A High Efficiency Light Emitting Diode (LED) Lighting System Driver with Photovoltaic System

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ABSTRACT

This paper presents new improvements and real result of a stand-alone photovoltaic power system for LED lighting that was developed previously. The actual system, during day, charges a lead acid battery using MPPT algorithm for power transfer optimization, and, during night, it supervises battery discharge and controls the current in the power LED array. The improvements are in hardware and software. The hardware was simplified using only one DC/DC converter and only one microcontroller making it more efficient. The system board uses an ATMEL ATTINY861V microcontroller, a single-ended primary inductance converter (SEPIC), and sensors to read input and output voltages and currents to control all system. The software improvements are made in the battery charging algorithm, battery discharging algorithm, and in current control of the power LED array adjusting the light intensity. Moreover, results are presented showing the balance of energy in a period of 24 hours: first results of the MPPT algorithm in bulk battery charge phase and then the over battery charge phase, both in a sunny day. The power LED current control results are also presented showing a very small error. It turns off at 00 : 00 at each day to reduce the waste of energy. Finally, the balance of energy is studied and presented to help the right projection of the PV power panel needed and the necessary battery capacity..

I. Introduction

The use of stand-alone photovoltaic lighting system has increased in remote rural areas and in towns. Conventional street lighting is energy intensive and can represent a high cost to local governments, which creates an impetus to investigate more efficient light sources such as photovoltaic- (PV-) powered light emitting diodes (PLEDs) lighting systems.
Photovoltaic system is gaining increased importance as a renewable source due to its advantages such as little maintenance and no noise and wear due to its absence of moving parts. But there are still two principal barriers to the generalization use of photovoltaic systems: the high installation cost and the low energy conversion efficiency.
To increase the ratio output power/cost of installation it is important that PV panel operates in its maximum power point (MPP) to absorb the maximum power possible. The combination of PV panels with power LEDs makes the called new green light sources.

Battery is the energy store element in this system. State measure and energy management are critical issues for the battery in PV LED lighting system, such as the state of charge
(SOC) [1].
(1) The fast charging capability may not be obtained because of the weather uncertainty.
(2) The charge time is limited by the sunshine time every day.

(3) Under charging usually happens to shorten the battery life since the PV panel size is limited by economy consideration.

The battery charge and discharge processes should be made correctly to enlarge its durabilitymaximizing the stored energy [2, 3]. To reduce the PV panel size it is important to maximise the power transference from PV panel to battery using some maximum power point tracker (MPPT) like the Perturbation and Observation (P&O) algorithm [4–6]. P&O algorithm is a very popular algorithm duo to its simplicity, convergent capacities, and to its low computational needs.

To create light with good yield the LED is the best option, it has been widely used and investigated having many advantages: high luminous efficiency, low environment pollution, long life, and firmness. LED lighting system supplied by batteries is one of most popular solutions to home, public lighting, vehicle, and signalizing lighting system [5–12].

Autonomous LED lighting system consists in three major parts: batteries, lighting controller module, and LED array module. Boost DC/DC converter is usually used as main circuit of the lighting controller module [5, 9]. It is not easy to control the brightness of LED lighting system, due to its nonlinearity electrical characteristics, and temperature sensitivity [5, 9]. In [9], it is refereed that constant voltage control has disadvantages relatively to constant current control. However, conventional simple constant current control strategy may cause overcurrent and overheats if the control algorithm ignores LED temperature characteristics [9].

This work proposes an intelligent, economic, and efficient system to control a stand alone photovoltaic lighting system.It presents improvements in charging algorithm, in particular in P&O algorithm, improvements in monitoring the battery discharge, and in LEDarray current control algorithm. These improvements will considerably improve the stand alone photovoltaic lighting results.

During day, the battery is charged using the photovoltaic panel energy and, during night, the power LED brightness is controlled with the PI algorithm always supervising the battery discharge energy consumption. This is the first work hat makes such a system using only one DC/DC converter, in this case, a Single Ended Primary Inductance Converter (SEPIC), reducing hardware costs. As the input voltage of the SEPIC can be higher or lower than the output voltage, this converter presents obvious design advantages [4]. The input and output modules connected to the SEPIC correctly changed using two switches controlled by the microcontroller.

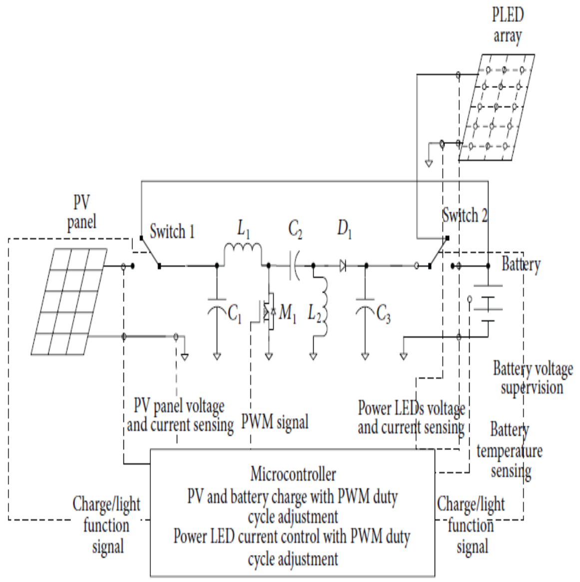

Figure 1: Stand alone photovoltaic lighting block diagram (PWM used to define the duty cycle).

II. System Architecture

The proposed PV lighting system generates energy from sunlight by PV panel during the day, and illumination load only works at night, and a battery is adopted for energy storage. The most common battery type used is the valve regulated lead-acid (VRLA), because of its low cost, maintenance-free operation, and high efficiency characteristics [4, 13]. The system also needs a long life and environmental illumination source, and high power white LED fits well this demand. Figure 1 shows the block diagram of the proposed lighting system which is composed of a PV panel, a unique DC/DC converter regulated by the electronic and microcontroller module, a VRLA battery, and a high power white LED array. The PV lighting system controller is used to achieve battery charge regulation, to execute MPPT algorithm, and to control brightness intensity. The DC/DC converter is used to interface the PV panel to the battery using the two switches (switch 1 and switch 2). The same DC/DC converter is also used to provide the power to the high power white LED array from the battery. An NTC sensor is used to measure the battery temperature that is needed to battery charge algorithm.

In PV lighting system, choosing the electronic components is very important for cost reduction, reliability, and efficiency [2, 7]. PV panel and high power white LED array are the most expensive components of the overall system, so the microcontroller board should make full use of them.

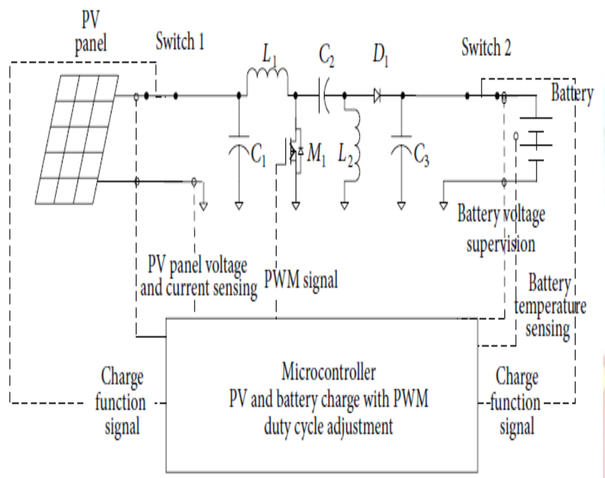

Figure 2: Photovoltaic battery charging block diagram (PWM used to define the duty cycle).

III. Energy Management System and Charging Controller

A detailed block diagram of the charge regulation module is shown in Figure 2 (similar to Figure 1 but with switches 1 and 2 connected as showed in Figure 2). The system consists of a nonlinear current source, an SEPIC, a battery, and electronics and the microcontroller board.The SEPIC is used to interface PV to battery controlling its charge.

In this system, in order to save components and to increase system efficiency, the power converter acts not only as a maximum power point tracker but also as a charger to manage the state-of-charge of the battery by regulating the charging current or voltage. In this case, control of the power converter is actually a multi objective control problem. Rather than being controlled to serve as a sole voltage or current regulator, the power converter is required to regulate and balance the power flow between the solar array and the battery under different insolation and load conditions.

3.1. Charging Control Strategy. Thecomplete battery charging demands to the controller a complex control strategy, in which it would be possible to charge the battery, between its limits, in the faster possible way since working periods of energy generation of the PV panel are limited [14]. To achieve a fast, safe, and complete battery lead-acid charging process, some of the manufacturers recommend dividing the charging process in four stages [2, 3] that are designated by: (1∘) trickle charge, (2∘) bulk charge, (3∘) over charge and (4∘) float charge illustrated in Figure 3.

3.1.1. 1∘ Stage (from T0 to T1)—Trickle Charge. This first stage appears when the battery voltage is below the value VCHGENB

This voltage value, specified for the manufacturers, shows that the battery arrives at its critical discharge capacity. In this condition the battery should receive a small charge current defined by ITC that has a typical value of $C/100$ where C is the normal battery capacity with a 10 hours charging process. This small current ITC is applied until the battery voltage reaches the value of V_{CHGENB}. This stage also avoids that some accident could happen in the case when the one battery element is in curt circuit; therefore if this really happens the battery voltage will not grow and then the battery charging process does not pass for the next stage.

3.1.2. 2∘ Stage (from T1 to T2)—Bulk Charge. After the battery voltage reaches the value VCHGENB it delivers to the battery a constant current IBULK. The IBULK is the maximum charge current that battery supports without a big water losing, and its value is specified by the manufacturers. This current is applied until the battery voltage reaches the maximum value of overcharge voltage, defined by VOC and specified by the manufacturers.

3.1.3. 3∘ Stage (from T2 to T3)—Overcharge. During this stage the control algorithm should regulate the battery voltage in the VOC so that the complete charge has been reached.When the charging current falls down to a preestablished value IOTC and the voltage stays in the value V_{OC}, the next stage will be executed.The value of I_{OCT} is around 10% of the I_{BULK}.

3.1.4. 4∘ Stage (from T3 until the End)—Float Charge. In this stage the control algorithmwill apply in the battery a constant voltage V_{FLOAT} which is a specified value by the battery manufacturers. This voltage is applied to the battery with the objective to avoid its auto-discharge. During the discharging process the battery voltage will fall down andwhen it achieves 0.9 V_{FLOAT} the control algorithm will execute again the 2◦ stage providing the I_{BULK} current. The control algorithm only returns to the 2◦ stage if the PV panel is producing energy, if not the battery will continue the discharge process that could reach a voltage below the value V_{CHGENB}; in this situation the control algorithm should restart the charging process in 1◦ stage when the PVpanel will have energy again.

In this work there are some simplifications made in the implementation of the four different charging stages of a leadacid battery. The 1◦ stage was not implemented because the discharge battery with this prototype board does not pass below V_{FLOAT} (minimum lowest security voltage specified by the battery manufacturers). In this situation the applied load is disconnected from the battery by the control algorithm to avoid reaching critical discharge. The value of V_{FLOAT} depends onor is a function of the battery temperature. The 4◦ stage was not implemented but the 3◦ stage is continued until the charge current reaches I_{STEADY} (10% of I_{BULK}) and finally the charging process is ended.When the PV panel has energy to deliver and the battery voltage is below the V_{OC} the control algorithm executes the 2◦ stage. The battery charging algorithm implemented in this work can be seen in Figure 4.

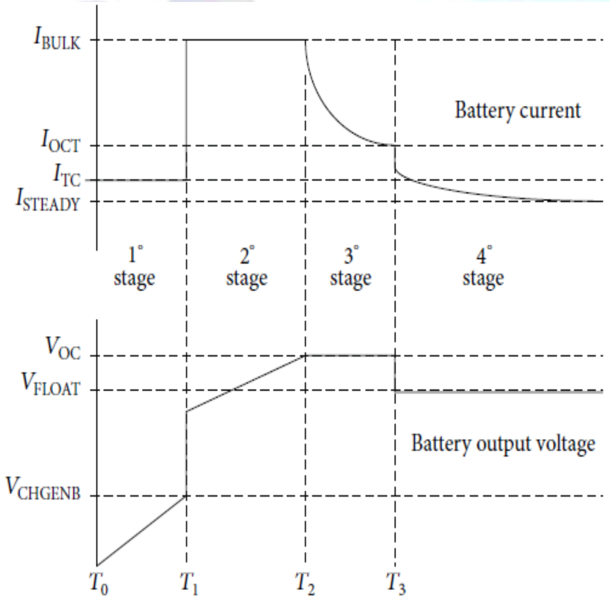

Figure 3: Current and voltage curves in the four stages of battery charging.

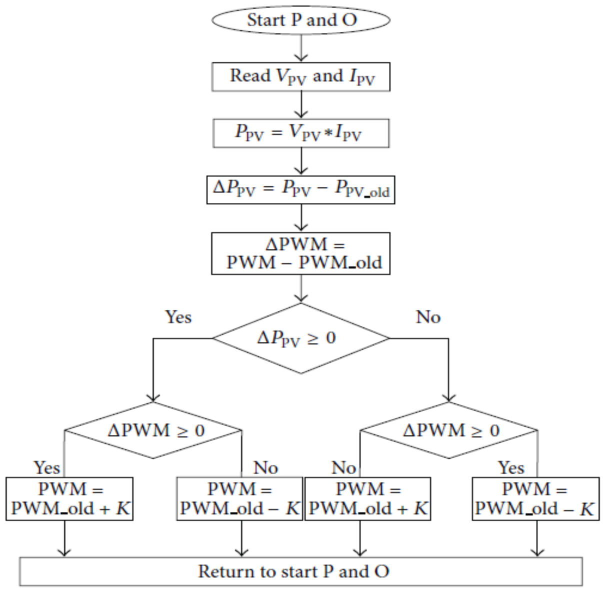

Figure 4: P&O MPPT algorithm (PWM used to define the duty cycle applied in the MOSFET gate).

IV. Simulation Results

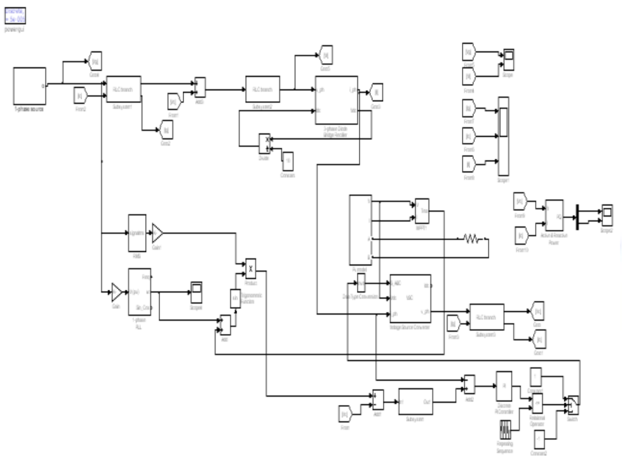

Fig 5: SIMULINK DIAGRAM

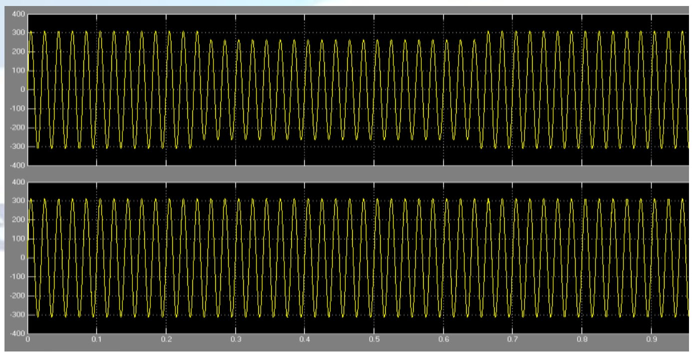

Fig 6: Model of single phase photovoltaic system

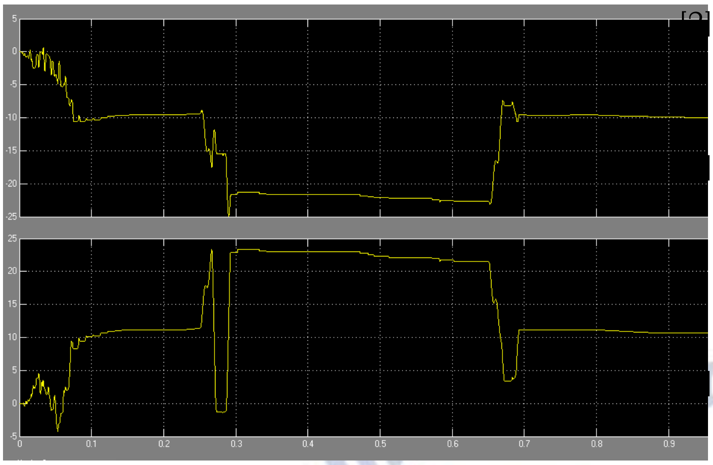

Fig 7:Active and reactive power provided by the shunt-connected multifunctional converter to compensate the voltage sag of 0.15 Pu

V. Conclusion and Future Scope

In this paper, modeling issues and design guidelines for LtL systems in which the sun irradiation is directly converted into artificial light have been discussed. The LtL system investigated in this paper is composed by a PV panel, a LED array, a dc–dc MPPT converter, and a dc–dc converter dedicated to driving the LEDs array. Using the dynamic model presented in the paper, a system matching the power extracted from the PV source and the power absorbed by the LED array, by means of a low- frequency dimming driven by a suitable controller, can been designed. A numerical example has been discussed to highlight the fundamental gain functions and related constraints to be adopted in the control system design. An experimental prototype has been designed and realized to prove the functionality of the LtL system. Experimental results obtained by means of the LtL prototype system show the correct operation and the stability of the BVC in the presence of sudden sun irradiance variations. Future evolution of this paper is aimed at a full digital integrated implementation of the MPPT, LED driver, and bulk voltage controls by means of a unique microcontroller.

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