A Practical Method for the Electrical Characterization of Low Energy - Indoor Photovoltaic Cells

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***Abstract*—The majority of electronic devices, mainly peripherals, are used most of the time at indoor environments, such as home and office rooms. These devices are usually power supplied by wiring or batteries. The use of wires can sometimes compromise the practicality of some electronic devices, and batteries must be frequently replaced or recharged. Energy harvesting is a great solution to overcome this problem, since the energy provided by the environment, such as lighting, can be harvested by a photovoltaic (PV) cell in order to power supply the electronic devices. A PV cell electrical characterization is important to know the electrical quantities that the cell provides operating under certain conditions, such as at indoor only with artificial lighting. In this context, the present paper proposes a practical method for PV cells indoor electrical characterization using a capacitor charge strategy. Two small PV cells are characterized following the proposed procedure and results show that the maximum obtained power of a small PV cell operating only with artificial light is limited to some dozens of μW.**

I. Introduction

The predominant energy source of the majority electronic devices are batteries. Even with the increase in the energy density of batteries by a factor of 3 over the last 15 years, in several cases their presence has a large impact, or even dominate, size and operational cost [1]. Also, the constant replacement of batteries can harm the environment due to toxic metals such as cadmium and mercury, lead and lithium which some batteries contain and it can pose threats to health and the environment if improperly disposed [2].

There is a trend in which the number of electronic devices per person has been continuously increasing for decades. In addition, there is another and older trend that is the human tendency of spending larger amount of time in protected environments, especially buildings [3]. The collection and use of ambient energy in the environment, called energy harvesting or scavenging, is a good idea in order to avoid the need for user intervention and extra wiring, and also it assures that the product is available whenever required. In some applications, this approach can even replace the battery usage [4].

Energy can be harvested from different ambient sources, and the most commonly used to generate electrical energy are solar, thermal, mechanical movement or vibration, and ambient radio-frequency (RF) [5]. Harvesting from ambient light is the best option for outdoor applications [1]. This type of harvesting source does not present a higher power density than other sources at indoor, however there are advantages in performing indoor solar energy harvesting. In addition to the artificial light provided by the lamps, some extra energy can be harvested, at daylight, from the natural solar radiance through the windows. Even a mixture of these two artificial and natural sources can be used to harvest energy. PV cells can be cheap and easy to obtain, they can be built in many different sizes and shapes, and they also allow an easy integration with electronic devices and peripherals. In addition, PV cells can be easily associated in series or parallel in order to provide more voltage or current to the load [6].

Before designing a photovoltaic energy harvesting system, it is really important to perform a PV cell electrical characterization in the environment where the cell will operate most of the time. This characterization gives a notion about the operating limitations, as well as the maximum values for voltage, current and power provided by the cell. Another important parameter that needs to be known is the PV cell equivalent internal resistance and its variation with lighting conditions. The knowledge of all these parameters facilitates the design of other system blocks, such as the DC-DC converter topology, circuit for maximum power point tracking, and type of energy storage element.

In this context, the present paper proposes a practical method for electrical characterization of PV cells operating under artificial indoor light. The method is based on a capacitor charge strategy which is possible to obtain PV cells electrical characterization curves with practicality and good resolution.

II. Electrical Characterization Method

A very simple way to characterize a photovoltaic cell is connecting it in parallel with a variable resistor, as depicted in Fig. 1.

A voltmeter is necessary to measure the variable resistor voltage drop, and this measure represents the PV cell output

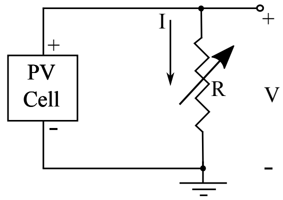


Fig. 1: Simple PV cell characterization circuit.

voltage. In order to obtain the PV cell output current, an ammeter can be connected in series with the variable resistor. This way, varying the resistor, it is possible to measure directly the output voltage and current of the PV cell. This approach presents a problem, for indoor conditions, where the PV cell output values are very low compared to the outdoor condition, the ammeter internal resistance can affect the measurements.

One way to mitigate this problem is using an ohmmeter to measure the resistance that is being varied with the variable resistor. With the resistance value and the voltage drop, the current can be simply calculated by Ohm's law. There is also a problem with this approach, when the resistance is adjusted, the variable resistor must be disconnected from the circuit in order to measure its resistance using the ohmmeter and connected again. It consists in a laborious process and almost impossible to perform if several measurements need to be executed. Also, it can ruin the resolution of the PV cells characterization curves.

A more elaborated circuit can be used to solve all these problems, the circuit depicted in Fig. 2 can be used to facilitate and expedite the PV cell characterization process [7].

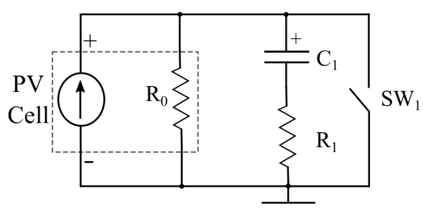


Fig. 2: PV cell characterization circuit.

Fig. 3 presents the equivalent circuit when the switch SW_1 is opened.

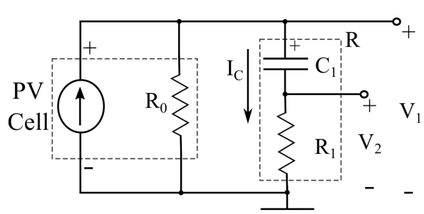


Fig. 3: PV cell equivalent characterization circuit for the capacitor charging phase.

This circuit emulate the variable resistor by using the charging of a capacitor which in DC can vary from a short circuit to an open circuit, that is, $R_{C1_{DC}} = \infty - 0\ \Omega$. There is a resistor R_1 in series with the capacitor C_1, so the equivalent resistance variation will range from ∞ to $R_1\ \Omega$:

$$R = R_1 + \frac{V_{C_1}}{I_{C_1}} \tag{1}$$

With the aid of an oscilloscope the curves of the voltages V_1 and V_2 can be obtained. The current I_C and the voltage V_C can be obtained by the following relations:

$$I_{C_1} = \frac{V_2}{R_1} \tag{2}$$

$$V_{C_1} = V_1 - V_2 \tag{3}$$

Using V_1 and I_C that represents the PV cell output voltage and current, respectively, the PV cell output power P can be calculated by simply multiplying V_1 by I_C.

The equivalent resistance variation can be obtained by substituting Eq. 2 and 3 in Eq. 1:

$$R = R_1 + \frac{V_1 - V_2}{\frac{V_2}{R_1}} \tag{4}$$

Rearranging the terms in order to simplify Eq. 4, the following relation can be obtained:

$$R = R1 \cdot \frac{V_1}{V_2} \tag{5}$$

Relating the resistance variation and the PV cell output power in one graph, R x P, we can discover which value of resistance provide the maximum output power. Through the maximum power transfer theorem we can find the PV cell internal equivalent resistance R_0 simply by matching it with the resistance that provides the maximum output power: $R_0 = R_{Pmax}$.

III. Experimental Results

As an experiment example, the PV cell characterization was performed at night in the university research room which is illuminated by an arrangement of six luminaries containing two 32 W tubular fluorescent lamps each.

The flat surface of the test bench where the tests were performed is about 1.7 m away from the luminaries.

A capacitor of 69μ F was used for C_1 and the series resistor R_1 was 1 kΩ, this value was chosen so that the V_2 voltage drop could be easily identified by the oscilloscope resolution. The constant $R_1 C_1$ must be adjusted depending on the PV cell to be characterized and the illuminance level employed.

Two distinct PV cell were tested, a 42x42 mm and a 45x45 mm PV cell depicted in Fig. 4. As well their parallel and series combinations.

According to [8] the illuminance in offices must range from 200 to 750 lux, depending on the task. For example, a minimum illuminance of 200 lux is required for archives storage and a minimum illuminance of 750 lux is required for technical drawing.

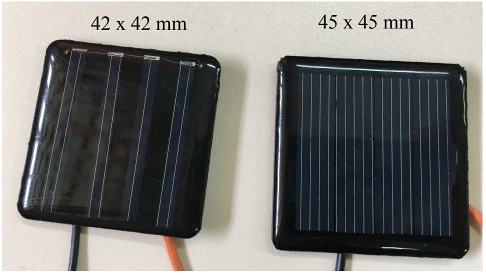
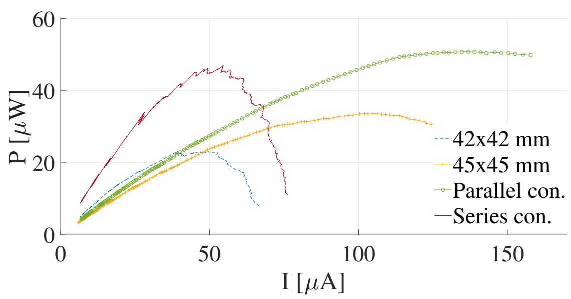


Fig. 4: Chosen PV cells for electrical characterization.

Two illuminance levels were applied in the tests, an intensity of 470 lux obtained at the test bench level and an intensity of 700 lux that was obtained approximating the PV cell to the luminaries. The curves obtained with the PV cell characterization were IxP, VxI, RxP and VxP. The tests were performed with a single 42x42 mm PV cell, a single 45x45 mm PV cell, their parallel connection and series connection.

Figure 5 shows the IxP curves for the single 42x42 mm PV cell, single 45x45 mm PV cell, PV cells parallel connection and PV cells series connection with illuminance levels of 470 lux and 700 lux. There is a noticeable quadratic relation between current and power in the curves for the 42x42 mm PV cell and series connection. While for 45x45 mm PV cell and parallel connection, power increases linearly with the current until it saturates and reaches a maximum value.



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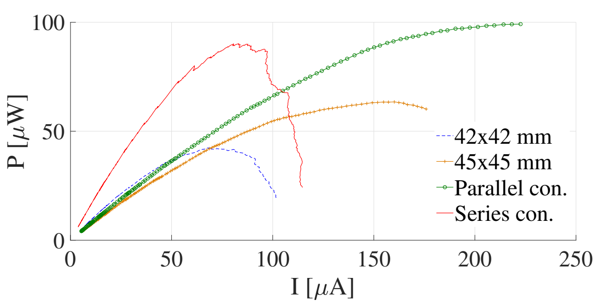
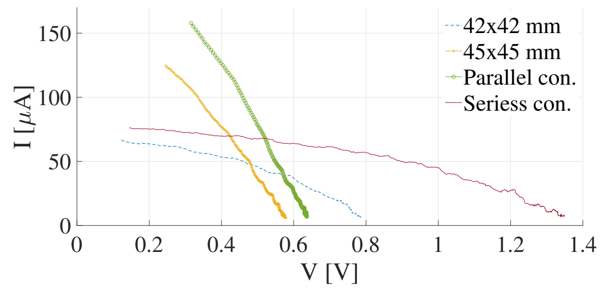


(b)

Fig. 5: PV cells IxP curve with: (a) 470 lux and (b) 700 lux of illuminance level.

Figure 6 shows the VxI curves for the single 42x42 mm PV cell, single 45x45 mm PV cell, PV cells parallel connection and PV cells series connection with illuminance levels of 470 lux and 700 lux. It can be noted in all curves that there is a linear relation between the voltages and currents of the tested PV cells. In the curves for the 45x45 mm PV cell and parallel connection this linear relationship is more accentuated.



(a)

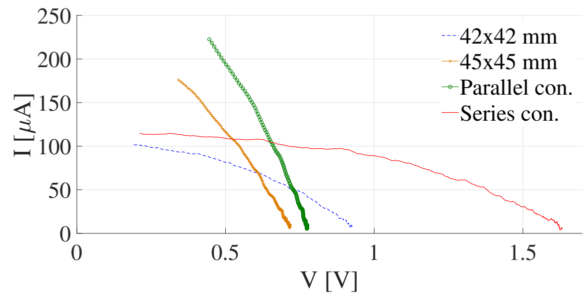


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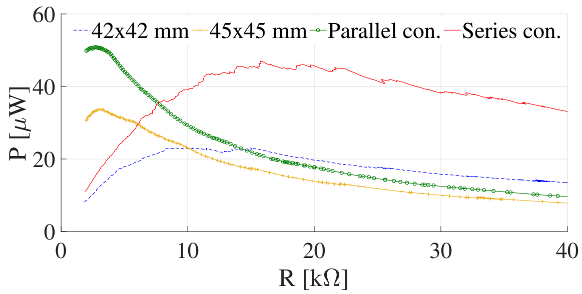
Fig. 6: PV cells VxI curve with: (a) 470 lux and (b) 700 lux of illuminance level.

Figure 7 presents the RxP curves for the single 42x42 mm PV cell, single 45x45 mm PV cell, PV cells parallel connection and PV cells series connection with illuminance levels of 470 lux and 700 lux. As expected, the curves show that the power starts at a lower value, increases with the resistance increasing, reaches a maximum value and then decreases. The PV cell equivalent internal resistance can be estimated through this maximum power point.

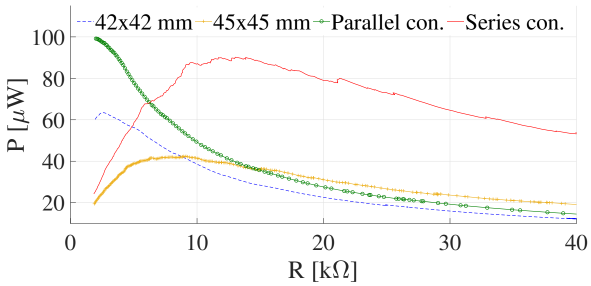
Figure 8 presents the VxP curves for the single 42x42 mm PV cell, single 45x45 mm PV cell, PV cells parallel connection and PV cells series connection with illuminance levels of 470 lux and 700 lux. The curves present a quadratic relation between PV cells voltage and power, but in the curves for parallel connection this characteristic is not so visibly exposed.

The values for PV cells maximum obtained power, as well as equivalent internal resistance, voltage and current related to this maximum power are presented in Table I, and they were extracted from the presented PV cells electrical characterization curves.

With the characterization curves and values presented in Table I, it can be noted that for both tested single cells the obtained power almost doubled with an increase of approximately 50% in the illuminance level. It can be also observed that the resistance of the same cell may change slightly with an illuminance level variation. It is interesting to note that, disregarding the configuration in series, all the other cases

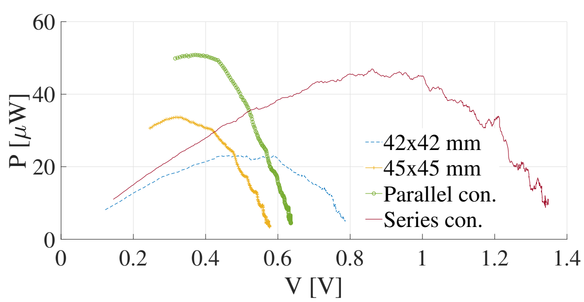


(a)

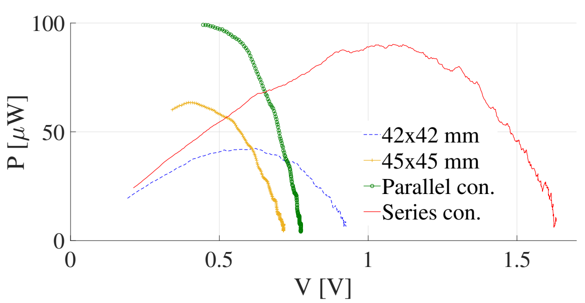


(b)

Fig. 7: PV cells RxP curve with: (a) 470 lux and (b) 700 lux of illuminance level.



(a)



(b)

Fig. 8: PV cells VxP curve with: (a) 470 lux and (b) 700 lux of illuminance level.

presented a maximum obtained power with correspondent voltages until 0.6 V, and low voltage applications may benefit greatly from this characteristic. The PV cells characterization also showed that the maximum extracted power can be increasing by connecting the PV cells in parallel or in series. If more current is needed, so a parallel connection is more appropriate. On the other hand, a series connection is more adequate for providing a higher voltage.

TABLE I: Summary of the PV cells characterization electrical quantities.

	Illuminance	
	470 lux	700 lux
PV cell max. P		
42x42 mm	23 μW	42 μW
45x45 mm	33 μW	63 μW
Parallel con.	50 μW	99 μW
Series con.	54 μW	90 μW
PV cell $R_{0_{maxP}}$		
42x42 mm	10 kΩ	9.5 kΩ
45x45 mm	2.8 kΩ	2.5 kΩ
Parallel con.	2.7 kΩ	2 kΩ
Series con.	16 kΩ	14 kΩ
PV cell I_{maxP}		
42x42 mm	47 μA	69 μA
45x45 mm	102 μA	160 μA
Parallel con.	125 μA	225 μA
Series con.	47 μA	83 μA
PV cell V_{maxP}		
42x42 mm	0.59 V	0.6 V
45x45 mm	0.33 V	0.39 V
Parallel con.	0.37 V	0.45 V
Series con.	0.93 V	1 V

IV. Conclusion

It was proposed a simple characterization method for electrical characterization of the PV cells operating at indoor. It was noticed that the operation with lower voltages is advantageous to provide a higher power. The maximum obtained power of a small PV cell operating only with artificial light is limited to some dozens of μW. A maximum power point tracking circuit must be employed in the system in order to match the PV cell and the converter impedance, since internal equivalent PV cell resistance may suffer variations with changes in the illuminance levels.

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