6074,Wonkwang Univ.
[*]Dept. Information Communication Engineering Wonkwang Univ., Korea

To effectively operate the independent photovoltaic LED street light system, the control of discharge currents must secure the limited stored current and the control to adaptively operate according to remains of battery is required to prevent early outage caused by lack of charged electricity and battery outage due to over discharge. It also must be taken into consideration that the standardized voltage current had reduced lifespan as well as caused system breakdowns. Moreover, the necessity for changes of white-colored LED lights in accordance with the surrounding environments is raised, without influencing the overall intensity and when designing the control system, accurate standards and capacities must be calculated and applied.

2. PHOTOVOLTAIC LED STREET LIGHT SYSTEM

2.1 System Configuration

Main components of our system are sensing part, control part and indicating part. The sensing part includes the PV(Photovoltaic) module to charge the battery with power produced from solar cells, battery, high-brightness LED lamp, standby and storage battery, and the main control part, which enables to adaptively control according to surrounding environment and system conditions. Moreover, the indicating part displays the system conditions as well as uses the RS-232(Recommended Standard 232) serial communication or serial to TCP/IP (Transmission Control Protocol/Internet Protocol) convertor to use the TCP/IP network in enabling to monitor the system status.

2.2 Battery Condition

The monitoring of remaining battery life in an independent photovoltaic light system is an essential factor for reliable system operation. While charging, the photovoltaic LED street light system must be controlled according to conditions of battery to prevent over-charge and over-discharge to extend the lifespan of battery and system. To control in accordance with battery conditions, calculating the SoC(State of Charge) of battery is the most important part and those information can be obtained by measuring the battery socket voltage in the charge and discharge characteristic curves of the battery. Figures 1 displays the relationship between battery voltage and SoC in discharge situations. The C/XX display currents according to the battery quantity. For example, if the battery quantity is 100 Ampere-Hours, C/20 is the charge/discharge current of 5 Amperes. Since the charge currents of the battery tend to differ according to the weather and solar rays, it is favorable to measure the SoC of the battery by using the discharge current enabled for control rather than using the charge voltage of battery.

$$S_0C_1 = \frac{Q_1}{Q_{MAX}} S_0C_2 = \frac{Q_2}{Q_{MAX}} \qquad (1)$$

$$Q_{MAX} = \frac{\Delta Q}{S_0C_1 - S_0C_2} (2)$$

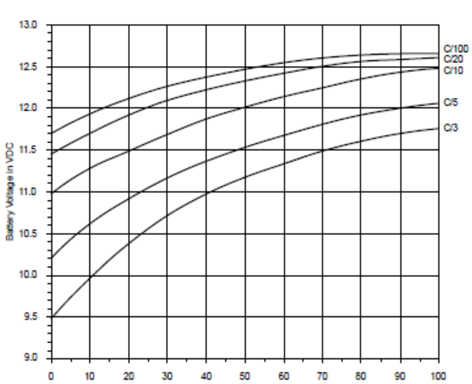

Fig. 1. Relationship between Discharge Battery Voltage and SoC

In formula(1), S_0 C_1 is the calculated value by measuring the battery voltage from the starting point of discharge in fixed current and S_0 C_2 is the calculated value by measuring the battery voltage after discharging the fixed current for fixed amount of time. In formula (2), the value of ΔQ can be calculated as discharge current x discharge time and therefore, enables to calculate Q_MAX . To minimize the effects of battery voltage by charge, the remaining battery can be calculated as follows by using Q_MAX and the battery measured voltage with passage of fixed amount of time after starting discharge

$$Q_C = S_oC_C \times Q_{MAX} (3)$$

$$R_{DAY} = (Q_C - \propto \times\, Q_{MAX})/Q_{DAY} (4)$$

In the formula stated above, Q_C is the current quantity, S_0S_C is the current, S_0C and R_{DAY} are remains, α is the discharge depth and Q_{DAY} is the daily amount of discharge. The LED discharge current is controlled according to the remains of battery as displayed in the following. Moreover, the LED discharge current is controlled differently in accordance with the discharge sections as displayed in Figure 2.

(1) Over 3 days of remains: ①③ 100% light, ② 50% light

(2)Under 3 days of remains: ①③ 100% light, ② 30% light

(3) Under 2 days of remains: ①③ 60% light, ② 30% light

(4) Under 1 day of remains: ①③ 30% light, ② 30% light

Battery over-charge is prevented in the 2-step method of lighting at 30% when the battery voltage drops below standard voltage in phase 1 and cutting off light current when the standard voltage drops again in phase 2. In such ways, battery over-charge is prevented according to S_o C and operational voltage of battery to extend the lifespan of LED street lights.

2.3 LED Discharge Current Control

LED discharge current control operates by using the PWM control. It measures the LED discharge current of the ON section to control the PWM duty proportion to create fixed currents. In this control method, the average current can be maintained by controlling the duty proportion if large amounts of currents exist in the ON section. However, if large amounts of currents flow through the LED during the short period of time, it places bad effects on the LED efficiency and therefore, the method of limiting the maximum current by using the current limiting circuit was used. If the discharge current of LED street lights are increased during hours with greater usage and decreased during hours with lesser usage, less amounts of energy can be put to effective use. The overall lighting current control method is controlled in the 3-step method by determining the section as displayed in

Figure 2. Section① displays the 6 hour period after the initial lighting when there is the most human activity, section② displays the late night period with fewer human activities and section③ displays the hour prior to sunrise with beginning of human activity.

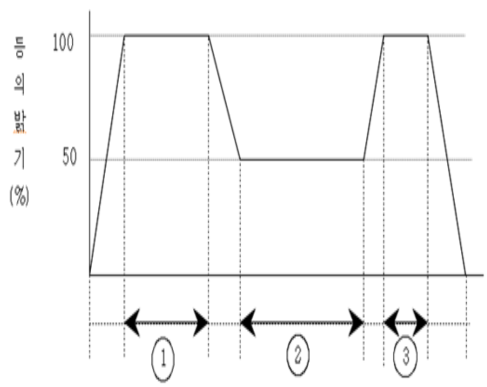

Fig. 2. Lighting Rates per Section

3. SYSTEM IMPLEMENTATION

The smart LED street light system proposed in this study is as displayed in Figure 3. In general, LED lights use driver ICs to control constant currents. However, the proposed LED street light system uses the PWM(Pulse Width Modulation) without the driver IC to control LED current control. When the LED street light output capacity is determined, the sectional time and quantity is calculated as displayed in Figure 2.

Fig. 3. Photovoltaic LED Street Light System

In winter season, the entire lighting period is 14 hours and the daily power usage is calculated based on 6 hours for section①, 7 hours for section② and 1 hour for section ③. When the daily power usage is calculated, the information is used to calculate the solar cell and battery capacities. Based on a daily 3-hour charge, the solar cell capacity must be greater than the daily power usage amount and the battery capacity must be calculated by considering the number of sunless days and discharge depths. Figure 4 and 5 show charge/discharge current trends and voltage trends respectively

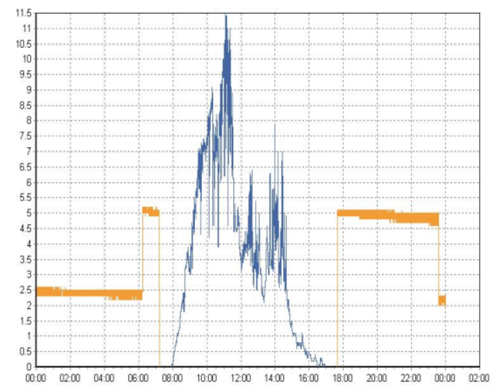

Fig. 4. Charge/Discharge Current Trends for 1 Day

Although the GPS(Global Positioning System) or RTC(Real Time Clock) could be used for turning on and off the LED street lights, the solar cell measured voltages were used in consideration of cost reduction. However, the solar cell voltage may falsely turn on the street lights during the day due to heavy clouds, shadows and snow. Such errors cause problems of reducing battery life due to over-discharge of battery in the independent systems. To prevent the occurrences of such errors, internal timers were used to measure the average time of day and night as well as determining the time for turning on and off the street lights.

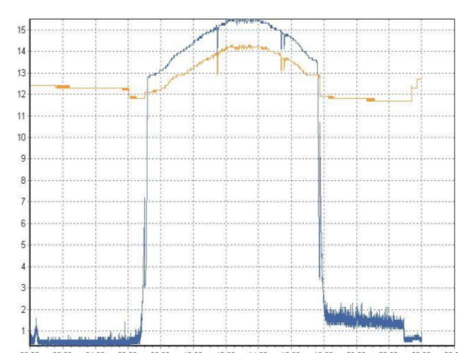

Fig. 5. Charge/Discharge Voltage Trends for 1 Day

The monitoring of LED street light systems is performed by regularly collecting and storing the solar voltage, battery voltage, discharge current, discharge current and temperature data by using serial communication from the control unit. Figure 4 displays the graph of monitoring the charge and discharge currents during 1 day period. It can be observed that the charge current is greatly influenced by the cloudy weather and the discharge current is controlled per section. Figure 5 plots the graph of monitoring the charge and discharge voltages graph for 1 day period. As the battery voltage rises while charging and falls while discharging, it can be observed that greater fall occurs during discharge. To prevent the over-discharge of battery due to this voltage drop, the LED discharge current control by operational voltage and SoC of battery was implemented.

4. CONCLUSIONS

The independent LED street light system using solar cells was designed in the present study. Such independent systems using solar cells are most vulnerable in winter seasons with lack of sunlight, cold weather and snow. To overcome such inadequate environments of winter seasons, the discharge current control was controlled in accordance with the SoC of battery. Moreover, the discharge current was controlled per section in consideration for effective use of street lights.

Future studies tasks must including enabling integrated management for status of independent photovoltaic light systems by structuring the wireless sensor network and integrated management for generation of solar module, charge capacity, battery status(voltage, temperature, exchange period, etc.), ON/OFF time for street lights and lighting current capacity by using the TCP/IP network. This network configuration will serve as the foundation for studying the "Microgrid" technology enabled for operation that is separate from the electrical grid through the calculated control of small new renewable energy and decentralized power supply system.

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Byun Gon Kim received the B.S degree in Electronic Engineering from Chonbuk National University and the M.S.E degree in Electronic Engineering from University of Chonbuk National University in Korea. He received his Ph.D degree in Korea Research Institute of Standards and Science. He is currently in Professor at Department of Electronic Engineering, Kunsan National University, Korea. His research interests are Ad-hoc networks, Wireless Sensor Networks, and Optical Burst Switching Networks.

Kwan Woong Kim received the B.S degree in Electronics Engineering and the master's degree in Chonbuk University. He received his Ph.D degree in Electronic Engineering in Chonbuk National University. He worked at Korea Atomic Energy Research Institute by senior researcher from 2009 to 2011. He is currently president of Thunder Technology. His research interests are measurement and control system, wireless communication, cyber security.

Tae Su Jang received the B.S degree in Electrical Information Communication Engineering from WonKwang University. He is currently the master's degree in Information Comm. Engineering, Wonkwang University, Korea. His research interests are LED visible communication, LED Optical signal processing and sensor design.

Jun Myung Lee received the B.S degree in Electrical Information Communication Engineering from WonKwang University. He is currently the master's course in Information Comm. Engineering, Wonkwang University, Korea. His research interests are LED display, Optical visible communication and optical signal processing.

Yong Kab Kim received the Ph.D degree in Electrical & Computer Engineering from North Carolina State University. He is currently in Professor in Dep't of Electrical and Information Comm. Engineering, Wonkwang University, Korea. He is Director in the POST-BK21 Center and LED Research Center. His research interests are remote sensing for visible communication, LED communication, optical fiber sensing, Power intelligent control, and Fuzzy sensing control.