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A low-cost PV Emulator for testing MPPT algorithm

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Abstract. The high cost of commercial PV emulators requires finding new solutions for building low-cost system having similar behavior of PV panel. In this work, we present a low-cost emulator using a variable DC supply with a series variable resistor; based the maximum power transfer theorem. On the other hands, a study of the behavior of this emulator is done. The results of experiments test are shown that our PV emulator can provide a simple, efficient and a low-cost way for researchers to test and verify their MPPT algorithms in a laboratory environment.

1. Introduction

The demand for energy in different forms is constantly increasing, particularly renewable energies, namely: hydraulic, wind, solar, geothermal and bioenergy energy. Today, solar energy has taken a large part of the market due to the continued development of PV system technology and lower prices. The power provided by the PV panel is maximum only when the latter operates at its maximum power point (MPP). As a result, several studies have been presented in the literature aimed at monitoring this point, such as: Perturb & Observe (P & O) [1], [2], incremental conductance (INC) [3] - [6], fractional open circuit voltage [7], fractional short-circuit current [8], fuzzy logic control [9], and neural network [10], etc.

On the other hands, the conversion of solar energy into electricity varies aleatory according to the level of solar radiation and the atmospheric temperature [11], [12]. Therefore, proposed MPPT algorithms must be tested under different conditions so as to validate their robustness. In general, there are some methods for testing MPPT algorithms in a laboratory environment. For example, we found one which is based on using an actual outdoor installed PV panel/array in the laboratory [13]. But, the disadvantages of this method are the requirement of external space, dependence on the weather condition, and the expensive solution of the PV system. To solve all these limitations, PV emulators [14], [15] have been proposed to replace PV systems, which make easy the set of a test profile desired by the researcher. Recently, there have been several types of commercial PV emulators, among them, the Agilent Solar Simulator used in [16], and other PV emulators based on a programmable DC power supply, but they are very expensive. Therefore, this work proposes a low-cost PV emulator to test the real implementation of MPPT algorithm for PV systems. This PV emulator is based on a simple DC supply and resistor, thus it allows a variety of I-V and P-V curves for different values of solar radiation to be simulated inside laboratory regardless of actual solar radiation levels. This PV emulator is simple and easy to build in a conventional laboratory environment. The design of the proposed emulator is based on the ‘maximum power transfer theorem’.

This paper is organized as follows. The next section exposes design of PV emulator. Section 3 presents the experimental results. Finally, the conclusion is given in section 4.

2. Design of PV emulator

2.1. Maximum power transfer theorem

PV emulator must give a power curve as this of PV panel that exhibits a peak. Therefore, the principle of the maximum power transfer theorem is used for the PV emulator design which is composed of a variable DC supply in series with a variable resistor. This DC supply can provide its maximum power when load resistor equals to the series resistor and as presented in Fig. 3, this emulator can give a P-V curve that exhibits a peak in the power curve which can be tracked by the MPPT algorithm to be tested. The 'maximum power transfer theorem' can be explained as follows [17]:

Based on Fig. 1, the following equations can be found:

$$\boldsymbol{P}_{load} = \boldsymbol{I} * \boldsymbol{V} = \boldsymbol{I}^2 * \boldsymbol{R}_{load} \tag{1}$$

$$\boldsymbol{I} = \frac{\boldsymbol{E}}{\boldsymbol{R}_{series} + \boldsymbol{R}_{load}} \tag{2}$$

Replacing (2) in (1), equation (3) is found:

$$\boldsymbol{P}_{load} = \frac{\boldsymbol{R}_{load}}{(\boldsymbol{R}_{series} + \boldsymbol{R}_{load})^2} * \boldsymbol{E}^2 \tag{3}$$

$$\frac{d\boldsymbol{P}_{load}}{d\boldsymbol{R}_{Load}} = \boldsymbol{E}^2 \frac{\boldsymbol{R}_{series} - \boldsymbol{R}_{load}}{(\boldsymbol{R}_{series} + \boldsymbol{R}_{load})^3} \tag{4}$$

The power is at its maximum when its derivative is equal to zero and from equation (4) this can be reached when the load resistor is equal to the series resistor as follows:

$$\boldsymbol{R}_{load} = \boldsymbol{R}_{series} \tag{5}$$

Therefore, in this case, maximum power transfer condition (5) will appear when the voltage of the load is half of that generated by the DC supply.

$$\boldsymbol{V} = \frac{\boldsymbol{E}}{\boldsymbol{2}} \tag{6}$$

2.2. Description of the set-up

Fig. 1 presents the basic schematic of the proposed PV emulator, which is constituted of a DC power supply and a series resistor to give a P-V curve that exhibits a peak. In Fig. 2 the proposed PV emulator gives the I-V curves with a negative slope for a fixed $\boldsymbol{R}_{series}$ and $\boldsymbol{R}_{load}$ is varied from its minimum to maximum, this is experimentally validated in section 3. Fig. 3 illustrates the power goes through the maximum when the load voltage is half of the DC supply voltage. On the other side, the P-V curve generated by the PV module shows that the peak occurs at 0.7 V_{oc}. Therefore, the maximum power is transferred to the charge when the equivalent resistor of DC/DC converter and the load is equal to the value of series resistor

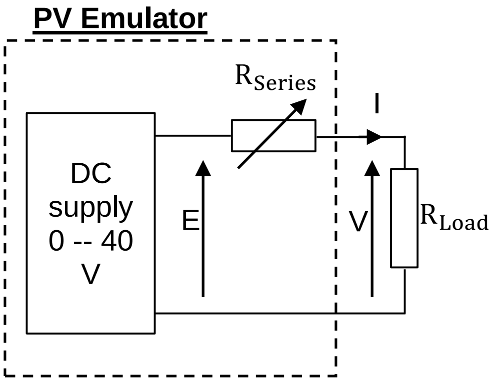
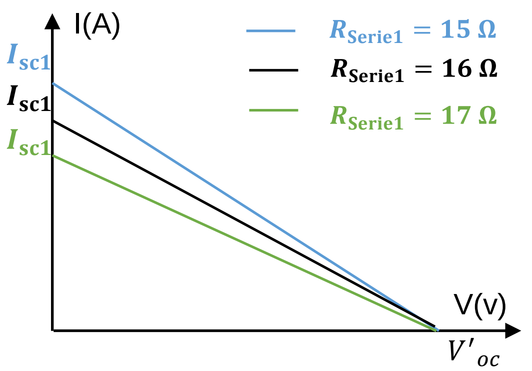


Figure 1. Basic schematic of the PV emulator**.**



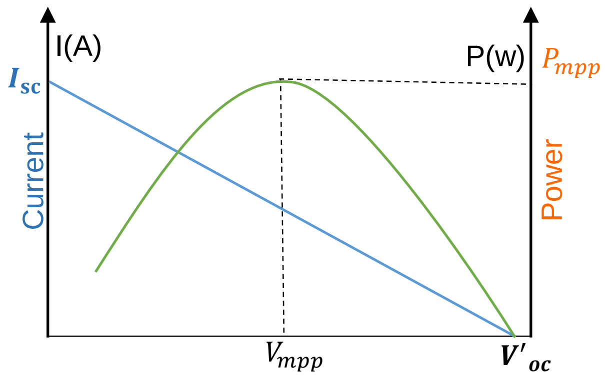


Figure 2. I–V curves for different series resistor. **Figure 3.** P-V and I-V characteristics of emulator

2.3. Dimensioning of the PV emulator

The maximum power is transferred to the load resistor by the PV emulator when the equivalent resistor (between PV emulator and load) is equal to the value of the series resistor. In order to dimension the series resistor of our emulator that will translate the actual behavior of the point of maximum power, the voltage and current values of the PV panel at MPP are required. Thereafter, the series resistor can be calculated by the following equation:

$$\boldsymbol{R_{serie}} = \boldsymbol{R_{mpp}} = \frac{\boldsymbol{V_{mpp}}}{\boldsymbol{I_{mpp}}} \tag{7}$$

Generally, and as known in the literature, it is a single resistor value can lead the PV panel to operate at MPP [17], [18]. Therefore, a DC/DC converter controlled by an MPPT algorithm must be placed between the panel and the load to operate the PV panel at MPP. In Fig. 4, a complete schematic view of the PV emulator control is shown.

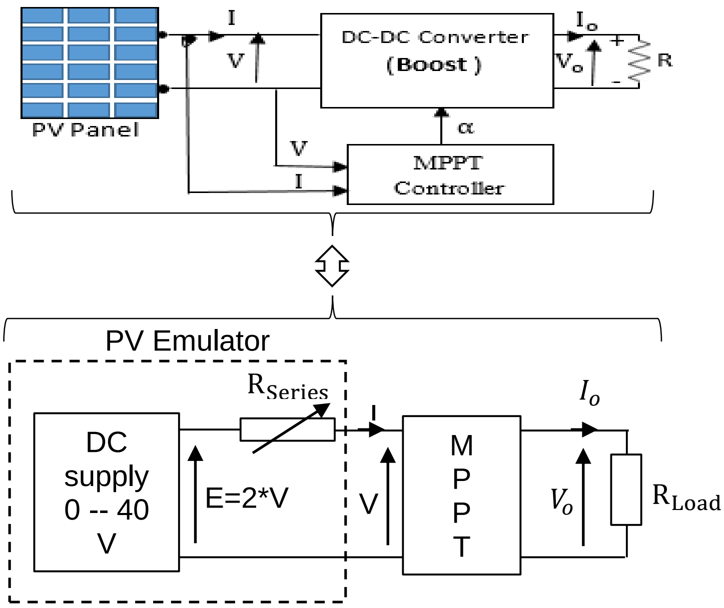


Figure 4. A complete schematic of the PV emulator control.

3. Experimental results

3.1. Validation of the proposed PV emulator

The circuit model and the experimental setup of the developed system are presented in Fig. 5 and Fig. 6 respectively in order to validate the performance of the proposed PV emulator.

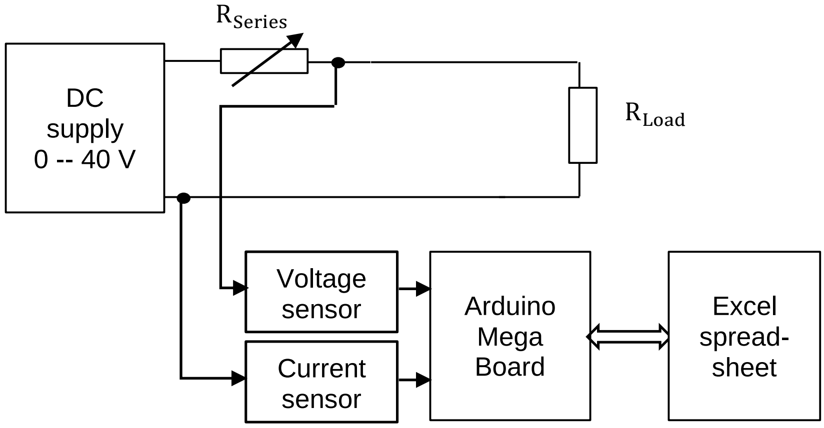


Figure 5. Circuit model of the developed PV emulator.

The voltage and current data of the PV emulator obtained by voltage and current sensors are transmitted directly in real-time in Excel. That by using the PLX-DAQ data acquisition Macro which allows communication between the microcontroller of the Arduino Mega and Excel spreadsheet by the intermediary of a serial communication [19]. Fig. 7 presents the experimental P-V and I-V curves characteristics of the PV emulator. We then experimentally notice that the peak in the power curve occurs when the output voltage of PV emulator equals half of the DC power supply voltage.

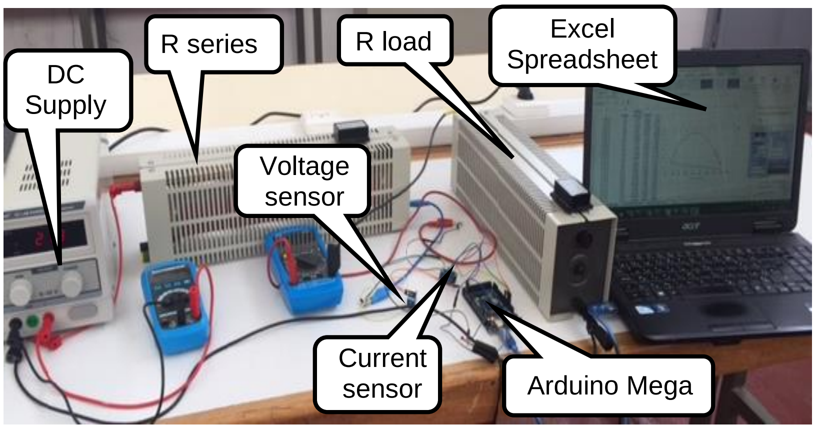


Figure 6. Experimental setup of the PV emulator system.

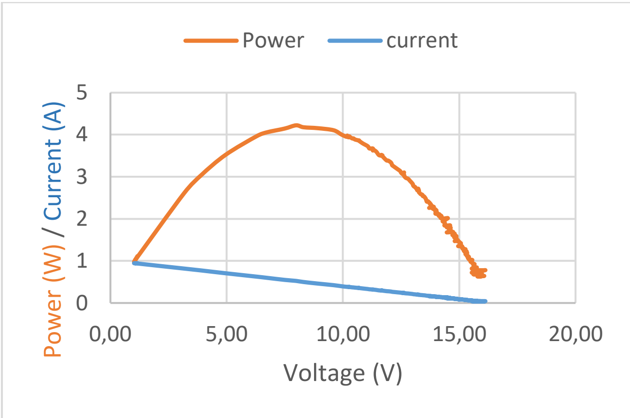


Figure 7. Experimental P-V and I-V curves characteristics of the PV emulator.

3.2. Effect of sun radiation variation

Fig. 8 shows the experimental I-V curves for a fixed $\boldsymbol{V'_{oc}}$ and various series resistors. According to this figure, the short-circuit current changes on the PV emulator when the value of $\boldsymbol{R_{serie}}$ varies.

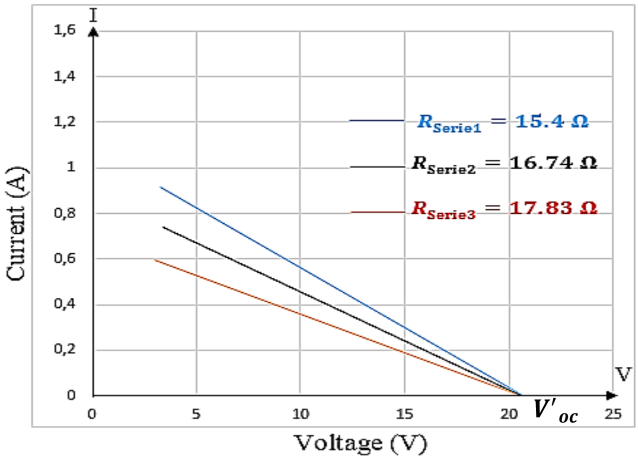


Figure 8. Experimental I–V curves for different series resistance at fixed $\boldsymbol{V'_{oc}}$.

When the solar insolation varies, the short-circuit current changes linearly. Fig. 9 presents the experimental P–V curves for a fixed $\boldsymbol{V'_{oc}}$ and various series resistances. This situation is similar to variation of the insolation in case of PV panel.

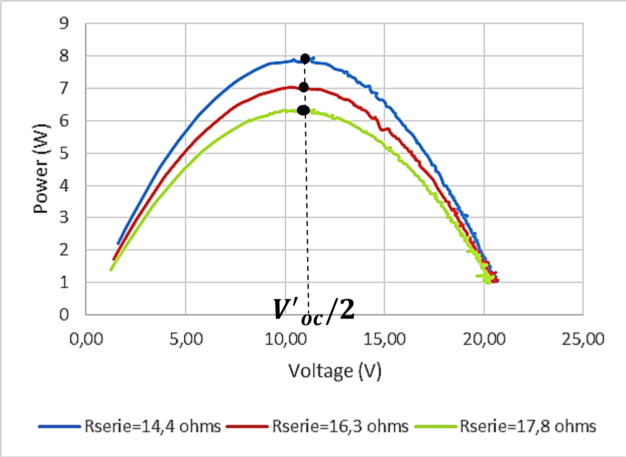


Figure 9. Experimental P–V curves for many series resistance at fixed V'_{oc}.

3.3. The effect of temperature variation

When the cell temperature changes, the open-circuit voltage changes significantly. So, this case is simulate the principle of the maximum power transfer theorem is used for the PV emulator in the present system by guarding the R_{series} constant and varying the DC supply voltage. Fig. 10 presents the experimental P-V curves for a fixed R_{series} and various V'_{oc}.

The V_{mpp} point moves to the right as the Maximum value of the voltage DC supply is increased. This is similar to changing temperature conditions in PV systems.

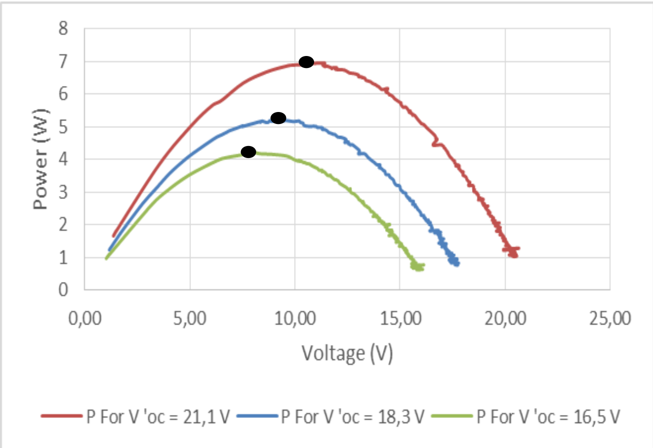


Figure 10. Experimental P–V curves for different V'_{oc} at fixed R_{series}.

Consequently, we can simulate the effects of solar radiation and temperature variations by varying, respectively, the value of the series resistor and the voltage of the DC supply.

4. Conclusion

In this paper, a low-cost PV emulator to emulate the behavior of PV panels device has been designed and implemented. The principle of the maximum power transfer theorem is used for the PV emulator design, which is composed of a variable DC supply in series with a variable resistor. Thus, various experimental tests to confirm the effectiveness of the developed PV emulator are presented in this study. It has been found also from the P-V curve that it exhibits a peak in the power, which can be tracked by an MPPT algorithm. Hence, the obtained results suggest that the proposed system is suitable and can be profitable for researchers to test their MPPT algorithms in a laboratory environment with a reduced budget.

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References

[1] Pandey A, Dasgupta N and Mukerjee A K 2008 High-performance algorithms for drift avoidance and fast tracking in solar MPPT system. IEEE Transactions on Energy Conversion, 23(2), 681-689.

[2] Femia, N, Petrone G, Spagnuolo G and Vitelli, M. 2005 Optimization of perturb and observe maximum power point tracking method. IEEE transactions on power electronics, 20(4), 963-973.

[3] Motahhir S, El Ghzizal A, Sebti S, & Derouich A 2018 Modeling of photovoltaic system with modified incremental conductance algorithm for fast changes of irradiance, International Journal of Photoenergy.

[4] Safari A and Mekhilef S 2011 Simulation and hardware implementation of incremental conductance MPPT with direct control method using cuk converter. IEEE transactions on industrial electronics, 58(4), 1154-1161.

[5] Hsieh, G C, Hsieh H I, Tsai C Y and Wang C H 2013 Photovoltaic power-increment-aided incremental-conductance MPPT with two-phased tracking. IEEE Transactions on Power Electronics, 28(6), 2895-2911.

[6] Motahhir S, El Ghzizal A, Sebti S, and Derouich A 2017 MIL and SIL and PIL tests for MPPT algorithm, Cogent Eng, 4(1), 18.

[7] Ahmad J 2010 A fractional open circuit voltage based maximum power point tracker for photovoltaic arrays. In Software Technology and Engineering (ICSTE), 2010 2nd International Conference on (Vol. 1, pp. V1-247).

[8] Singh G K 2013 Solar power generation by PV (photovoltaic) technology: A review. Energy, 53, 1-13.

[9] Bianconi E, Calvente J, Giral R, Mamarelis E, Petrone G, Ramos-Paja C A and Vitelli, M 2013 A fast current-based MPPT technique employing sliding mode control. IEEE Transactions on Industrial Electronics, 60(3), 1168-1178.

[10] Dolan D, Durago J and Crowfoot J 2010 Simulation of a photovoltaic emulator. In North American Power Symposium (NAPS), 2010 (pp. 1-7). IEEE.

[11] Mei Q, Shan M, Liu L and Guerrero J M 2011 A novel improved variable step-size incremental-resistance MPPT method for PV systems. IEEE transactions on industrial electronics, 58(6), 2427-2434.

[12] Schofield D M K, Foster, M P and Stone, D A 2011 Low-cost solar emulator for evaluation of maximum power point tracking methods. Electronics Letters, 47(3), 208-209.

[13] Hohm D P and Ropp, M E 2000 Comparative study of maximum power point tracking algorithms using an experimental, programmable, maximum power point tracking test bed. In Photovoltaic Specialists Conference, Conference Record of the Twenty-Eighth IEEE (pp. 1699-1702).

[14] Khouzam K, Ly C, Koh C K and Ng, P Y 1994 Simulation and real-time modelling of space photovoltaic systems. In Photovoltaic Energy Conversion, Conference Record of the Twenty Fourth. IEEE Photovoltaic Specialists Conference-1994, 1994 IEEE First World Conference on (Vol. 2, pp. 2038-2041).

[15] Mukerjee A K and Dasgupta, N 2007 DC power supply used as photovoltaic simulator for testing MPPT algorithms. Renewable Energy, 32(4), 587-592.

[16] Tey K S and Mekhilef S 2014 Modified incremental conductance MPPT algorithm to mitigate inaccurate responses under fast-changing solar irradiation level. Solar Energy, 101, 333-342.

[17] Kong C S 1995 A general maximum power transfer theorem. IEEE Transactions on Education, 38(3), 296-298.

[18] Motahhir S, El Ghzizal A, Sebti S and Derouich A 2015 Une ressource pédagogique pour l'enseignement par simulation: cas des panneaux photovoltaïques. In Workshop International sur les Approches Pédagogiques & E-Learning.

[19] El Hammoumi A, Motahhir S, Chalh, El Ghzizal A and Derouich A 2018 Low-cost virtual instrumentation of PV panel characteristics using Excel and Arduino in comparison with traditional instrumentation Renewables: Wind, Water and Solar 5 (1), 3.

Nomenclatures

- E : DC supply output voltage [V]
- I : PV emulator output current [A]
- I_0 : MPPT output current [A]

- I_{mpp} : panel output maximum power point current [A]
- P_{load} : Load power [W]
- R_{load} : Load resistance [Ω]
- R_{Series} : series resistance [Ω]
- R_{mpp} : resistor value at MPP [Ω]
- V : PV emulator output voltage [V]
- V_{mpp} : voltage at MPP [V]
- V_0 : Boost output voltage [V]
- V'_{oc} : PV emulator open-circuit voltage [V]
- V_{oc} : panel open-circuit voltage [V]

Greek Letters

- α : duty cycle

Abbreviations

- CV: constant voltage
- DC: Direct Current
- INC: Incremental Conductance
- MPP: maximum power point
- MPPT: maximum power point tracking
- PV: Photovoltaic
- P & O: Perturb and Observe