A Real Time Simulation of a Photovoltaic System with Maximum Power Point Tracking

CHEHOURI ADAM[*1], GHANDOUR MAZEN[1], LIVINTI PETRU[2]

[1]*Lebanese University, Faculty of Engineering, Branch 3, Rafic Harriri Cam,pus, Hadath, Beirut, Lebanon*
[2]*Université "Vasile Alecsandri"du Bacău, Calea Mărăşeşti 156, Bacău, 600115, Roumanie*

Abstract: This work presents an experimental stand for the study of a power electronics control system to locate and track the maximum power point of a photovoltaic (PV) array to ensure efficient power transfer from the solar cells to the load under varying environmental conditions. A real-time photovoltaic solar cell measurements and a control system was developed to guarantee that the maximum power output is attained. This stand is built at the Electrical Machinery Laboratory of "Vasile Alecsandri" University of Bacau, Romania.

Keywords: MPPT, photovoltaic, power electronics, microcontroller

1. INTRODUCTION

With the limitations of fossil fuels becoming more apparent, it is apparent that the solar energy is emerging as the renewable energy source that could change the future. It is abundantly available and unlike fossil fuels, its usage does not harm the environment with greenhouse gas emissions [1]. Although the technology to grasp solar energy has existed since the 1970s, it still presents several challenges [2]. With the help of control strategies as solar tracking and maximum power point tracking, work was done to meet the main challenge of improving the efficiency of solar energy systems [3, 4].

The amount of electrical power generated by a photovoltaic system depends on the solar irradiance, which is the solar energy per unit area of the solar panel's surface, and is also dependent of other conditions such as temperature and cloud coverage. The current and voltage at which a solar module generates the maximum power is known as the maximum power point, but the location of the maximum power point is not known in advance.

If the output voltage of the solar array is fixed, the maximum power output cannot be continuously generated. Hence, we must use maximum power point tracking (MPPT) algorithms to increase the overall power generation efficiency by continuously locating and tracking the maximum power point by adjusting the voltage output of the array using a DC to DC converter. MPPT techniques reduce PV array system costs by reducing the number of solar panels needed to obtain a given amount of output power. Many MPPT techniques have been proposed; examples are the Perturb and Observe (P&O) methods [5-8], the Incremental Conductance (IC) methods [5-9], Artificial Neural Network method [10, 11], Fuzzy Logic method [12, 13]. Comparison of photovoltaic array maximum power point tracking techniques and algorithms was discussed in [9, 14-18].

To improve the control design of solar cell MPPT, we developed an MPPT system based on the Incremental Conductance (IC) method. The system produces a high-speed pulse-width modulation (PWM) signals to control the voltage converter. We used NI CompactRIO 9074 with NI LabVIEW to develop a stable, efficient, and integrated system. We used analog measurements and actual test results to validate the feasibility of the system to develop an MPPT controller.

_____

[*] Corresponding author, email adamchehouri@gmail.com

2. EXPERIMENTAL SETUP

2.1. Application

We designed a solar energy MPPT device using LabVIEW software, since it allows a flexible way to generate new algorithms with a manageable user interface. We used the LabVIEW FPGA Module to acquire high-speed signals and transfer them to the processor using direct memory access (DMA) data transfer. We also used the LabVIEW Real-Time Module to program the processor to execute the MPPT IC algorithm, and the CompactRIO embedded system to obtain the cell current (I) and voltage (V) values and transfer the signals to the real-time processor for calculations and processing. Then, the FPGA is programmed to generate the desired PWM duty cycle signals for the step-down buck converter circuit to produce output voltage at the maximum power point.

2.2. System Architecture

The experimental stand for the study of the MPPT of the photovoltaic system is shown at Fig. 1 and is composed of: (a) Compact Rio 9074, (b) Analog and digital input and output modules, (c) LabVIEW software.
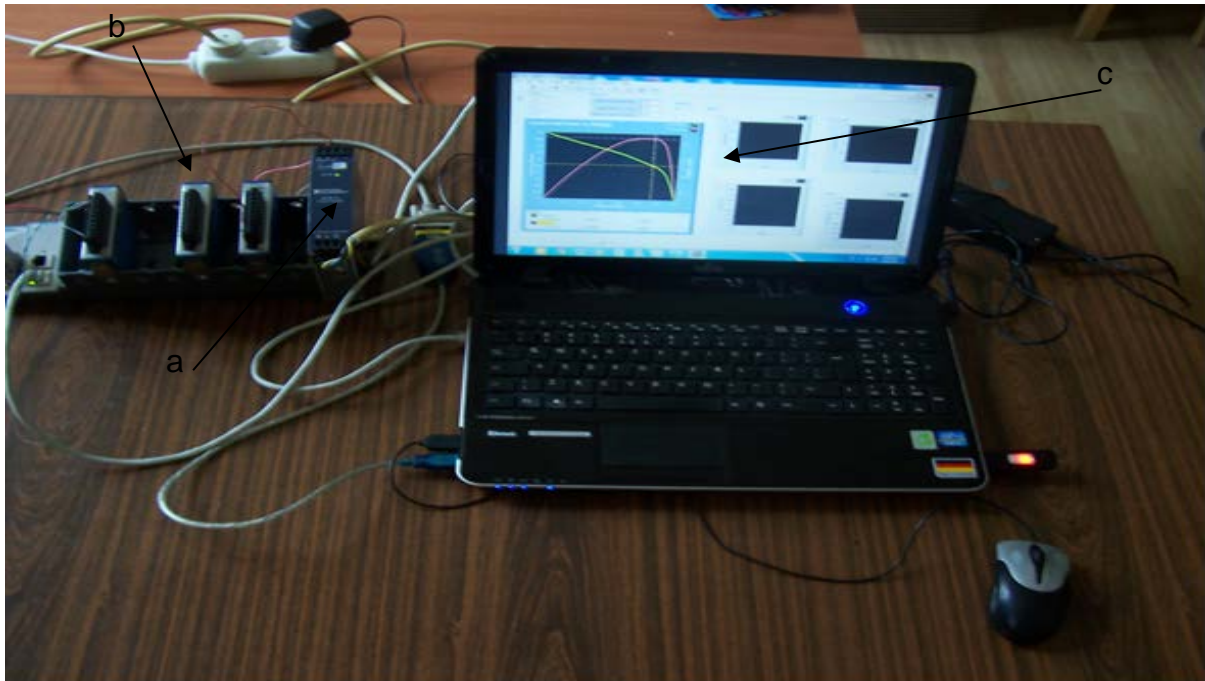

Fig.1. Experimental stand

The test bench with photovoltaic panels was carried out in the laboratory of electrical machinery at the University of "Vasile Alecsandri" in Bacau, Romania under the research project "Hybrid PV - Wind system" financed by the AUF Bucharest [19]. The test bench shown in Fig.2 is composed of the following elements:

    1 - Photovoltaic panels;
    2 - The solar controller;
    3 - Batteries for storing electrical energy;
    4 - UPS 24 VDC / 220 VAC
    5 - Switch;
    6 - Pump with electromagnetic vibrator;
    7 - The reservoir.
    8 - Ammeter
    9 - Meter
  10 - Electric lamps

The photovoltaic panels are of type 5M6.1 BS-185. The characteristics of the photovoltaic panel are: every module consists of 72 cells monocrystalline silicon of 125 mm x 125 mm each, connected in series. The frame of the PV modules is made of aluminum 35 mm x 35 mm with a thickness of 1.5 mm. The dimensions of a photovoltaic module are:

- Length: 1580 mm;
- Width: 808 mm;
- Thickness: 46 mm;
- Weight: 15.5 kg.

The technical characteristics of the modules are:

- Rated power output: 170 to 190 W;
- Guaranteed Minimum power:
- At least 90% of rated power for a period of over 10 years;
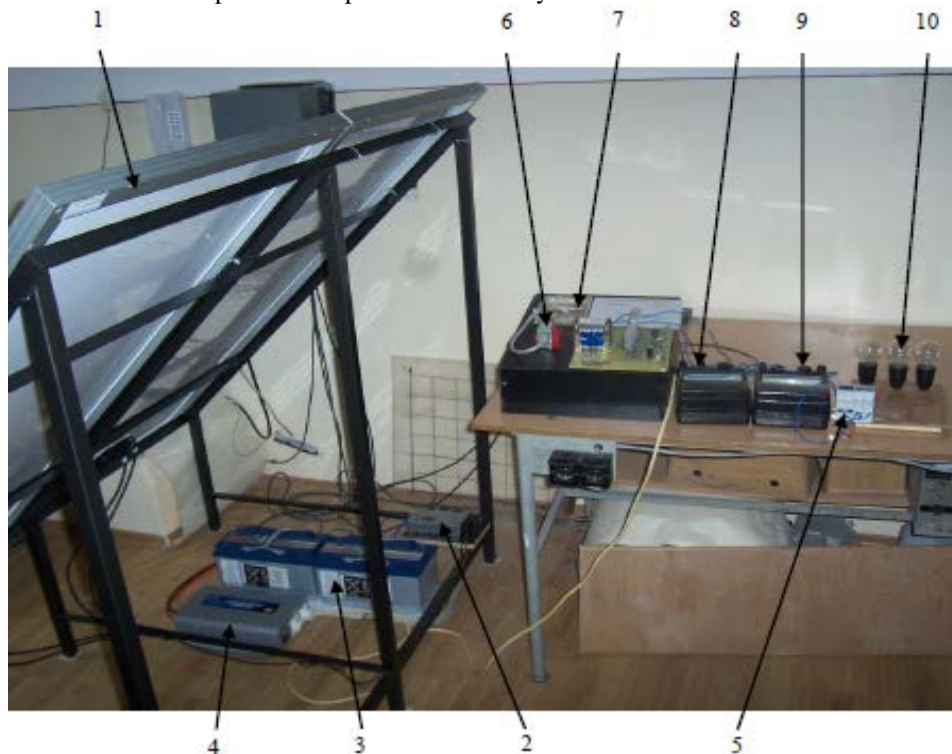- At least 80% of the rated power for a period of over 25 years.

Fig.2. The test bench with the photovoltaic panels [19]

3. RESULTS AND DISCUSSION

From the designed MPPT algorithm designed on the LabVIEW platform, many results can be extracted concerning the flexibility of the IC method. However, it is important to note that the perturb and observe (P&O) algorithm is the most commonly used in practice due to its ease of operation [20], in order to compare the implementation of both MPPT algorithms.

The P&O algorithm operates as follows. Consider Fig. 3, which shows a family of PV array power curves as a function of voltage (P–V curves), at different irradiance (G) levels. These curves have global maxima at the MPP. Assume the PV array to be operating at point A in Fig. 3 [5], which is left of the global maxima at the 1000 W/m^2 illumination.

In the P&O algorithm, the voltage of the PV array is perturbed by a small increment, and a resulting change in power, ΔP, is measured. If ΔP is positive, then the perturbation of the operating voltage moved the operating

point A, closer to the MPP. Further voltage perturbations in the same direction should move the operating point toward the global maxima. If ΔP is negative, the system operating point has moved away from the MPP, and the algebraic sign of the voltage perturbation should be reversed.

The advantages of this algorithm, as stated before, are simplicity and ease of implementation. However, P&O has limitations that reduce its MPPT algorithm efficiency. One such limitation is that when the amount of sunlight decreases, a natural phenomenon which is bound to occur during operation, the P–V curve flattens out, as seen in Fig.3. This makes it difficult for the MPPT to distinguish the location of the global maximal.

Another fundamental and important drawback of P&O algorithm is that it cannot determine when it has actually reached the MPP but rather it will oscillate around the MPP. In addition it has been shown that P&O can exhibit erratic behavior under rapidly changing irradiance levels [4]. Several improvements of the P&O algorithm have been proposed [21-23].
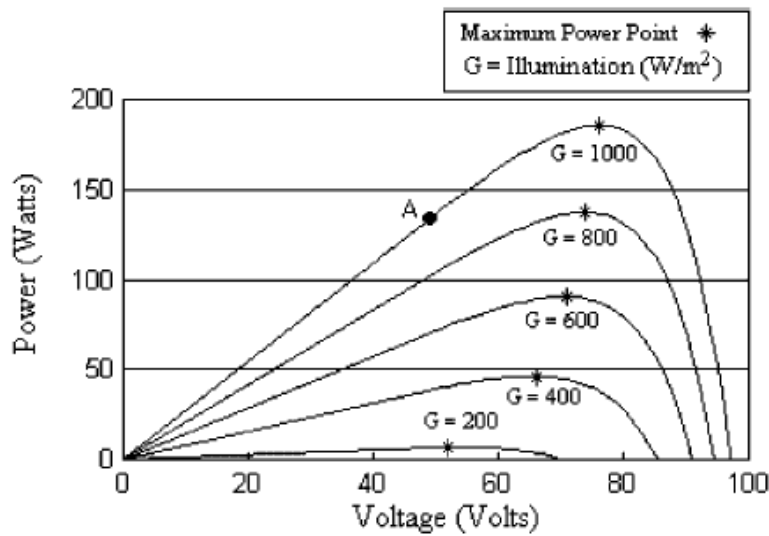

Fig.3. Voltage relationship – PV array power [5]

The incremental conductance algorithm is derived by differentiating the PV array power with respect to voltage and setting the result to zero [9], as shown in Equation 1.

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V\frac{dI}{dV} = 0 \text{ at the [MPP]} \tag{1}$$

Rearranging Equation (1) gives,

$$-\frac{I}{V} = \frac{dI}{dV} \tag{2}$$

I/V represents the opposite of the PV array's instantaneous conductance, while the right-hand side represents its incremental conductance. Thus, at the MPP, these two quantities must be equal in magnitude, but are opposite in sign. If the operating point is off of the MPP, a set of inequalities can be derived from Equation (2). These relationships [9] are summarized in Equations (3a, b and c).

$$\frac{dI}{dV} = -\frac{I}{V} \qquad \left(\frac{dP}{dV} = 0\right) \tag{3a}$$

$$\frac{dI}{dV} > -\frac{I}{V} \qquad \left(\frac{dP}{dV} > 0\right) \tag{3b}$$

$$\frac{dI}{dV} < -\frac{I}{V} \qquad \left(\frac{dP}{dV} < 0\right) \tag{3c}$$

Equations 3(b and c) are used to determine the direction in which a perturbation must occur to move the operating point toward the MPP, and the perturbation is repeated until Equation 3(a) is satisfied. Once the MPP

is reached, the MPPT continues to operate at this point until a change in current is measured. This change in current will correlate to a change in irradiance on the array. The iterative flow chart is shown in Fig. 4.
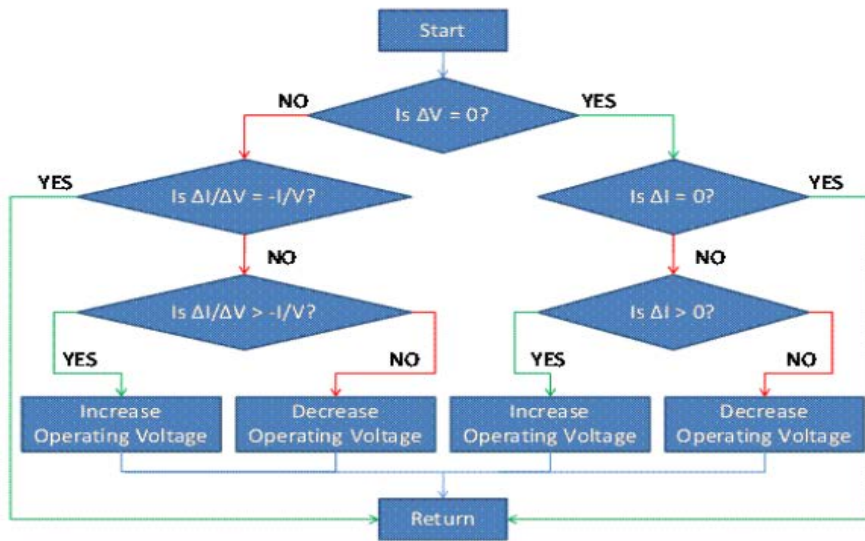

Fig.4. Incremental conductance (IC) method (www.ni.com)

The implementation of Figure 4, is translated onto the graphical platform of LabVIEW, using case structures inside a main while loop (Figure 5). The front panel of the implemented IC algorithm is shown in Figure 6.
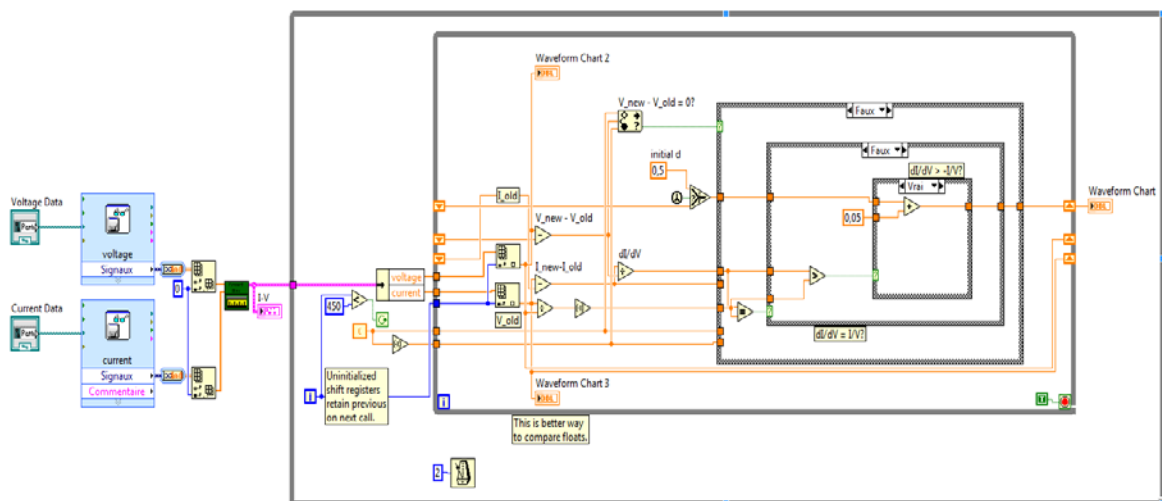

Fig.5. LabVIEW blog diagram of the IC method

The inputs of the algorithm are the voltage and current data, in other words the parameters of the I-V curve for different irradiation. In our experiment, 200, 400, 600, 800 and 1000 W/m^2 are extracted from the datasheet of the photovoltaic cell.

Performance parameters such as the fill factor (ratio of the maximum obtainable power to the product of the open circuit voltage and the short circuit current), V_{oc} open-circuit voltage, I_{sc} short-circuit current, and power parameters such as the characteristics of the global maximum (MPP) I_{mp}, V_{mp} and P_{max} and most important, the overall efficiency are listed in Figure 6.
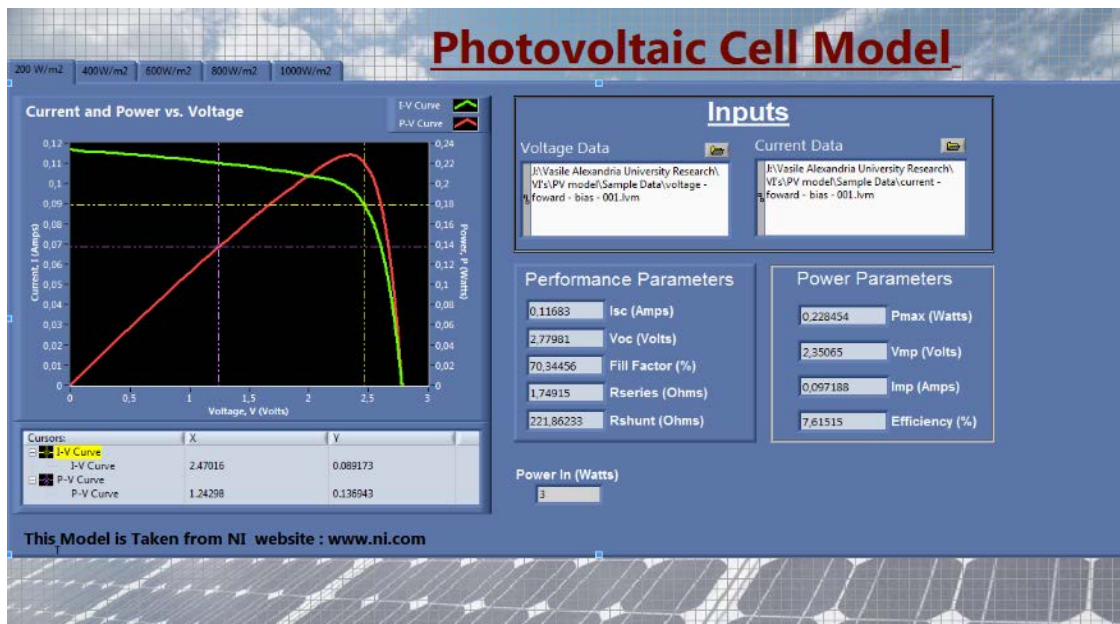
Fig.6. LabVIEW front panel of the MPPT algorithm

4. CONCLUSIONS

This study presents an experimental implementation of the maximum power point tracking efficiency of a photovoltaic cell. The scope of the study was limited to the incremental conductance method thought to be the best applicable solution at low-cost implementations with the available hardware. The results suggest that, on the basis of maximum power point tracking efficiency the incremental conductance performed well but in order to justify the results in terms of global efficiencies, a comparison study between the IC method and the perturb-and-observe (P&O method) and the parasitic capacitance, should be further included in the study. The Real Time processing of the Compact Rio resulted in a stable, efficient, and a very well integrated system to carry out the measurements and validate the feasibility of the MPPT controller algorithm.

REFERENCES

[1].   Kalogirou, S.A., *Solar energy engineering: processes and systems*. 2013: Academic Press.
[2].   Armaroli, N. and V. Balzani, *The future of energy supply: Challenges and opportunities.* Angew Chem Int Ed Engl, 2007. **46**(1-2): p. 52-66.
[3].   Hua, C. and C. Shen. *Study of maximum power tracking techniques and control of DC/DC converters for photovoltaic power system*. in *Power Electronics Specialists Conference, 1998. PESC 98 Record. 29th Annual IEEE*. 1998. IEEE.
[4].   Kawamura, T., et al., *Analysis of MPPT characteristics in photovoltaic power system.* Solar Energy Materials and Solar Cells, 1997. **47**(1-4): p. 155-165.
[5].   Hohm, D. and M. Ropp. *Comparative study of maximum power point tracking algorithms using an experimental, programmable, maximum power point tracking test bed*. in *Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth IEEE*. 2000. IEEE.
[6].   Hua, C. and C. Shen. *Comparative study of peak power tracking techniques for solar storage system*. in *Applied Power Electronics Conference and Exposition, 1998. APEC'98. Conference Proceedings 1998., Thirteenth Annual*. 1998. IEEE.
[7].   Femia, N., et al., *Optimized one-cycle control in photovoltaic grid connected applications.* Ieee Transactions on Aerospace and Electronic Systems, 2006. **42**(3): p. 954-972.
[8].   Wu, W., et al. *DSP-based multiple peak power tracking for expandable power system*. in *Applied Power Electronics Conference and Exposition, 2003. APEC'03. Eighteenth Annual IEEE*. 2003. IEEE.

[9].   Hussein, K.H., et al., *Maximum Photovoltaic Power Tracking - an Algorithm for Rapidly Changing Atmospheric Conditions.* Iee Proceedings-Generation Transmission and Distribution, 1995. **142**(1): p. 59-64.

[10].   Bahgat, A.B.G., et al., *Maximum power point traking controller for PV systems using neural networks.* Renewable Energy, 2005. **30**(8): p. 1257-1268.

[11].   Sun, X., et al. *A research on photovoltaic energy controlling system with maximum power point tracking.* in *Power Conversion Conference, 2002. PCC-Osaka 2002. Proceedings of the.* 2002. IEEE.

[12].   Karlis, A.D., T.L. Kottas, and Y.S. Boutalis, *A novel maximum power point tracking method for PV systems using fuzzy cognitive networks (FCN).* Electric Power Systems Research, 2007. **77**(3-4): p. 315-327.

[13].   Kottas, T.L., Y.S. Boutalis, and A.D. Karlis, *New maximum power point tracker for PV arrays using fuzzy controller in close cooperation with fuzzy cognitive networks.* Ieee Transactions on Energy Conversion, 2006. **21**(3): p. 793-803.

[14].   Esram, T. and P.L. Chapman, *Comparison of photovoltaic array maximum power point tracking techniques.* Ieee Transactions on Energy Conversion, 2007. **22**(2): p. 439-449.

[15].   Salas, V., et al., *Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems.* Solar Energy Materials and Solar Cells, 2006. **90**(11): p. 1555-1578.

[16].   Femia, N., et al., *Optimization of perturb and observe maximum power point tracking method.* Ieee Transactions on Power Electronics, 2005. **20**(4): p. 963-973.

[17].   Singh, R. and B. Rajpurohit, *Performance Evaluation of Grid-Connected Solar Photovoltaic (SPV) System with Different MPPT Controllers*, in *Renewable Energy Integration.* 2014, Springer. p. 97-124.

[18].   Ali, A.N.A., et al., *A Survey of Maximum PPT techniques of PV Systems.* IEEE Energytech, USA, Cleveland, 2012: p. 1-17.

[19].   Livinti, P.G., Mazen. *Banc d'essai pour l'alimentation d'une pompe avec vibrateur électromagnétique et des lampes électriques.* in *Procedings of Francophone Multidisciplinary Colloquium on Materials, Environment and Electronics.* 2013.

[20].   Kim, Y., H. Jo, and D. Kim. *A new peak power tracker for cost-effective photovoltaic power system.* in *Energy Conversion Engineering Conference, 1996. IECEC 96., Proceedings of the 31st Intersociety.* 1996. IEEE.

[21].   Enslin, J.H.R., et al., *Integrated photovoltaic maximum power point tracking converter.* Ieee Transactions on Industrial Electronics, 1997. **44**(6): p. 769-773.

[22].   Femia, N., et al., *A technique for improving P&O MPPT performances of double-stage grid-connected photovoltaic systems.* Industrial Electronics, IEEE Transactions on, 2009. **56**(11): p. 4473-4482.

[23].   Liu, X. and L.A. Lopes. *An improved perturbation and observation maximum power point tracking algorithm for PV arrays.* in *Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual.* 2004. IEEE.