Design and realization of LED Driver for solar street lighting applications

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Abstract

The use of white LEDs in photovoltaic standalone lighting systems requires knowledge of electrical, optical and thermal characteristics. These parameters allow us to improve and develop this type of system. Luminous intensity and life time of LEDs components are functions of the current intensity. To have stable LEDs characteristics various configurations are proposed for the Driver circuit (Direct Current “DC” mode, Pulse Width Modulation “PWM” mode). Various selection criteria are discussed such as: the simplicity of the circuit, the cost of manufacturing, energy consumption and losses (thermal and electrical) generated by this specific LED’s Driver. This study allowed us to implement a command control (DC Driver) to solar LEDs lamp based on white diodes of phosphorus GaN semiconductors. This system is applied to street lighting by means of photovoltaic standalone system. The aim of this work is to obtain a stable LEDs control command by using a minimum of electric power for operation with long service life and stable illumination.

Keywords: Standalone Photovoltaic System ;White LEDs ; LED’s Driver Solar Lamp ; Photovoltaics.

1. Introduction

Initially, LEDs were used as an electronic component to emit light at a certain wavelength and a unique color (red, green, blue, etc). The wavelength of emitted light depends on the deference between the minimum energy of the conduction band and the maximum energy from the valence band. The LEDs light intensity depends on the current passing through it in direct mode [1, 2]. Today, white LEDs (Figure 1-a) appear in the field of photovoltaic lighting technology as a promising solution. In fact, they consume...
much less than conventional incandescent bulbs and CFL (Compact Fluorescent lamps). The LEDs lighting device is characterized by the absence of components emitting electromagnetic radiation (EMI: Electromagnetic Interference) as do CFL bulbs. The LEDs luminaries are characterized by a long life time (>50000 hours), higher luminous efficiency (>80%) and an energy saving. In order to assure all of these excellent performances, we have to power LEDs components by a stable current intensity obtained from a specific Driver. In first, we proposed a DC Driver type for these LEDs devices.

However, DC control approach involves some problems to solve which are the thermal management of components heating and its low energetic efficiency. On the other hand, we could improve LEDs performances with the PWM control which uses a signal whose frequency varies between 100 and 1000 Hz to bring the LED in ON or OFF mode [1, 2]. This technique is very helpful for minimizing energy consumption and lowering operating temperature of the device and it is under development by our research group.

In this paper, we will present our study results based on DC current regulation of LEDs luminaries and which can be directly applied to solar lighting systems [3, 4]. Our designed DC driver is using a conventional electronic regulator LM317T having a TO-220 package (Figure 1-b) that has three (03) pins. Its output voltage (V_{OUT}) varies from 1.2V to 37V and has a maximum output current of 1.5A. For a well functioning of the LM317 voltage regulator, the values of (V_{IN}-V_{OUT}) must stay in the interval from 1V to 3V [5]. If all of these conditions are respected then the LM317 regulator assures that (V_{OUT} - V_{ADJ}) = 1.25V all the time. Then, in order to assure a regulation of current, we must insert a resistance (R_1) between the pin V_{OUT} and V_{ADJ}. An optional capacitor can be connected between the output and ground to give more stability to the regulator.

2. Experimental Bench for LEDs characterizations

From a homemade characterization bench shown on Figure 2, we can extract the thermal, electrical and optical parameters of a white LED diode (example: Threshold Voltage (V_{Th}), Forward Voltage (V_{F}), series resistance (R_s) and ideality factor (n)). To limit the current in the LED, we applied a protection resistor R_1 of 22 Ω value and 4W maximal admissible power. By using a digital Luxmeter of DVM1300 type we measure illumination parameters.

The DVM1300 Luxmeter is composed of a silicon photodiode with a filter. Its measurement precision is 5% and light intensities range from 0.01 to 50.000 Lux.
In this paper, we are focusing our study on electrical and optical parameters extraction and this in order to design our first DC Driver for LEDs luminaries designated to be powered by a photovoltaic standalone installation.

3. Results and discussion

3.1. Electrical and optical characterization of a single LED

The Figure 3(a) shows the characteristic result of a white LED tested by our experimental bench. Thus, we deduced a threshold voltage of 2.6V, a forward current $I_F = 350\text{mA}$ and a forward voltage $V_F = 3.02\text{V}$. The Figure 3(b) gives typical characteristics for white LEDs which are forward voltage $V_F = 3.2\text{V}$ very close to our result test. Also, we have to notice that white LEDs have a certain voltage tolerance of $\pm 15\%$ [2]. This tolerance is function of the temperature. Then, the thermal management of the LED is an important topic to study [7].

From the curve 3(a), we estimated the equivalent series resistance ($R_s$) to $1\Omega$ value. This value is in the known interval for high power white LEDs which include the values from 1 to $2\ \Omega$ [2]. For low voltage values, the influence of $R_s$ is negligible in the Shockley formula:
\[ I = I_{SAT} \exp \left( \frac{q(V - R.I)}{n.k.T} \right) - 1 \],
\[ n = \frac{q}{kT} \left( \frac{dV}{d \ln(I)} \right) \]

Based on Figure 4(a), we deduced the value of the ideality factor (n) of the diode. We founded that n=1.96 (is close to 2); this result gives us a look into the mechanism of charge transport in the white LED, which is dominated by the direct radiative recombination.

By the DVM1300, we plotted (Fig. 4(b)) the variation of the Luminous Flux (E) of illumination of the LED according to the forward current (I_{LED}). For this purpose, we have used a box of 27cm height to perform lighting measurements. A single LED is deposited inside and the luxmeter allowed us to measure at the distance of 27cm of the luminous flux through a hole in the box. The Room temperature is about 20°C during the test of LED. The illumination of a LED is a linear function of the direct current (Fig. 3(b)), the increase on the current line implies a linear increase in light intensity; however the voltage is a logarithmic function of current, so a small variation on the voltage implies a large variation in the current. So, the current control gives a good optical and thermal stability of the LED.

![Graph a) and b) showing the variation of Luminous Flux (E) with LED Current (I_{LED}).](image)

3.2. Design and realization of a DC Driver for LEDs luminaries

To perform the installation command is taken as parameters of the diode (I_F = 0.350 mA, V_F = 3.2V, n = 1.96), the lamp has 20 white LEDs arranged in four (04) strings of LEDs each LEDs string contains seven (05) LEDs, the LEDs Printed Circuit Board is placed on a Heat sink in order to stimulate heat evacuation. Figure 6 shows the electrical assembly of developed DC Driver.

![Assembly of developed DC Driver](image)
A resistance $R_1$ is positioned between the $V_{OUT}$ and $V_{ADJ}$ pins whose value depends on the output current, the tension between these two branches is always equal to 1.25V, the role of the capacitors $C_1$ and $C_2$ is to ensure the stability of the regulator, a protection diode ($D_p$) is placed at the input of the regulator $V_{IN}$ and a second one ($D_1$) to assure a non-return current is placed between the $V_{OUT}$ pin and $V_{IN}$.

Fig. 6. (a) Electrical circuit of realized DC Driver; (b) Layout design of DC Driver (Orcad simulator);

As indicated here below, we calculated the maximal of number LEDs by string ($N_{max}$) that can support our developed DC Driver. On the other side, we checked by PSpice simulator the effectiveness of regulation when we have 5 LEDs by string and a total number of 4 strings.

Indeed, the condition to obtain regulation with LM317T integrated circuit [5] is $V_{IN} - V_{OUT} > 3$ V, thus:

\[ V_{OUT} - V_{ADJ} = 1.25V \]  

if we apply $R_1=1\Omega$, then we obtain $I_{LEDs} = 1.25A$

\[ V_{OUT} = V_{LEDs} + R_1 I_{LEDs} \]

\[ V_{IN} > 3V + (V_{LEDs} + R_1 I_{LEDs}) \]

\[ V_{LEDs} < V_{IN} - R_1 I_{LEDs} - 3V \]

If we assume $V_{IN}=22V$ (case of 2 discharged solar batteries of 12V in series); then,

\[ V_{LEDs} < 17.75V \]

With $V_F = 3.2V$, $N_{max} < 17.75/3.2=5.55$. We deduce $N_{max} = 5$.

Consequently, our light fixture consisting of 20 LEDs divided into 4 parallel branches each branch containing 5 LEDs in series can be easily commanded by our developed DC Driver. On the other side, we checked by PSpice simulator the effectiveness of current regulation when we have 5 LEDs by string and a total number of 4 strings (Figure 7(a, b)). Thus, as $N = 5$ (Number of LEDs in series by string) and $V_F=3.2V$ the current regulation could starts for $V_{sup} > V_{LEDs} + R_1 I_{LEDs} + 3V = 20.25V$. This result is in good concordance with Pspice simulation (See Fig. 7(b)).
This first approach for design of an economic DC Driver destined to LEDs lighting is interesting from point of view of cost and development times. On the other side, we are optimising this DC Driver for thermal management of LM317 regulator and LEDs component for assuring a good reliability of the final system. The future step for our research group is the development of PWM regulators [8] to reduce energy consumption and extend life time of LEDs lighting devices.

4. Conclusion

This study has enabled to set an experimental bench allowing to extract the parameters of a high power white LEDs. Then, a simple design for a current DC regulator is proposed. This DC driver has been tested and has given a good regulation for luminaries composed of 20 LEDs. These experimental results for regulation of current are in agreement with Pspice simulation. In perspective, this experimental design and study will allow the development of a new driver with PWM technique. The LEDs luminaries are a very promising technology for future development and deployment of photovoltaic lighting applications.

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