Variable Step Size P&O MPPT Controller to Improve Static and Dynamic PV System Performances

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Abstract. *In this paper, a variable step size P&O algorithm is used in order to improve the performance of a photovoltaic system in both dynamic and static plans. The efficiency of the proposed algorithm has been investigated successfully using the BP SX150S solar module connected to the DC-DC derived by a P&O MPPT algorithm. The comparative study results of both conventional fixed step size and the proposed variable step size P&O algorithms prove the effectiveness of the proposed algorithm compared to the standard fixed step size PO MPPT. The proposed algorithm reduces response time between 13.86% and 45.28% and the steady state oscillation between 83.33% and 100% leading to less power loss especially in case of fast changing atmospheric conditions.*

Keywords

Photovoltaic, MPPT, P&O, Fixed step size, Variable step size, DC-DC converter.

1. Introduction

Photovoltaic systems provide green renewable power by exploiting solar energy. They can be used as an alternative energy source in place of electricity generated from conventional fossil fuels. Photovoltaic, also called solar cells, are electronic devices that convert sunlight directly into electricity. This electrical energy can feeds many systems like: water pumping systems used for irrigation, hydrogen production, electrical power systems, ...etc [1]-[4].

The I-V characteristics of a PV module will vary with solar insolation and atmospheric temperature. In general, there is a unique point on the I-V or P-V characteristics, called the Maximum Power Point (MPP), at which the entire PV system (array, converter, etc...) operates with maximum efficiency and produces its maximum output power [5].

To determine the MPP of PV systems, many methods have been developed in the literature such as sliding mode algorithm [6]-[9], fuzzy logic algorithm [10]-[12], Incremental and Conductance (IC) algorithm [13]-[15] and Perturbation and Observation (P&O) algorithm [16]-[18].

In this work, a variable step size Perturbation and Observation algorithm is proposed to improve the performances in both dynamic and static regimes. The efficiency of the proposed algorithm has been studied successfully using Matlab/Simulink environment where the whole system including PV module as well as the DC-DC boost converter derived by the proposed variable step size P&O MPPT algorithm is modeled and investigated. The results of a comparative study between the fixed and variable step size P&O algorithms confirms that the proposed algorithm can effectively and simultaneously improve: the accuracy, the rapidity, the ripple and the overshoot in case of fast and changing atmospheric condition compared to the conventional fixed step size algorithm.

The rest of this paper is organized as follows: Section 2 describes the PV system modeling. The proposed variable step size P&O MPPT is detailed in Section 3. While, Section 4 show the simulation results and their discussion. Finally, Section 5 concludes the paper by dressing the main contributions and giving the perspectives of some future works.

2. PV SYSTEM MODELING

A PV cell equivalent circuit is shown in Fig. 1. The mathematical model can be simply expressed as [19]:

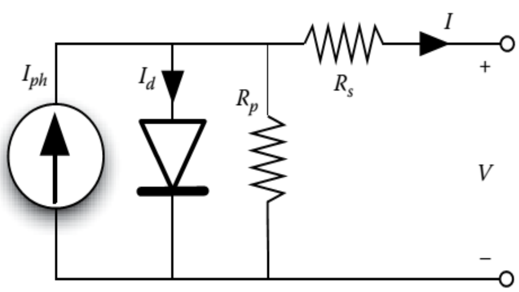

Fig. 1: One diode model.

$$I_{pv} = I_{ph} - I_{R_p} - I_d, \tag{1}$$

where I_{ph} is the photo-current; I_{Rp} is the shunt current; I_d is the diode current.

$$I_{ph} = \frac{\zeta}{\zeta_{ref}}[I_{sc,ref} + \vartheta_{I_{sc}}(T - T_{ref})] \tag{2}$$

$$I_{R_p} = \frac{V_{pv} + I_{pv}R_s}{R_p} \tag{3}$$

$$I_d = I_s(\exp\left(\frac{V_d}{AV_t}\right) - 1) \tag{4}$$

The diode saturation current is given by:

$$I_s = I_{s,ref}\left(\frac{T}{T_{ref}}\right)^3 \exp\left(\frac{qE_g(\frac{1}{T_{ref}} - \frac{1}{T})}{kA}\right), \tag{5}$$

with

$$I_{s,ref} = \frac{I_{sc,ref}}{\exp\left(\frac{V_{oc,ref}}{AV_t}\right) - 1} \tag{6}$$

and

$$V_t = \frac{kT}{q} \tag{7}$$

From equations (1) to (7), I_{pv} is defined by:

$$I_{pv} = I_{ph} - I_s\left(\exp\left[\lambda\left(V_{pv} + I_{pv}R_s\right)\right] - 1\right) - \frac{V_{pv} + I_{pv}R_s}{R_{sh}}, \tag{8}$$

where

$$\lambda = \frac{1}{AV_t} = \frac{q}{AkT} \tag{9}$$

The BP SX150S module parameters used to draw the PV characteristics are listed in Table 1. Figures 2 and 3 show the typical output characteristics (I-V) and (P-V) of PV cell, which are simulated under variable solar irradiation ($\zeta = 600, 700, 800, 900$ and $1000\,\mathrm{W/m^2}$) and constant temperature ($T = 25^o$C); while Figures 4 and 5 show the typical output characteristics (I-V) and (P-V) of PV cell under variable temperature ($T = 25, 50$ and 75^oC) with constant irradiance ($\zeta = 1000\,\mathrm{W/m^2}$).

3. PROPOSED VARIABLE STEP SIZE P&O MPPT

From mathematical model and Figures 2 to 5, it is clear that solar PV presents nonlinear characteristics varying with solar irradiation and temperature. Consequently, it is mandatory to integrate maximum power stage to adapt and guarantee the maximum power transfer to the load

Table 1. On diode PV cell model.

Parameter	Value
Maximum Power (P_{max})	150 W
Voltage at P_{max} (V_{mpp})	34.5 V
Current at P_{max} (I_{mpp})	4.35 A
Warranted minimum P_{max}	140 W
Short circuit current (I_{SC})	4.75 A
Open-circuit voltage (V_{OC})	43.5 V
Maximum System Voltage	600 V
Temp. Coefficient of I_{SC}	$(0.065 \pm 0.015)\,\%/^{o}C$
Temp. Coefficient of V_{OC}	$(160 \pm 20)\,mV/^{o}C$
Temp. Coefficient of Power	$(0.5 \pm 0.05)\,\%/^{o}C$
NOCT	$47 \pm 2^{o}C$

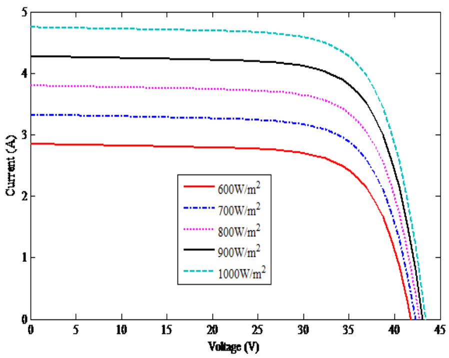

Fig. 2: I-V characteristics under variable irradiation.

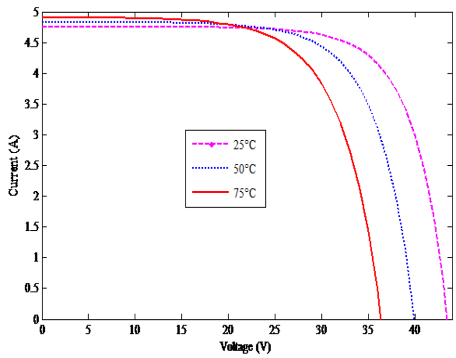

Fig. 4: I-V characteristics under variable temperature.

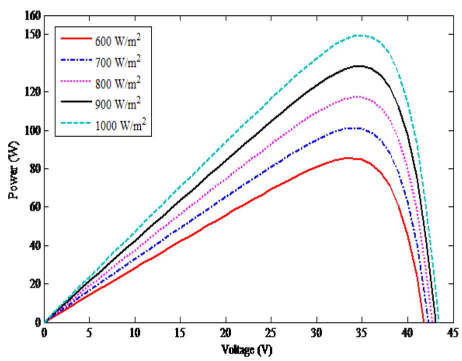

Fig. 3: P-V characteristics under variable irradiation.

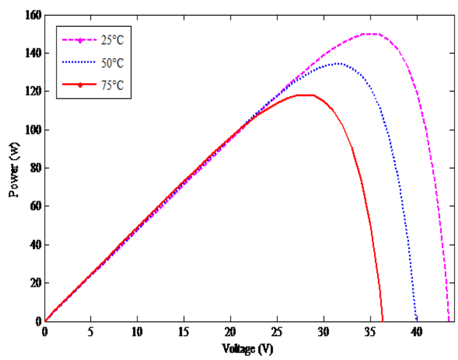

Fig. 5: P-V Characteristics under variable temperature.

in case of alteration of atmospheric conditions. For this purpose, various MPPT algorithms have been proposed in the literature, among them the Perturbation and Observation method is the most commonly algorithm used in photovoltaic systems due to its simplicity of implementation and few control parameters required [15, 16]. The P&O flowchart is shown in Fig. 6.

The aim is to get the maximum power point by adjusting perturbation in the duty cycle by continually measuring voltage/current from PV panel, the power output is measured then: if the value of power output $P_k > P_{k-1}$ then perturbation is uninterrupted in the same sense. If the new value of power output $P_k < P_{k-1}$ then perturbation is applied in the opposite sense. This operation operates while maximum power point is not reached. In general, the conventional P&O algorithm with fixed step size has two major drawbacks [17, 18] represented by the relationship between the oscillation and response speed. With a small fixed step size, we get low oscillation at the expense of response speed and in case of large step size we have a good speed with over strong oscillations. In order to overcome

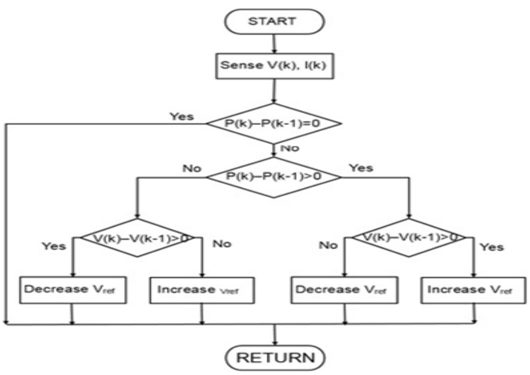

Fig. 6: Flowchart of conventional P&O algorithm.

the drawbacks of the fixed step size algorithm, a variable step size P&O algorithm operates with a variable step size, where the duty cycle is adjusted directly with large step size when far from the MPPT point and with small step size around the MPPT point. The novel step size is given by:

$$D_k = D_{k-1} \pm \Delta D * SF, \tag{10}$$

where SF is the scaling factor equal to $|dP/dV|$; dP and dV are the changes in power and voltage.

4. RESULTS AND DISCUSSIONS

To verify the performance of the proposed variable step size P&O MPPT algorithm, the whole system including PV module as well as the DC-DC boost converter drived by the proposed variable step size P&O MPPT algorithm is modeled and investigated using Matlab/Simulink environment.

Figure 7 shows the output power for both conventional fixed step size and proposed variable step size P&O method when the irradiance changes. From Fig. 7, we can see that both algorithms track the maximum power point in case of variable irradiation with best performances for the proposed algorithm compared to the fixed step size algorithm in term of rapidity and overshoot.

A) Dynamic Performances.

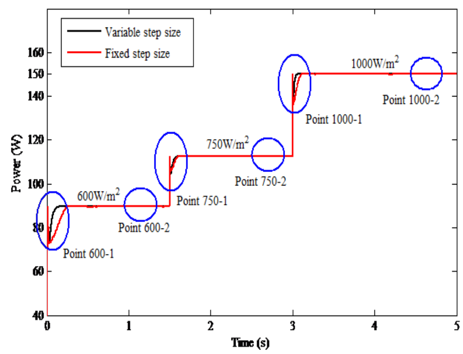

Fig. 7: Output power.

Figures 8 to 10 show the zoom-in of the points 600-1, 750-1 and 1000-1 giving the dynamic response of both fixed and variable step size PO MPPTs corresponding to irradiation level $600\,\mathrm{W/m^2}$, $750\,\mathrm{W/m^2}$ and $1000\,\mathrm{W/m^2}$, respectively. In this case we compare the response time for the proposed variable step size MPPT (Tr-VSS) to the response time of the classical fixed step size MPPT (Tr-FSS). From Figs. 8

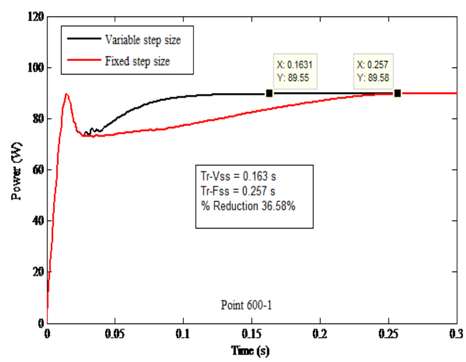

Fig. 8: Output power: Zoom in Point 600-1.

to 10, we can see that the proposed variable step

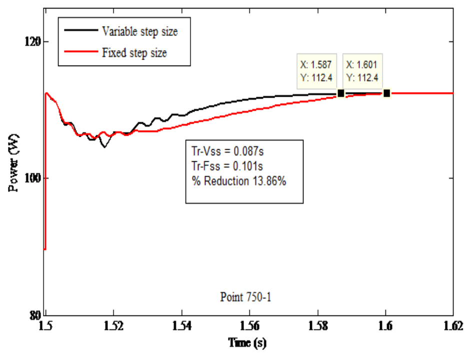

Fig. 9: Output power: Zoom in Point 750-1.

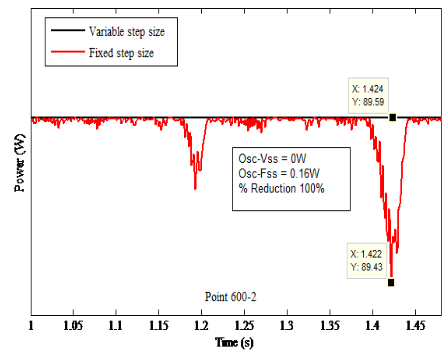

Fig. 11: Output power: Zoom in Point 600-2.

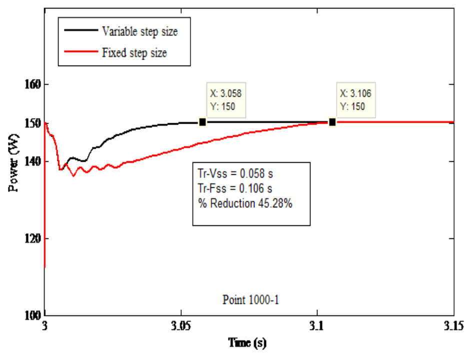

Fig. 10: Output power: Zoom in Point 1000-1.

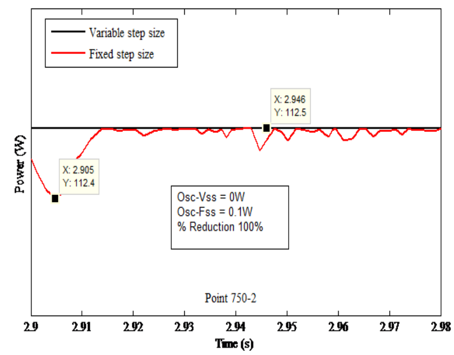

Fig. 12: Output power: Zoom in Point 750-2.

size PO MPPT outperforms the standard fixed step size PO MPPT in case of changing irradiation level from 600 W/m^2 to 750 W/m^2 and from 750 W/m^2 to 1000 W/m^2. The response time reduction ratio using the proposed variable step size PO MPPT is between 13.86% and 45.28%.

B) Steady State Performances.

Figures 11 to 13 show the zoom-in of the points 600-2, 750-2 and 1000-2 giving the steady state response of both fixed and variable step size PO MPPTs corresponding to irradiation level 600 W/m^2, 750 W/m^2 and 1000 W/m^2, respectively. In this case we compare the oscillation around the MPP point for the proposed variable step size MPPT (Osc-VSS) to the oscillation around the MPP of the classical fixed step size MPPT (Osc-FSS). From Figures 11 to 13, it is clear that the proposed variable step size PO MPPT performs better than the standard fixed step size PO MPPT in case of changing irradiation level from 600 W/m^2 to 750 W/m^2 and from 750 W/m^2 to 1000 W/m^2. The steady state oscillation reduction ratio using the proposed variable step size PO MPPT is between 83.33% and 100%.

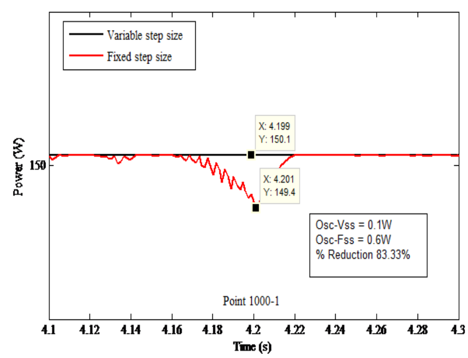

Fig. 13: Output power: Zoom in Point 1000-2.

C) Course Around MPP.

Table 2. Response time reduction.

	Tr-FSS (s)	Tr-VSS (s)	Red ratio (%)
Point 600-1	0.257	0.163	36.58
Point 750-1	0.101	0.087	13.86
Point 1000-1	0.106	0.058	45.28

The MPP point tracking using both PO MPPTs in case of changing irradiation level from 600 W/m^2 to 750 W/m^2 and from 750 W/m^2 to 1000 W/m^2 is given in Fig. 14. While the zoom-in around the MPP point is given in Figs. 15 and 16, respectively. In this case we evaluate the course of the MPP point (Osc-MPP) for both algorithms the classical fixed step size and the proposed variable step size one. From Figs. 15 and 16, we can see clearly that we have less oscillation around the MPP point with the proposed variable step size algorithm compared to the fixed step size algorithm (around 0.0001 W for the variable step size PO MPPT instead of 0.0225 W for the fixed step size PO MPPT). Figure 17 gives the corresponding duty cycle computed by both algorithms.

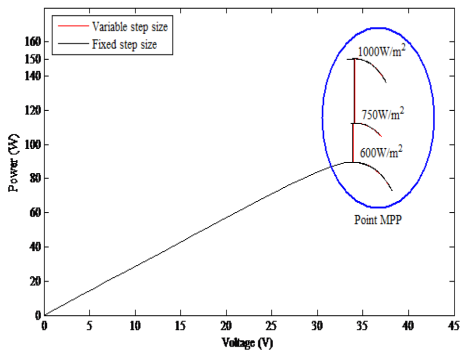

Fig. 14: P-V characteristics.

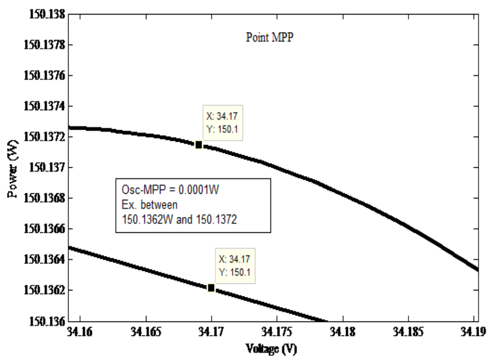

Fig. 15: P-V characteristics: Zoom in Point MPP (oscillation in the case of the variable step size MPPT).

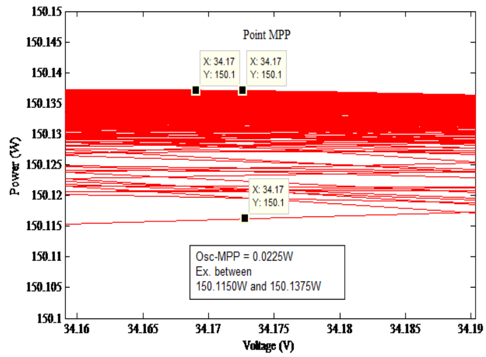

Fig. 16: P-V characteristics: Zoom in Point MPP (oscillation in the case of the fixed step size MPPT).

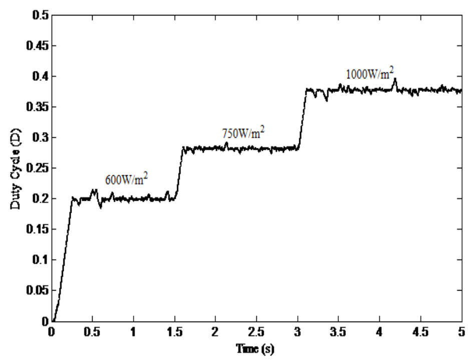

Fig. 17: Variable step size Duty Cycle.

Tables 2 and 3 summarize the main contributions of this study regarding the reduction of the response time as well as the oscillation around the MPP.

Table 3. Steady state oscillation reduction.

	Osc-FSS (W)	Osc-VSS (W)	Red ratio(%)
Point 600-2	0.16	0.00	100
Point 750-2	0.10	0.00	100
Point 1000-2	0.60	0.10	83.33

5. CONCLUSIONS

In this paper, a variable step size P&O maximum power point controller for PV systems has been proposed and investigated via the modeling of the whole system including the PV generator as well as the DC-DC boost converter derived using the P&O MPPT controller under Matlab/Simulink environment. The comparative study of results for both conventional fixed step size and the proposed variable step size P&O algorithms prove the effectiveness of the proposed algorithm compared to the standard fixed step size PO MPPT. The proposed algorithm reduces response time between 13.86% and 45.28% and the steady state oscillation between 83.33% and 100% leading to less power loss especially in case of fast changing atmospheric conditions. As future works, we plan to validate experimentally the proposed algorithm using a hardware in the loop platform.

References

[1] Motalleb, M., Đukić, A., & Firak, M. (2015). Solar hydrogen power system for isolated passive house. International journal of hydrogen energy, 40(46), 16001-16009.

[2] Campana, P. E., Li, H., Zhang, J., Zhang, R., Liu, J., & Yan, J. (2015). Economic optimization of photovoltaic water pumping systems for irrigation. Energy Conversion and Management, 95, 32-41.

[3] Akyuz, E., Coskun, C., Oktay, Z., & Dincer, I. (2011). Hydrogen production probability distributions for a PV-electrolyser system. international journal of hydrogen energy, 36(17), 11292-11299.

[4] Bakos, G. C., & Soursos, M. (2002). Technical feasibility and economic viability of a grid-connected PV installation for low cost electricity production. Energy and Buildings, 34(7), 753-758.

[5] Gomathy, S. S. T. S., Saravanan, S., & Thangavel, S. (2012). Design and implementation of maximum power point tracking (MPPT) algorithm for a standalone PV system. International Journal of Scientific & Engineering Research, 3(3), 1-7.

[6] Garraoui, R., Hamed, M. B., & Sbita, L. (2015). A robust optimization technique based on first order sliding mode approach for photovoltaic power systems. International Journal of Automation and Computing, 12(6), 620-629.

[7] Arteaga Orozco, M.I., Vázquez, J. R., Salmerón, P., Litrán, S.P., Alcántara, F. J. (2009). Maximum power point tracker of a photovoltaic system using sliding mode control. *International Conference on Renewable Energies and Power Quality Valencia (Spain)*, 1.

[8] Garraoui, R., El Aroudi, A., Hamed, M. B., Sbita, L., & Al-Hosani, K. (2016). A Comparative Study Between Two MPPT Controllers Based on the Principe of Sliding-Mode Control Theory and Intelligent Control Technique in Photovoltaic Systems. In Proceedings of the Mediterranean Conference on Information & Communication Technologies 2015 (pp. 505-515). Springer, Cham.

[9] Garraoui, R., Hamed, M. B., & Sbita, L. (2017). MPPT Controllers Based on Sliding-Mode Control Theory and Fuzzy Logic in Photovoltaic Power Systems: A Comparative Study. In Applications of Sliding Mode Control (pp. 215-231). Springer, Singapore.

[10] Mahamudul, H., Saad, M., & Ibrahim Henk, M. (2013). Photovoltaic system mod-

eling with fuzzy logic based maximum power point tracking algorithm. International Journal of Photoenergy, 2013.

[11] Makhloufi, M. T., Khireddine, M. S., Abdessemed, Y., & Boutarfa, A. (2014). Maximum Power Point Tracking of a Photovoltaic System using a Fuzzy Logic Controller on DC/DC Boost Converter. International Journal of Computer Science Issues (IJCSI), 11(3), 1.

[12] Harrag, A., Messalti, S. (2018). Improving PV Performances using Fuzzy-based MPPT, In book: Artificial Intelligence in Renewable Energetic Systems, 236-244.

[13] Selvan, D. S. (2013). Modeling and simulation of incremental conductance MPPT algorithm for photovoltaic applications. International Journal of Scientific Engineering and Technology, 2(7), 681-685.

[14] Kharb, R. K., Shimi, S. L., Chatterji, S., & Ansari, M. F. (2014). Modeling of solar PV module and maximum power point tracking using ANFIS. Renewable and Sustainable Energy Reviews, 33, 602-612.

[15] Harrag, F. A., Titraoui, S. A., & Bahri, T. H. (2017, May). P&O or IC for PV pumping system: What MPPT algorithm to improve performances?. In Systems and Control (ICSC), 2017 6th International Conference on (pp. 220-225). IEEE.

[16] Tlili, N., Neily, B. & Ben Salem, F. (2014). Coupling a Photovoltaic Generator, a PEM Fuel Cell and an Electrolyzer (Part I), IEEE, 1-7.

[17] Palizban, O., & Mekhilef, S. (2011, November). Modeling and control of photovoltaic panels base perturbation and observation MPPT method. In Control System, Computing and Engineering (ICCSCE), 2011 IEEE International Conference on (pp. 393-398). IEEE.

[18] Bahri, H., Harrag, A. (2017). Variable Step Size P&O MPPT ontoller to Improve Static and Dynamic PV System Performances, The Third Internnational Conference on Electrical Engineering and Control Applications (ICEECA'2017).

[19] Karami, N., Moubayed, N., & Outbib, R. (2014). Energy management for a PEMFC–PV hybrid system. Energy Conversion and Management, 82, 154-168.

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