Design and experimental test of an MPPT using an adjustable output buck-converter battery charger

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***Abstract* - In this paper, it is proposed a simple maximum power point tracking (MPPT) control algorithm for applications that harvest power using small Photovoltaic Solar (PV) panels. It is also described an experimental setup for adjusting and testing the MPPT by combining the microcontroller Atmega32u4 present in the Arduino board, together with a battery charger IC, such as the MAX1640 (from Maxim Integrated) used in the present paper. Results of the MPPT charging algorithm using real conditions are provided. The overall MPPT performance found shows a charging profile very close to a reference constant optimized charge curve. This paper presents an approach to develop a battery charger to be used in Solar Powered products, such as Solar Street Lights.**

I.Introduction

During the last decade great advances have been accomplished in battery technologies that allow for the development of products that live out of grid running standalone. One of those emerging products are Solar LED street lights. They provide a great way to illuminate streets which don´t have electrical grid installed, especially in underdeveloped countries. Although, several different MPPT solutions have been developed and characterized [1], this paper provides a different MPPT approach and a method for experimentally testing it.

A maximum power point tracking (MPPT) is an algorithm implemented in photovoltaic (PV) controllers to continuously adjust the impedance seen by the solar array to keep the PV system operating at, or close to, the max power point (MPPT) of the PV panel under varying conditions, such as changing solar irradiance, temperature, and load [2].

Several MPPT methods have emerged, such as the constant voltage tracking (CVT), perturbation and observation (P&O), or incremental conductance algorithms, among others. This paper proposes a MPPT algorithm which derives from the P&O approximation with the separate adjustment of the photovoltaic (PV) panel voltage due to temperature changes. The aim of the development follows what has been pointed out in [3]: that in stand-alone systems, simple but more reliable MPPT methods are normally chosen, thereby excluding more efficient, but also more complicated methods.

II. MPPT Method

MPPT algorithms developed, like those in ([4], [5], [6]), measure both PV current and voltage constantly, as inputs, to predict the instant position of the maximum power point (MPP). In the present work, a simpler MPPT was developed (depicted in the Fig. 1), that only uses the PV panel voltage to predict the position of the MPP. The sun light increases the PV panel temperature which in turn decreases its MPP optimal voltage, reducing efficiency [7]. It was proposed that the oscillations of power around MPPT are mainly affected by the sun light intensity changes rather than temperature changes, which take longer to affect the MPP voltage. So, the MPPT algorithm proposed here derives from the Perturb and Observe (P&O) approximation, introducing the slower temperature influence aforementioned. It still can be consider an online method described by Reza Reisi et al. [1], which has the main advantage that no information on the panel I-V curve regarding irradiation or temperature levels is required previously.

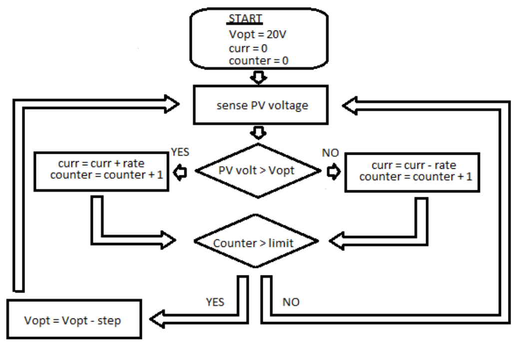

Fig. 1. Flow chart of the proposed MPPT algorithm.

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The algorithm starts with a fixed optimal solar voltage (Vopt) slightly lower than the open circuit voltage (OCV) of the PV. Then the current is increased, and the PV panel voltage is measured. If PV panel voltage is higher than the defined Vopt, it increases charging current, otherwise if the PV voltage is lower than the Vopt, it decreases the charging current. The new approximation comes with the separate rate imposed for the change of the Vopt. By tuning the limit parameter one can adjust how fast it changes with the increase of the temperature and by the step parameter one can tune how much it drops. Although not depicted in the Fig. 1, every time the PV panel voltage drops abruptly, which means too much of charging current is being drawn for the PV, the Vopt is increased by the step parameter and the counter is restarted to assure a cycling behaviour of the MPPT.

III.Experimental setup

MPPT methods can be tested experimentally like in [8], [9] or by the aid of computer simulations [10], [11], [12], although sometimes both kinds of procedures are combined [13], [14]. Experimental comparison of MPPT was chosen to show a more realistic view of the algorithm performance, but it should be mentioned that simulations have some important advantages in terms of fast results, lower cost, and higher versatility.

As an example of a solar powered product, in Fig. 2, a Solar LED street light controller diagram is shown, detailing how the different parts can be connected with each other in the same controller board.

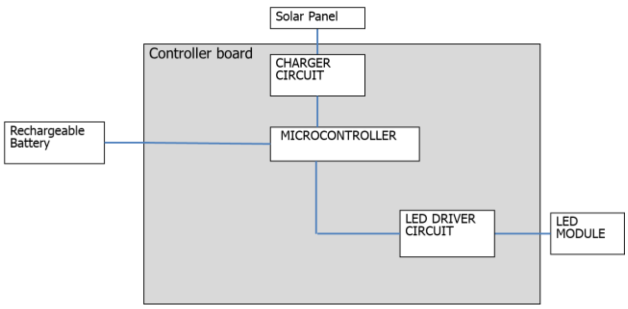

Fig. 2. Block diagram of the solar street light controller board.

For the MPPT application, the fundamental electronic circuits needed are the battery charger (DC-DC converter) and the microcontroller unit (MCU).

Several battery charger circuits, found in the market, are designed to operate in a buck-converter topology in order to charge the batteries efficiently. However, most of them are designed to work with constant power sources, such as DC constant voltage power supplies. In order to operate with a PV panel, (which can be seen as a variable DC power source), the charger circuit must provide a way to be controlled by the MCU, in order to effectively implement the MPPT algorithm to optimize power extraction.

In the present work, the MAX1640 was used. It is an adjustable-output, switch-mode current source that operates with input power source voltages up to 26V, making it suitable to work as a microprocessor-controlled battery charger with a PV panel.

The MPPT algorithm developed, was experimentally tested using the circuit depicted in Fig. 3. This circuit includes the MAX1640 charger evaluation board, with its circuit shown inside the dashed line rectangle, with a few components replaced to meet the current required for 50W PV panel used. For testing purposes, 4 LED modules (3-S1MLED12-1-40-B, produced by Arquiled) were connected in parallel and plugged to BATT+ and BATT- instead of a battery in order to eliminate any influence of the battery in the tuning of the MPPT algorithm. This approach turned out to be very useful in the experiment because LED's "accept" all current provided from the PV panel, (like a charge with very low resistance), and also helps visualizing the behaviour of the MPPT algorithm due to LED light intensity variation with the amount of charging current supplied by the charger. All peripheral control pins were connected to a Leonardo Arduino board, which is equipped with a microcontroller atmega32u4 from Microchip, running the implemented algorithm in C++ programming language.

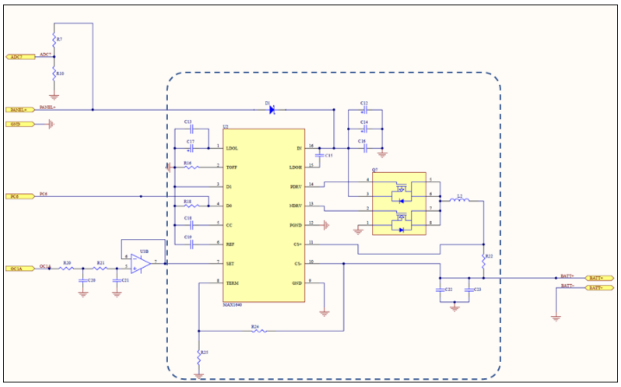

Fig. 3. Charger circuit for testing and tuning the MPPT algorithm.

The circuit in the lower left part, composed by the OpAmp U3B, R20, R21, C20 and C21, is used as a Low Pass Filter for the pulse width modulation (PWM) signal, which controls the amount of charging current imposed by the MPPT in V_{set} pin of the MAX1640. To impose the top-off current mode of the MAX1640, the Arduino must introduce 5V in the PC6 digital pin. When the MAX1640 is in this mode, the charging current in Amps, is defined by equation 1.

$$I_{charge} = \frac{V_{set}}{(13.3*R22)} \quad (1)$$

As shown in equation 1, the charging current is directly proportional to the voltage imposed in V_{set}, so by adjusting the voltage, the MPPT can control the charging current. To measure the PV panel voltage, an analogue to digital converter (ADC) pin with a voltage divider, composed by R7 and R10, was used. This circuit is used to convert the PV voltage to a proportional value lower than 5V, which is the MCU working voltage. All parts were assembled in a test bench shown in Fig. 4.

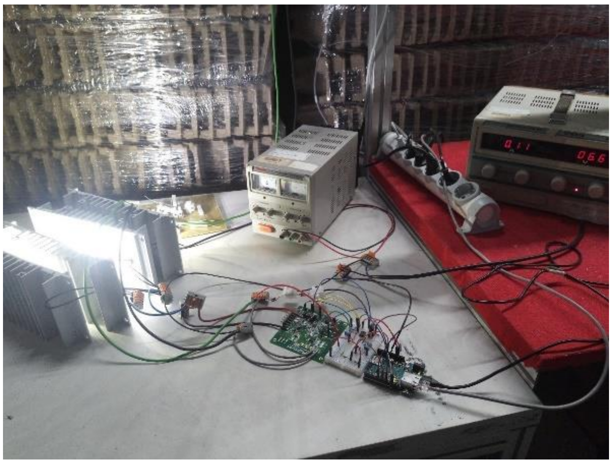

Fig. 4. Test bench with all parts mounted for the MPPT testing.

IV.MPPT adjustment procedure and results

First off, the power curve of the PV panel under a constant charge was studied. Fig. 5 shows the typical curve obtained from a 50W polycrystalline solar panel (purchased from *ERA SOLAR),* under blue sky. The constant charge used was a power resistance of 6.5 Ω. The value calculated was based on the maximum power point (MPP) voltage reported by the supplier which is 18V, under normal conditions. A large heat sink was used to keep the resistance at constant temperature.

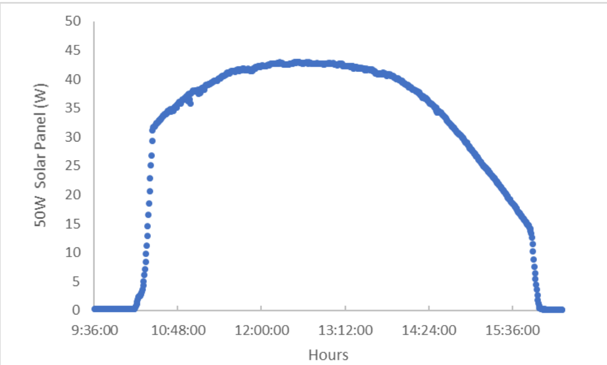

Fig. 5. Power measured of a 50W solar panel during a blue-sky day, using a 6.5 Ω power resistor.

The curve obtained shows a maximum extracted power of 44W, a value lower than 50W, due to PV panel temperature increase under sun light exposure. Despite this curve showing steep slopes, at the beginning and at the end of the day, due to shade induced in the PV panel from the local of the experiment, it can still be seen most of PV typical power curve shape under a blue-sky day.

The PV panel terminals were connected to the PANEL+ and GND pins of MAX1640 evaluation board, and the response of the MPPT algorithm was continually assessed as the parameters, described previously, were tuned. Here, the main tuning steps of the MPPT performed are highlighted.

Initially, the rate parameter used was a constant value, but the response of the MPPT was found to be very slow although very stable. To solve this issue instead of a constant, a directly proportional relation of the PV panel voltage and Optimal Voltage difference was used, as described in equation 2, with k_p being the proportional constant.

$$rate = k_P \, |(V_{opt} - V_{PV})| \tag{2}$$

However, to properly adjust the transient/steady-state relation of the system, k_p must be adjusted in conjunction with the speed of the MPPT cycle. 25ms were used for each MPPT cycle, setting a constant tracking speed as k_p was adjusted manually. After those successive adjustments, a good enough transient/steady-state relation was achieved, by covering the PV panel to abruptly vary the solar power available, results can be seen in Fig. 6.

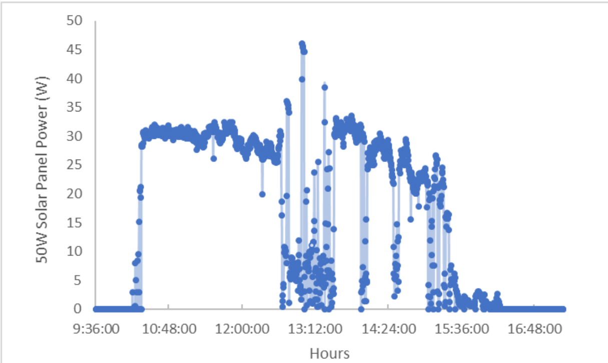

Fig. 6. PV power curve obtained during a blue-sky day after K_p was adjusted.

From Fig. 6, it is also evident that when stability was achieved, during the high plateaus of the curve, the power remained almost the same even though more solar power was available. This is explained by the high value of the limit parameter used initially, resulting in a low response to the change of the Vopt.

To address this low response, a second stage of tuning was executed: the step parameter was kept constant and the limit parameter was reduced. The result obtained after this reduction is pictured in the Fig. 7.

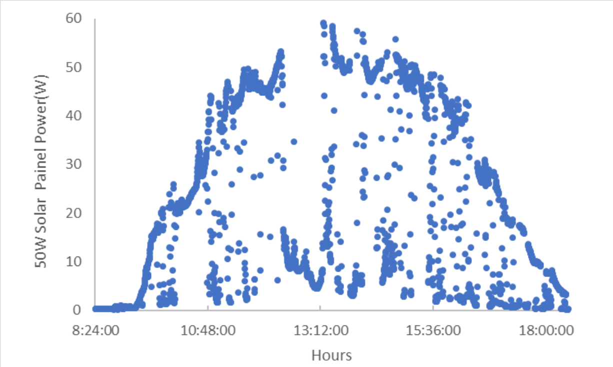

Fig. 7. PV power curve obtained during a blue-sky day after decreasing optimal voltage update limit.

In Fig. 7, it is already clear that the outer shape of the curve is similar to that obtained in Fig. 5. However, the curve shows a significant instability during the day due to the update of the Vopt being too fast, causing the PV voltage to decrease abruptly often, followed by the MPPT going after the MPP. In order to reduce those losses, the final tuning step of the MPPT was achieved by successively increasing the limit parameter until a sufficiently good transient/steady-state relation was reached. The final result is depictured in Fig. 8.

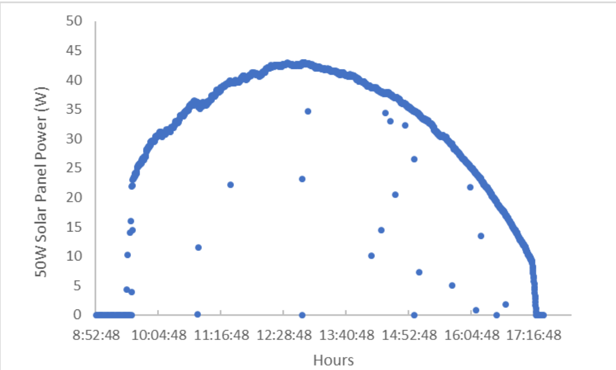

Fig. 8 - PV power curve obtained during a blue-sky day with the adjustment of the optimal voltage update limit.

Fig. 8 shows a curve very similar to the one in Fig. 5, which presents the maximum power extraction obtained during the all process of the development and successive adjustments of the MPPT algorithm. Its also visible a few dots under the curve which depict every time the MPPT was too fast decreasing the Vopt value during the day. That explains why more dots are present as it goes towards the end of the day, since solar power is constantly decreasing as the sun sets. It is worth mentioned that those dots represent insignificant losses during the entire day.

V.Conclusion

In the present paper, a new MPPT algorithm approach is presented, the main advantages are the simpler implementation needed since the PV voltage is the only input value measured and the separation of the solar irradiation from the temperature dependence in the MPPT implementation, which allows fast response due to abruptly power changes caused mainly by solar irradiation changes but also a fine tuning during stable conditions where the temperature affects the most.

It is also presented a successful way of how the MPPT can be implemented experimentally, using the MCU atmega32u4 to control the battery charger MAX1640, using real conditions. For the experimental setup, it is shown the main steps required for the adjustments of the MPPT, applied to a 50W PV panel, with the objective of increasing its maximum power extraction. It is also presented the different daily power curves obtained, from the PV panel under blue-sky, in each adjustment step, to visualize how certain parameters affect the MPPT response. It was verified that the temperature influence in the behaviour of the MPPT can be addressed independently from the solar radiation influence, as they have different rates for affecting the MPP.

VI.References

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