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Optimization of the electronic Driver and thermal management of LEDs lighting powered by solar PV

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Abstract

The developments of efficient photovoltaic (PV) standalone systems requires advanced technology for PV cells and modules for high performance but also the application of components or loads of use with low energy consumption. In this context, the development of lighting systems using solar energy and electroluminescent components like high power white Light Emitting Diodes (LEDs) is proposed. The integration of the light fixture with the choice of best technologies for high efficiency LEDs and the design of an ultra-economic driver as the PWM driver permit us to obtain a high lighting efficiency. Our study has taken in consideration thermal aspect and the choice of adequate heat sinks for thermal management. This study, allowed us to consider both effects of thermal and electronic order and allowed us to the achievement of a high efficiency lighting powered by solar energy. With the implementation of the PWM electronic controls, we should reach an energy efficiency of the LEDs Driver from 85 to 90%.

Keywords: Photovoltaic, standalone PV systems, Light Emitting Diodes (LEDs), PWM Driver, heat sink

1. Introduction

The high power white Light Emitting Diodes (LEDs) are a new generation of lighting components that has high energy efficiency and lifetime [1]. The LEDs components are becoming the best solution choice to street and public lighting situations when they are powered by photovoltaic energy [2]. The use of LEDs components assure saving of energy. However, thermal management and electronic control components of these LEDs are important for the stabilization of their performance [3]. In this study we present our simulation and experimental results to show the effect of temperature on the performance of

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the LEDs and confirm the need to supply the LEDs fixture with a heat sink. Following this, we calculated the thermal resistance of the fixture to determine the required area of the heat sink for good thermal dissipation.

The thermal aspect is crucial for power LEDs used in white light illumination. Indeed, since they generate a certain amount of heat generated at their backside, this heat must be dissipated through adequate heat sinks. In our study, we have demonstrated the effect of temperature on the performance of LEDs. Then, we calculated the thermal resistance of the fixture and the area of the heat sink. To obtain this result, we started first, by a single LED (1watt), then after we obtain the total thermal resistance and the total area of the heat sink adapted to a light fixture consisting of 28 LEDs (28 X 1watt).

2. Electronic drivers design effect on LEDs temperature

To investigate the effect of electronic drivers' types and the temperature on LED working, we conducted two types of design: the first driver design type is Direct Current (DC) while the second type is Pulse Width Modulation (PWM). The temperature variation results are shown on curves reported in Fig 1 (a), the black curve represents the result obtained by using the DC driver with the LM317 integrated circuit (IC) and the red curve represents the result obtained by using the PWM driver with NE555 IC. The latter circuit drives the LED at a frequency of 455HZ and a duty cycle of 90%.

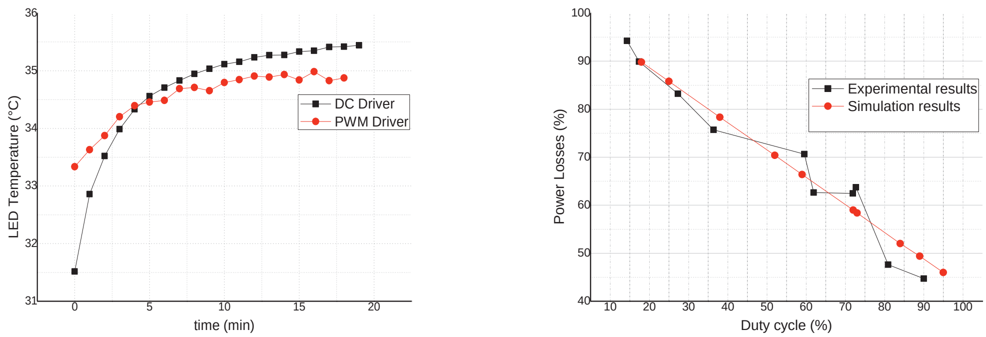
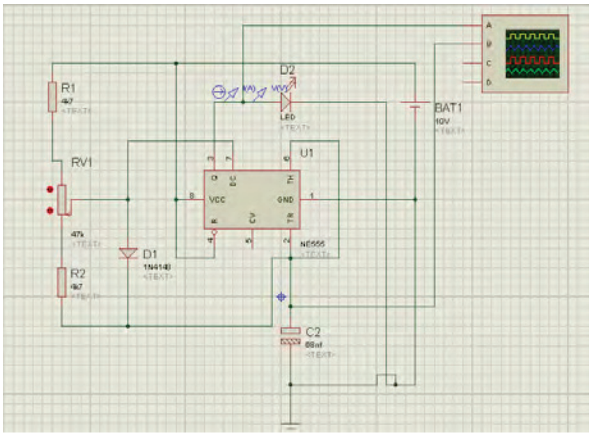


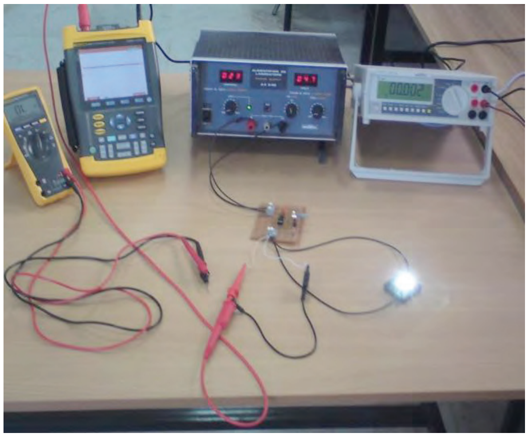
Fig. 1: (a)Temperature variation of LED package as function of time in the case of drivers PWM (NE555) and DC (LM317); (b)Power losses in tow cases of drivers (PWM and DC)

According to our results we saw that the DC control causes an increase in temperature greater than that caused by the PWM control. This has the effect of increasing the power losses and reducing the life time of the LED. Therefore, the PWM control is more favorable in terms of energy saving and heat dissipation than DC control.

PWM technique allows the LEDs to provide much less heat than analog. On the other hand, digital (PWM) signals are less susceptible to interference than analog (DC) signals and are therefore more robust. The main interest of the PWM technique is to limit the heating of electronic components. In fact, analog control, for a change in power must dissipate the additional maximum power consumption. In PWM, the power supplied is either maximum or zero. When maximum for a quarter of the time it does not need to dissipate residual heat. When zero, it does not need to dissipate more power not because it is not provided at all. This means that the LED keeps its performance and extends over its lifetime.



(a)



(b)

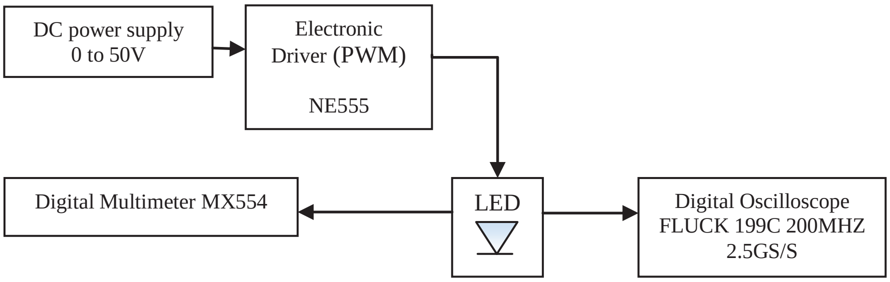


Fig. 2: (a) Driver circuit for PWM mode; (b)Experimental test of electronic drivers for a single LED; (c)Shematic of Electrical characterization of LED driver

In our previous study [4] we have done design and realization of DC driver for LED lighting devices. From this study we have shown experimentally by electrical measurement that this type of driver conducts to power losses of 59% which is very high. Then, we have done Electronic Design and test of PWM Driver circuit for a single LED to study power losses and main characteristics of LEDs working. Fig 2 (a), (b) and (c) show the designed circuit and its electrical test on LED. The simulated circuit by Protheus software has given very close results to our experimental measurements. On Fig 01 (b) we can see the estimated losses as function of duty cycle. Then we can conclude that we can reach a high performance and low power losses.

3. Thermal design of LEDs lighting fixtures

The successful thermal management of a lighting system using high-power LEDs is related to some design rules which are:

- ✓ Minimizing the amount of heat that must be evacuated. Also, it is important to separate the control circuits of the LEDs and output (LEDs PCB) so that the heat generated by the driver will not contribute to the increase in junction temperature of the LED.

- ✓ The decrease in ambient temperature inside the fixture by maintaining the flow path of air for cooling by natural convection.

- ✓ Improving the thermal conductivity between the heat sink and the LED is very beneficial for thermal management. Although the heat dissipation capacity depends on the conduction between heat sink and LEDs components. For this purpose, a special thermal glue is applied.

- ✓ The orientation of the heat sink / LED should be considered carefully. It is important to place the edge of the LED on heat sink so that the plane is vertical. If the plan is horizontal, it will block the formation of air currents and significantly reduces the potential for system cooling.

The thermal resistance of LED is essentially the addition of thermal resistances induced by the interfaces between the various elements that constitute it. The latter being in series, we add value to determine the total thermal resistance. The LEDs are mounted on heat sinks to facilitate the evacuation of heat from the junction. The thermal resistance between junction and ambient air is the sum of three thermal resistances:

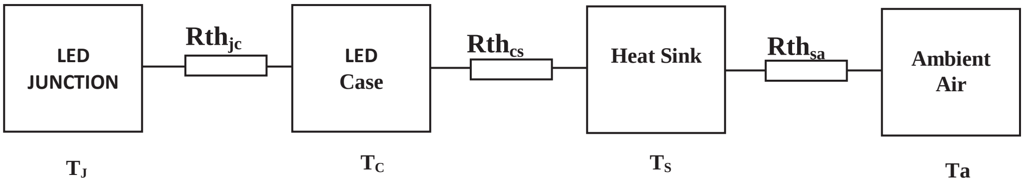


Fig. 03: Schematic of thermal resistances LED Junction / Air

Rth_{jc} : Thermal resistance junction/case (given by manufacturer of LED on data sheet),
Rth_{cs}: Thermal resistance case/Heat Sink (depends on assembly condition/experimentally determined)
Rth_{sa} : Thermal resistance Heat Sink /Air (given by Heat Sink constructor).

$$Rth = Rth_{jc} + Rth_{cs} + Rth_{sa} \quad (1)$$
$$R_{th\ j\text{-}c} = (T_j - T_c)/P \quad (2)$$
$$R_{th\ c\text{-}s} = (T_c - T_s)/P \quad (3)$$
$$R_{th\ s\text{-}a} = (T_s - T_a)/P \quad (4)$$

P is the power dissipated by the LED component.

4. Experimental

We have realized an experimental bench for testing LEDs and its schematic view is given by Fig 4. The Fig 5 represents the picture of our realized test bench for LEDs. It consists of a metallic box of $35X35X45cm^3$ sizes; its inner surface is covered by a sheet of glass wool in order to ensure thermal insulation. For the temperature measurement we connected k-type thermocouples to a Data logger. We attached on the top of the test box a Luxmeter to measure the light intensity. An adjustable DC power is joined to assure DC Voltage supply from 0 to 50V to the electronic driver (DC or PWM) of the LEDs. A digital multimeter is provided to measure current and voltage. Finally, the high power LED to test is positioned in the bottom of test box. The distance between the Luxmeter and LED is 36cm.

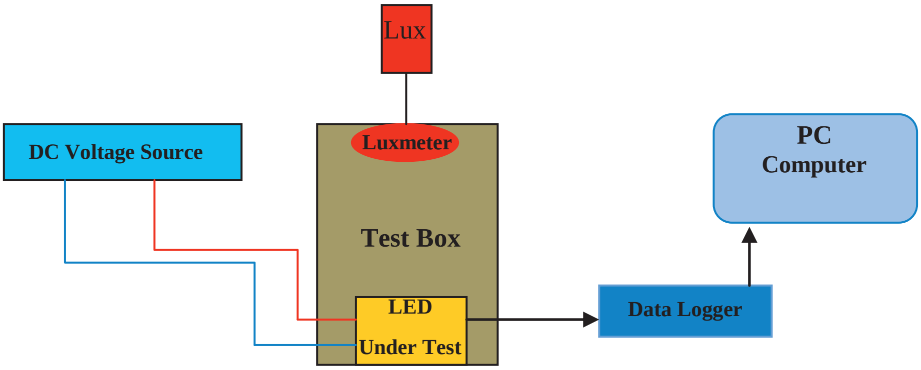
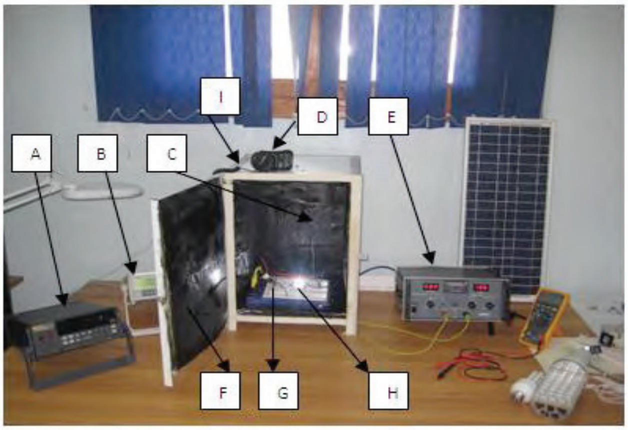


Fig. 4: Schematic representation of homemade experimental bench for LED optoelectronic and thermal testing



A) Data logger Hydra Fluke- B) Digital Multimeter- C) Thermocouple of k type- D) Digital Luxmeter-
E) Adjustable DC power supply 0 to 50V- F) Thermal Insulator, I) Metallic Box, H) High power white LED

Fig. 5: Picture of our homemade experimental bench for LEDs testing

5. Results and Discussion

We started the series of LED testing by a single LED of 1W power mounted on Metal Printed Circuit Board (MPCB) without a heat sink as picture represented on Fig 6. For each time during the LED test we make acquisition of current, voltage, temperatures (LEDs case and ambient) and the light intensity. These results are reported on Table 1.

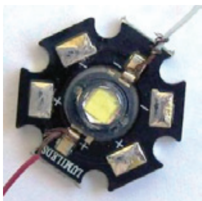


Fig. 6: Picture of high power white LED (1watt) without Heat Sink

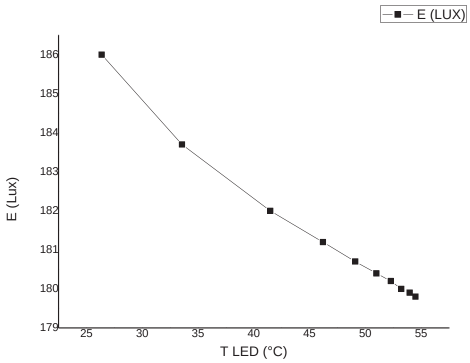
Table 1: Test results of LEDs (1watt) attached to MCPCB without heat sink

time (min)	T_{LED} (°c)	V_{LED} (V)	I(mA)	E(lux)	T amb(°c)
0	26,3715	3.075928	335	186	25,3976
1	33,5735	3,06284	340	183.7	25,4382
2	41,4835	3,02048	343	182	26,4716
3	46,2055	2,99903	345	181.2	26,5209
4	49,111	2,98738	346	180.7	26,6054
5	50,9981	2,97997	347	180.4	26,4513
6	52,2889	2,9752	348	180.2	26,7883
7	53,2252	2,97202	348	180	26,8878
8	53,9844	2,96911	348	179.9	27,1928

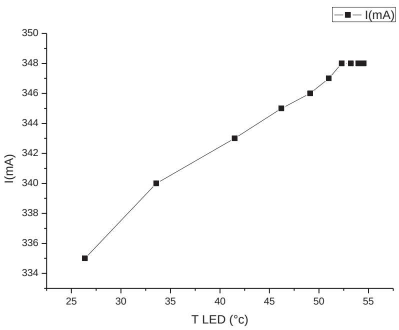
Using the curve of voltage versus temperature (see Fig 7) we deduced the temperature coefficient of voltage of the tested LED. The tested LED is a “Cree Xlamp7090" type. Then, the temperature coefficient of voltage is given by (5):

$$a= \frac{\Delta V_{LED}}{\Delta T_{LED}} \quad (5)$$

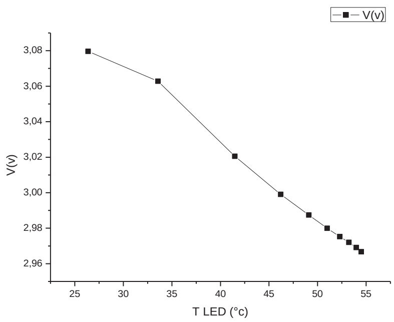
Then, we find a= - 4.5 mV / °C



a) Light intensity function of temperature



b) LED forward current function of temperature



c) LED forward voltage function of temperature

Fig 7: Temperature effect on characteristics of LED without heat sink (a);(b);(c)

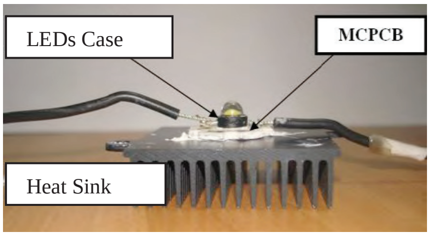
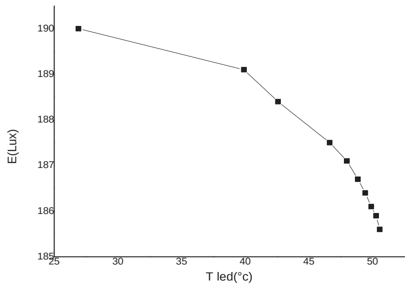


Fig. 8: High Power White LED (1watt) attached to a Heat Sink

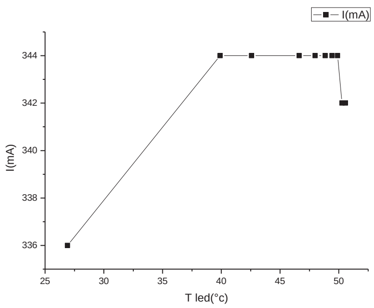
In the second step of LED testing we have attached the MCPCB LED on a heat sink (see Fig 8) and repeated the same test procedure and measurements as previously. Then we obtained results of table 2.

Table 2: Test results of LEDs (1watt) attached to MCPCB with a heat sink

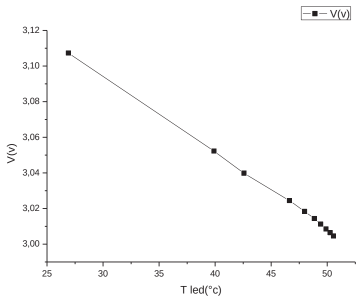
time (min)	T_{LED} (°c)	V_{LED} (V)	I(mA)	E(lux)	T amb(°c)
0	26,9066	3,10732	336	190	26,8458
5	39,8964	3,05225	344	189,1	31,169
10	42,5737	3,0398	344	188,4	33,4975
15	46,6294	3,02445	344	187,5	34,5728
20	47,9813	3,01836	344	187,1	35,2488
25	48,8412	3,01439	344	186,7	35,6918
30	49,4253	3,01121	343	186,4	36,0586
35	49,8877	3,00856	343	186,1	36,3433
40	50,271	3,00644	342	185,9	36,5885
45	50,5525	3,00459	342	185,6	36,7714



a) Variation of LED light intensity with temperature



b) Variation of LED forward current with temperature



c) Variation of LED forward voltage with temperature

Fig. 9: Temperature effects on characteristics of LED having a heat sink, (a);(b);(c)

From curves of Fig 9 we deduced the new value of temperature coefficient of voltage when LED is attached to a heat sink. Therefore, the temperature coefficient of voltage is given by the previous formula (5):

Then, we obtain: a= - 4 mV/°C

That implies whenever the temperature rises by 1°C LED loses 4 mV. This value is lower to previous one when there isn't a heat sink. Indeed, the heat sink allows better evacuation of dissipated heat and then the temperature coefficient of voltage decreases.

After determining the thermal resistance Rth of the heat sink for a single LED 1watt, we calculate it for lighting fixture having 28 LEDs organized in 4 strings of 7 LEDs, with the following method:

$$P_{LED}= V_{LED} \,.\, I_{LED}.\,(1+\text{Tolerance coefficient}) \quad (6)$$

The nominal current and voltage for the applied LED device are I_{LED} = 0.35 A and V_{LED}=3.2 V. We have considered a 20% Tolerance coefficient=0.2; Thus P_{LED}=1.34W. Therefore, we deduce the total power P_{total} of 28 LEDs lighting fixture, P_{total} = 37.52 W.

The given data to size the heat sink is the maximal ambient temperature for functioning the designed LED fixture which is Ta = 50°C.

Other data are given on data sheet of LED manufacturer which are: maximal junction temperature is T_j = 125°C and $R_{th\ j\text{-}c}$=8°C/W. Meanwhile, tow parameters $Rth_{c\text{-}s}$ and $R_{thermal\ interface}$ have been calculated from our experimental results and conditions. Then, we obtained $R_{thc\text{-}s}$=4°C/W and $R_{thermal\ interface}$=0.7°C/W.

$$R_{th\ j\text{-}s}\ \text{totale} = (R_{th\ j\text{-}c} + R_{th\ c\text{-}s} + R_{thermal\ interface}) / 28 \quad (7)$$

$$R_{th\ s\text{-}a} = (T_j - T_a)/P_{total} - ((R_{th\ j\text{-}c} + R_{th\ c\text{-}s} + R_{thermal\ interface})/28) \quad (8)$$

Then, we find $R_{th\ s\text{-}a}$ =2.2C°/W

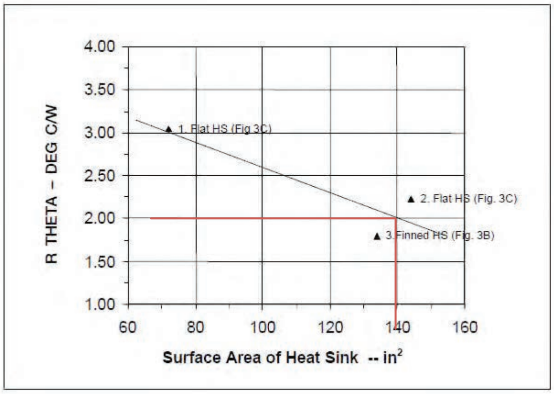


Fig. 10: Curve of thermal resistance as a function of the surface [6].

With the curve of Fig 10, we can easily deduce the required surface for Heat sink. Then, we find the heat sink area = 838.7 cm^2. The value of the required surface of the radiator is equal to 838.7 cm^2. In reality, our LED fixture light is equipped with a heat sink much smaller in occupied surface (247.5 cm^2) than we calculate. Because, our applied heat sink has a specific geometry of arborescence tree (see Fig. 11), the shape of the fins is mounted so to increase the total area and the heat will dissipate easily.

Fig 11: Heat sink of tree arborescence forma

Other solutions for cooling LEDs were considered. As a heat pipe [5] component which is in the form of a sealed chamber containing a fluid in equilibrium with its vapor and liquid phase in the absence of any other gas. At one end of the heat pipe, one near the element to be cooled, the liquid heats up and vaporizes by storing energy from the heat emitted by this element. This gas then diffuses into the heat pipe to the level of a heat sink (or other cooling system) where it is cooled until it condenses to become liquid again, and give energy to the surrounding air as heat. When properly sized, heat pipes offer a much higher thermal conductivity than the base metals (copper and aluminum), which makes them superior to the simple conduction. In some favorable cases, they can be applied without ventilation.

6. Conclusion

By this experimental study, we have shown the effect of temperature on the performance of the LEDs lighting devices and we have calculated the thermal resistances of the LED and determined the needed total area for heat sink adapted to 28 LEDs lighting fixture and we have proposed other ways to cool LEDs.

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