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DESIGN AND IMPLEMENTATION OF HIGH PERFORMANCE STAND-ALONE PHOTOVOLTAIC LIGHTING SYSTEM

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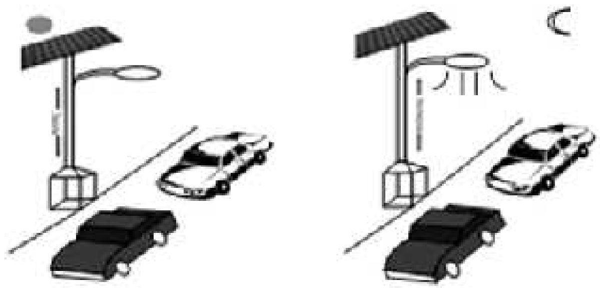
ABSTRACT

This paper presents a novel high-performance standalone photovoltaic (PV) lighting system which can provide functional illumination based on high power White LEDs. An improved incremental conductance Maximum Power Point Tracking (MPPT) method is proposed in PV system to maximize the photovoltaic array output power, irrespective of the temperature and irradiation conditions and of the load electrical characteristics. A novel strategy to charge the battery is designed from the analyses and comparison results. In order to provide a steady-state operating environment for high power White LEDs, a specially designed LED drive module is implemented. Further more, a self-adapting dimming control is designed to maintain a stable indoor illuminance. Experimental results show the performance of the proposed photovoltaic lighting system.

KEYWORDS: Photovoltaic High-Intensity-Discharge Street Lighting System, Single-Ended Primary Inductance Converter, Maximum Power Point Tracking, Battery Charging, Electronic Ballast, Power Factor Correction.

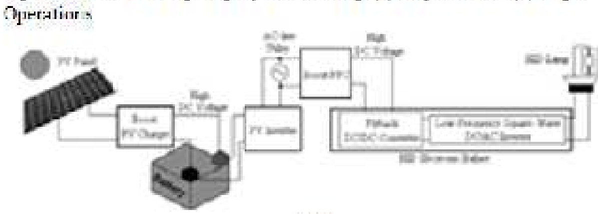
INTRODUCTION

The photovoltaic (PV) street lighting systems shown in Figure 1 have been used in many developing countries. They are highly economical when used in newly-built urban road sections and remote rural areas without an electricity network. During daytime, the battery is charged by a PV panel. At night, the solar energy stored in the battery is released to power the street lights. High-intensity-discharge (HID) lamps are commonly used as street light sources because of their high luminous efficacy, good color rendition, and long lifetime [1-3]. The HID lamp needs an auxiliary circuit called a “ballast” to ensure stable lamp operation because of its negative impedance characteristics [4]. Figure 2(a) shows the conventional PV HID street lighting system with a PV inverter that releases the solar energy in the battery to the AC-line utility. The boost maximum power point tracking (MPPT) PV charger is applied to extract maximum power from the PV panel in all solar irradiation conditions [5-10]. A boost power factor correction (PFC)circuit is series-connected with the electronic ballast to achieve high power factor input and drive the HID lamp. This PV HID street lighting system has the drawbacks of high circuit complexity and low system efficiency due to a four-stage power conversion from PV panel to the HID lamp. Figure 2(b) shows another PV HID street lighting system with a high-voltage DC bus (e.g. 400V) design. High conversion efficiency can be achieved due to only two-stage power conversion. However, the use of a high-voltage battery bank causes maintenance and safety issues. The voltage imbalance among series-connected battery stacks during charging and discharging process damages thebatteries. Figure 2(c) shows a PV HID street lighting system with a low-voltage DC bus (e. g. 24V or 48V) design. The used of a high-voltage battery bank can be avoided. However, the conversion efficiency at PFC mode is reduced due to the addition of a voltage-step-down battery charger behind of the boost PFC stage. Figure 3 shows the proposed PV HID street lighting system. With a SEPIC PFC converter, the proposed PV HID street lighting system is connected to the AC-line utility. As such, the HID street lighting system will not be extinguished even if the battery is fully discharged. High efficiency performance can be achieved due to only two-stage power conversion both at PV mode and PFC mode. A single-ended primary inductance converter (SEPIC) is also used for MPPT and battery charging under a wide range of PV panel voltage variations. A pulse-current battery charging scheme with an adaptive rest-period is proposed to avoid battery overcharging. The state of charge (SOC) is estimated to prolong battery lifetime. The solar energy stored in the battery can be released to power the HID lamp at night using the studied electronic ballast circuit. In the following sections, the system configuration and characteristic analysis will be addressed in detail.

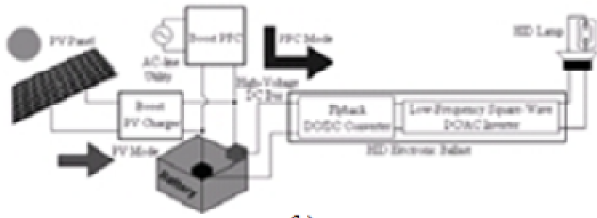


(a) (b)

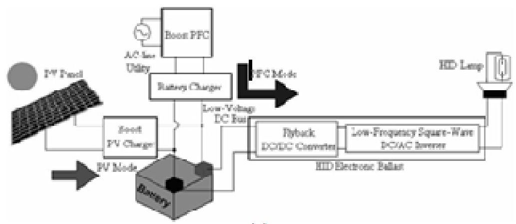
Figure 1 PV Street Lighting Systems during (a) Daytime and (b) Night Operations



(a)



(b)



(c)

Figure 2 Conventional PV HID Street Lighting Systems with (a) a PV Inverter, (b) a High-Voltage DC Bus and (c) a Low-Voltage DC Bus

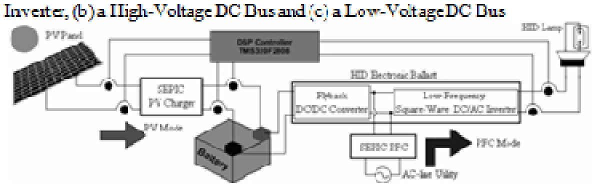


Figure 3 Proposed PV HID Street Lighting System

SEPIC MPPT PV CHARGER

Figure 4 shows the studied PV charger with MPPT function. For various solar irradiation conditions, the PV panel voltage may be higher or lesser than the battery voltage [11-16]. In this study, a SEPIC circuit is used to realize a PV charger that can both step up and step down the PV panel voltage for battery charging. Continuous input inductor current is helpful in achieving a high MPPT accuracy. According to the maximum power transferring theorem, the following relationship equation can be derived

$$R_{th} = \frac{V_{mp}}{I_{mp}} = R_{in} = R_b \frac{(1-D)^2}{D^2}, \qquad (1)$$

Where Vmp and Imp represent the PV panel voltage and PV panel current at maximum power point, respectively. The input resistance, Rin of the SEPIC circuit can be regulated by directly control the converter duty cycle D. As long as the circuit is operated at maximum power transfer condition, MPPT can be achieved.

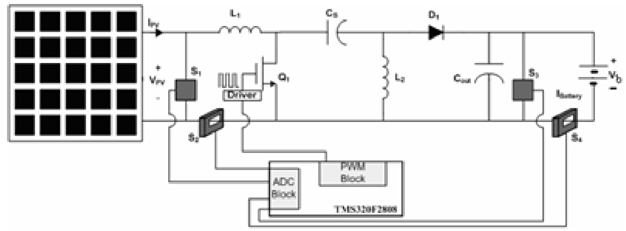


Figure 4 Circuit Diagram of the Proposed MPPT PV Charger

As shown in Figure 5, there are two charging stages for the proposed PV charger. At the beginning of the charging process, a continuous MPPT charging scheme is adopted to extract maximum power from the PV panel. At a constant solar power condition, the battery current will decrease in accordance with the increase in battery voltage. When the SOC of battery reaches a given condition, a pulse-current charging scheme with an adaptive rest-period is applied to obtain an average charging current with an exponential profile. During the charging period, the MPPT function is retained to achieve high charging efficiency. Overcharging of the battery can be avoided using the pulse-charging scheme with adaptive rest-period.

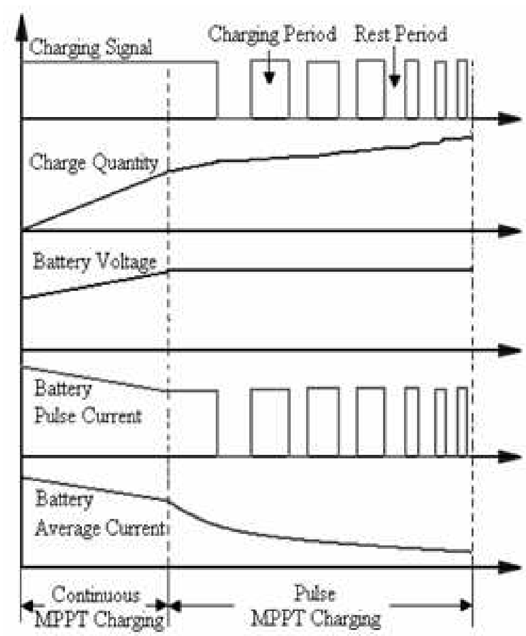


Figure 5 Theoretical Waveforms of the Proposed PV Charger

ELECTRONIC BALLAST FOR HID LAMPS

Figure 6 shows the circuit diagram of the studied electronic ballast for powering HID street-light lamps. The electronic ballast consists of a front-end Fly back DC/DC converter and a low-frequency square-wave DC/AC inverter. The front-end DC/DC converter releases the solar power stored in the battery and feeds a high-voltage DC bus for the post-stage DC/AC inverter. Periodic HID lamp excitation at a high frequency range can then lead to acoustic resonance that would produces an unstable arc and even cracks the tube. In this work, the DC/AC inverter was operated at a low frequency to avoid acoustic resonance of the HID lamps. A voltage doublers, a spark gap (S. G.), and a pulse transformer T2 were added to the power circuit. Prior to the ignition, the HID lamp can be considered an open circuit. The voltage doublers boosts the output voltage of the DC/AC inverter to reach the breakdown voltage of the spark gap.

When the spark gap turns on, the pulse transformer induces a required high voltage (about 20kV) at its secondary winding to ignite the HID lamp.

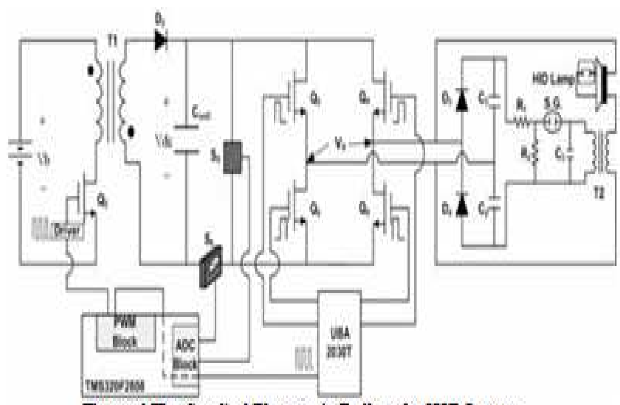


Figure 6 The Studied Electronic Ballast for HID Lamps

SEPIC PFC CONVERTER

The proposed PV HID street lighting system is connected to the AC-line utility with a SEPIC power factor correction (PFC) converter shown in Figure 7. When the battery voltage drops to a given value, the Fly back DC/DC converter is shutdown to prevent the battery from over-discharging. The SEPIC PFC circuit draws energy from the AC-line utility to drive the HID lamp via the low-frequency square-wave DC/AC inverter: thus, the HID street lighting system will not be extinguished even if the battery is fully discharged. With a coupled inductor, high input power factor can be achieved at the AC-line utility side using a simple transition-mode(TM) PFC control. The paper was mainly designed based on the base paper[17] .Some modifications were done and the modified results are shown below.

DESIGN CONSIDERATIONS

The aim of this paper is to study a high performance PV HID street lighting system[17]. The design considerations for the MPPT PV charger and the electronic ballast circuit are described and discussed below. The circuit is simulated using MATLAB and the wave forms obtained are given below wave forms led driver and output PV MPPT chargers.

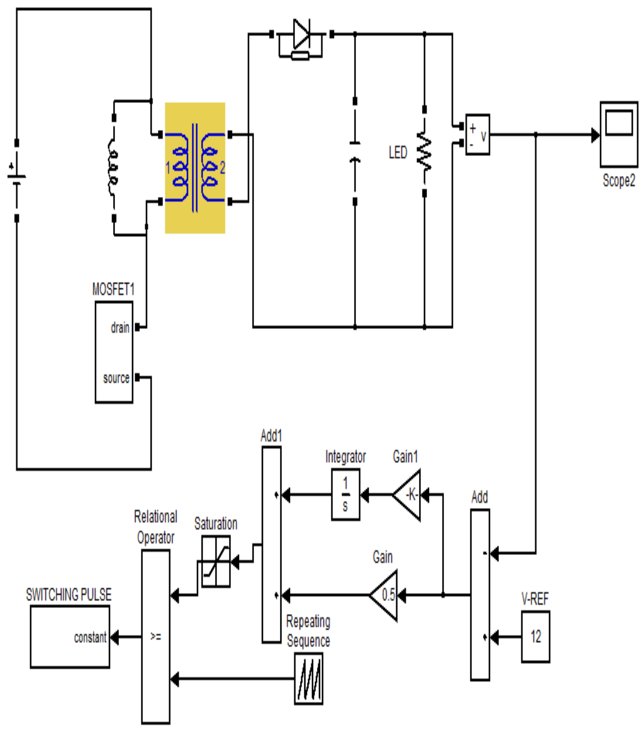


Figure 8 Leddriver

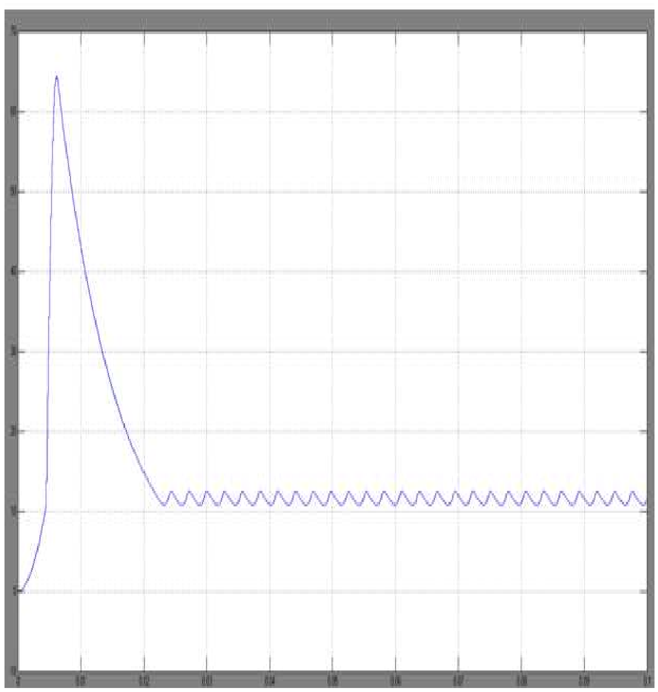


Figure 9 Led Driver Output

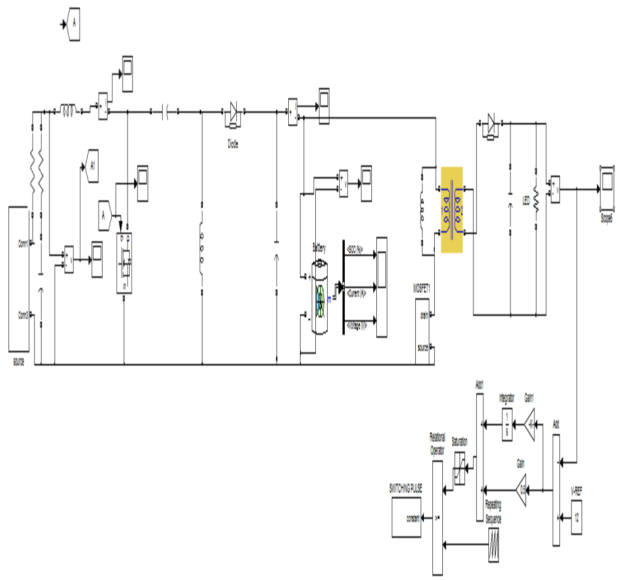


Figure 10 Pv Mppt Charger Circuit

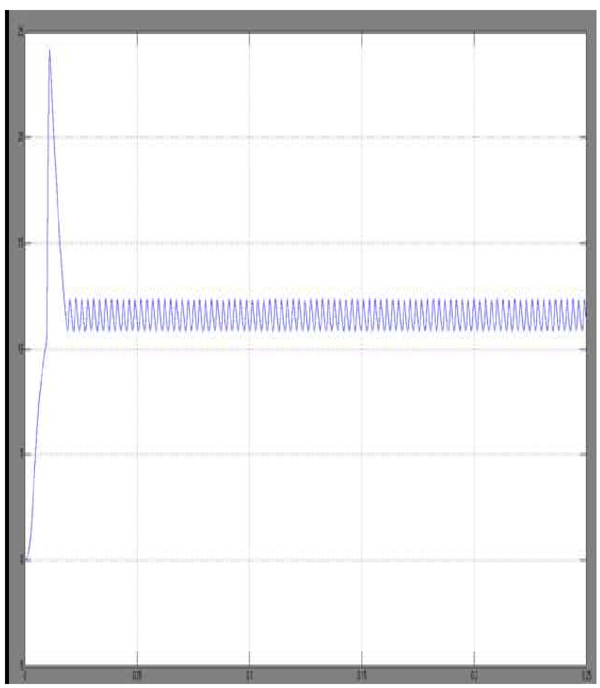


Figure 11 Pv Mppt Charger Output

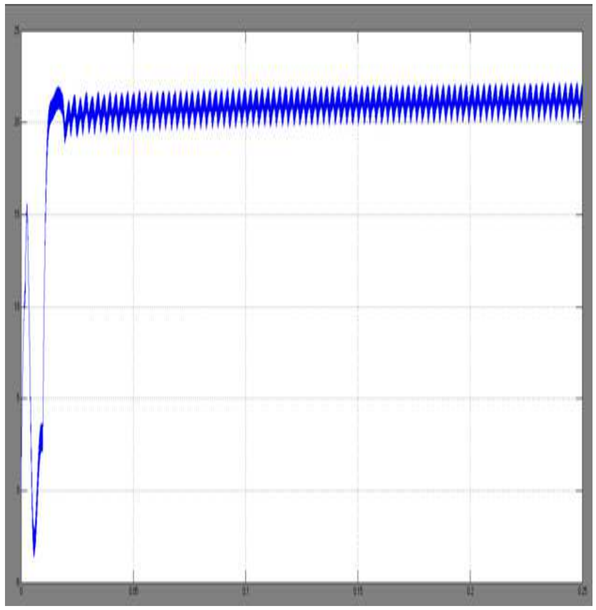


Figure 12 Pv Mppt Charger Battery Output Voltage

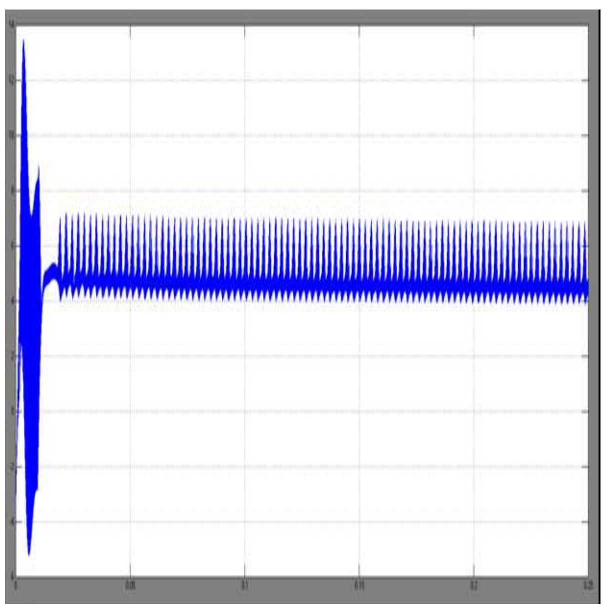


Figure 13 Pv Mppt Charger Battery Output Current

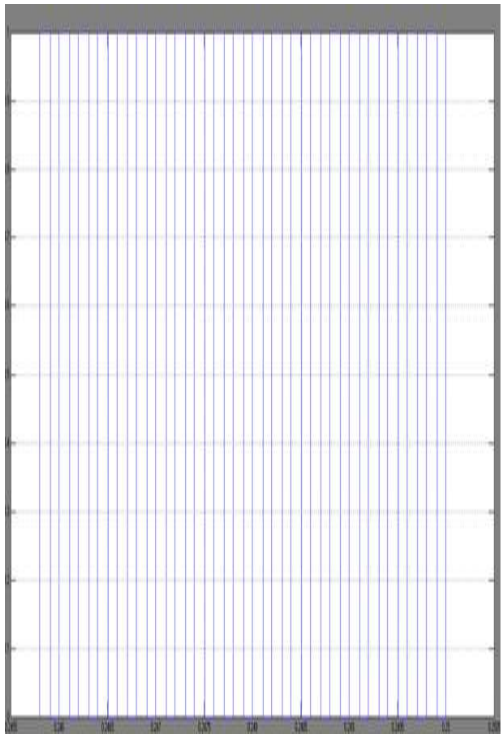


Figure 14 Pv Mppt Charger Gate Pulse For Mosfet

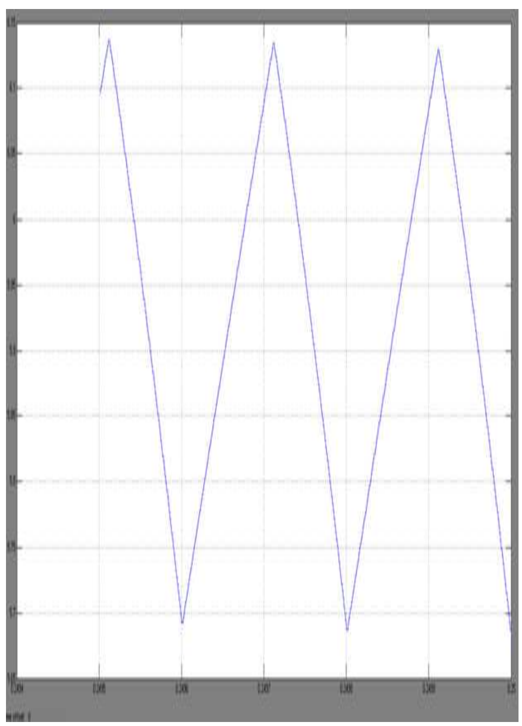


Figure 15 Pv Mppt Charger Input Current

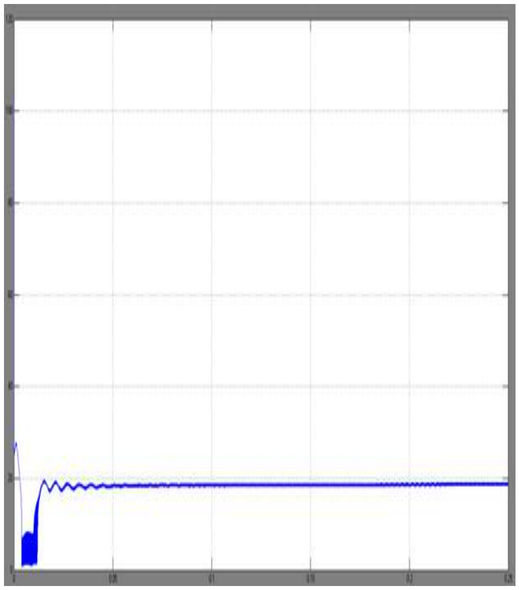


Figure 16 Pv Mppt Charger Input Voltage

CONCLUSIONS

This paper presents a PV HID street lighting system with MPPT function and pulse battery charging scheme. With the proposed SEPIC PV charger, high MPPT accuracy and high battery charging efficiency can be achieved under a wide range of PV panel voltage variation. An electronic ballast circuit was designed to release the solar energy stored in battery to power an HID lamp. A SEPIC PFC converter was also used to draw energy from the AC-line utility to prevent the battery from over-discharging. The operating principles and design considerations for the proposed PV HID street lighting system were described and analyzed in details.

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