MPPT based on a novel multi-swarm PSO with factor selection strategy for PV applications

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Abstract: This paper seeks to improve the efficiency of photovoltaic (PV) system using Multi-Swarm Particle Swarm Optimization algorithm with Factor selection strategy based Maximum Power Point Tracking (FMSPSO-MPPT). The FMSPSO-MPPT optimization algorithm has been used to saves the computation time and performs an excellent tracking capability with high accuracy, minimal oscillations around the Maximum Power Point MPP and high robustness. To demonstrate the superiority and robustness of the proposed FMSPSO-MPPT controller, the obtained results are analyzed and compared with others obtained from the Conventional Methods (P&O-MPPT) and Particle Swarm Optimization (PSO-MPPT). The obtained results show that the proposed FMSPSO MPPT controller gives the best performances under variables atmospheric conditions.

Keywords: Photovoltaic systems, Maximum Power Point Tracking (MPPT), Particle Swarm Optimization, Factor selection.

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1. Introduction

TE photovoltaic (PV) energy represents a very important and promising source where it provides very clean energy without any environmental effect like fossil resources. The PV solar modules have a relatively low efficiency level compared to the efficiency of conventional fossil fuel and to the efficiency of other renewable energy sources such as wind [1]-[4]. In order to improve the efficiency of PV system through tracking the Maximum Power Point (MPP), many classical MPPT techniques have been developed in literature such as perturb and observe (P&O) [5], [6] and incremental conductance (IncCond) [7], [8]. These classical algorithms are easy to implement and can guarantee a good performance under uniform radiation. However, their major drawbacks are the continuous oscillations around the MPP and longer response time when climatic conditions change [9].

In recent years, several control methods have been proposed to overcome the classical methods problems. Among them, we cite Ant Colony Algorithm (ACO) [10], Particle Swarm Optimization (PSO) [11], Cuckoo Search Algorithm (CSA) [12], Gray Wolf Optimization (GWO) [13]. Recently a new PSO algorithm based on factor selection have been presented in [14].

In this context, this paper presents the development of an efficient MPPT control based on (FMSPSO) strategy in order to track the maximum power in the PV system in case of solar irradiation and ambient temperature variations. To demonstrate the efficiency and robustness of the proposed control algorithm, simulation results are compared with conventional PSO-MPPT algorithm and classical P&O-MPPT controller.

This paper is organized as follows: in Section 2, the modelling of the studied system is presented. Section 3 is dedicated to the presentation of the FMSPSO algorithm for tracking technique of MPP. In Section 4, we present the obtained simulations results using MATLAB/Simulink concerning the PV system behaviors under the “FMSPSO”, “P&O” and “PSO” for variables atmospheric conditions. Finally, a conclusion is given.

2. Photovoltaic System Model

The system investigated in this paper is a stand-alone PV generator. As shown in Fig. 1, the system consists of PV panel and DC-DC boost converter. The proposed MPPT control action is carried out by the proposed FMSPSO algorithm. The different part of the PV system will be illustrated in the following subsections.

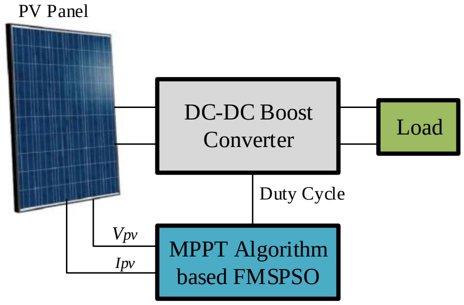

Fig. 1 general photovoltaic conversion chain

2.1 PV Panel Model

The most common equivalent scheme for a PV system is shown in Fig. 2. For (N_s) panels connected in series and (N_p) panels connected in parallel, the model of a PV system is given by the following equations:

$$I_{pv} = N_p I_{ph} - N_p I_0[\exp\left(\frac{q\left(V_{pv}+I_{pv}.R_s\right)}{a.k.T.N_s}\right)-1] - \frac{V_{pv}+I_{pv}.R_s}{R_{sh}} \quad (1)$$

$$I_0 = I_{0r}\left(\frac{T}{T_{ref}}\right)^3 \exp\left[\frac{q.E_G}{a.k}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)\right] \quad (2)$$

$$I_{ph} = \left[I_{sc}+k_T\left(T-T_{ref}\right)\right]\frac{I}{I_{ref}} \quad (3)$$

where I_{pv} is the output current of solar cells (Ampere), I_{ph} is the Photocurrent (Ampere), V_{pv} is the output voltage of solar cells (Volt), R_{sh} and R_s are Parallel and series resistance, respectively, q is the electron charge (1.60222×10^{-19}C), k is the Boltzmann's constant (1.381×10^{-23}J/K), a is the P-N junction ideality factor, I_0 and I_{0r} are real and reference cell reverse saturation current respectively, k_T is the temperature coefficient of the short circuit current, T and T_{ref} are the reference temperature of Solar Cells (Kelvin), I and I_{ref} are the Irradiance and reference irradiance, E_G is the silicon bandgap energy (E_G=1.12eV) and I_{sc} is the short-circuit current.

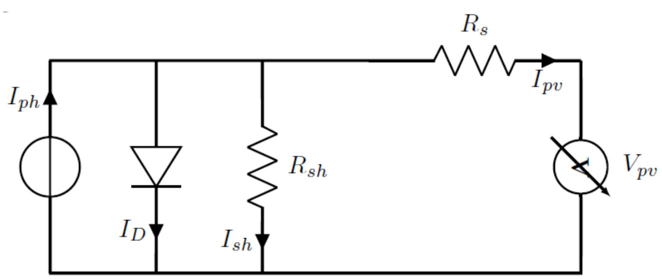

Fig. 2 equivalent circuit diagram of solar cell

The characteristics of the used PV panel in this work given in Table I.

Table I. parameters of PLM-300M-72 PV module

The voltage at MPP (VMPP)	36.59V
The current at MPP (IMPP)	08.20A
Open-circuit voltage (Voc)	45.60V
Short-circuit current (Isc)	08.78A
Maximum power	300W
Peak Efficiency	15.37%
Temp. Coefficient of Isc: µsc	0.06%/°C
Temp. Coefficient of VOc	-0.34%/°C
Temp. Coefficient of Pmax	-0.45%/°C
Number of Cells	72

The I-V and P-V characteristics of the PLM- 300M-72 PV module used in this study for different insolation are given in Figs. 3 and 4 respectively.

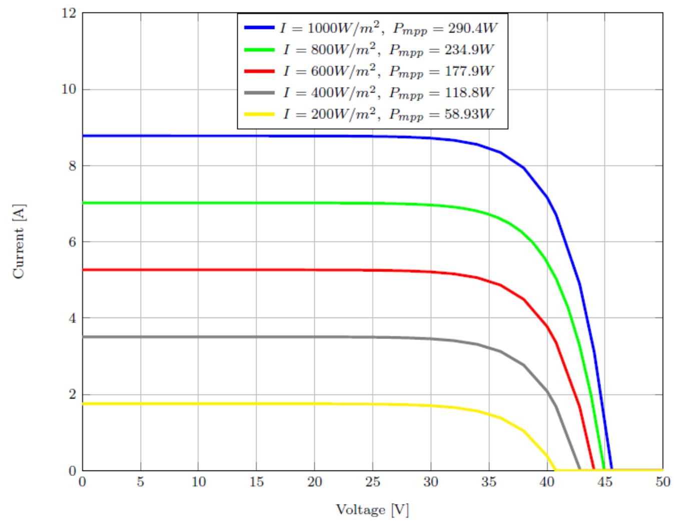

Fig. 3 I-V output characteristics of PV module for different irradiance levels (T = 25°C)

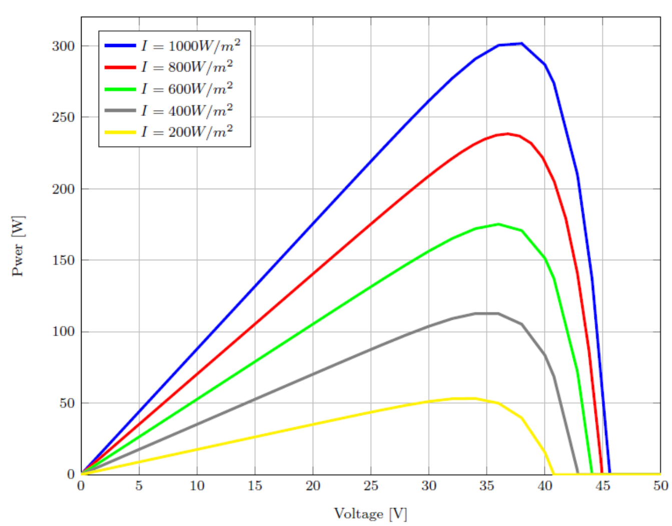

Fig. 4 P-V output characteristics of PV module for different irradiance levels (T = 25°C)

2.2 DC-DC Boost Converter Model

The maximum power point (MPP) is tracked using a boost converter, which enables the panel voltage to be adjusted by its duty cycle *D*. The photovoltaic panel is connected to the load through the boost converter as shown in Fig. 5.

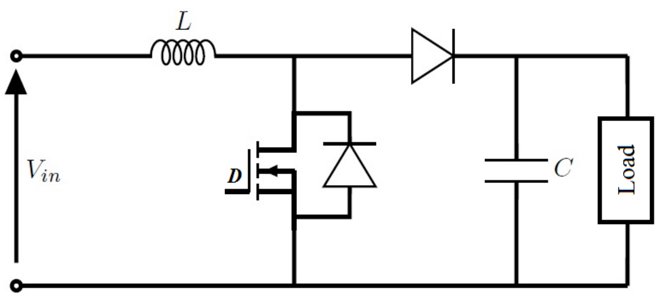

Fig. 5 DC-DC Boost converter circuit

The output voltage of the boost converter V_{out} is given by the following expression:

$$V_{out} = \frac{1}{1-D} V_{in} \quad (4)$$

The boost converter parameters values are calculated using the following expressions:

$$\frac{\Delta V_{out}}{V_{out}} = \frac{D}{R.C.f} \quad (5)$$

$$L > \frac{(1-D)^2.R}{2.f} \quad (6)$$

where *R* is the load resistor, *C* is the capacitor, *f* is the switching frequency and L is the inductance which ensure a continuous conduction.

3. MPPT Control Using MSPSO Algorithm Based on Factor Selection Strategy

The MSPSO algorithm based on factor selection strategy has been presented for the first time in 2021 by [16]. The FMSPSO have been tested on different benchmark functions in order to investigate the convergence speed, which is used to overcome the limitations of the conventional PSO algorithm mentioned previously. The classical MSPSO is composed by two basic sub-swarms, an adaptive sub-swarm and an exploration sub-swarm, that can perform heterogeneous search with the possibility to share information between them [17]. The position updates rules for the exploration sub-swarms, the basic sub-swarms and the adaptive sub-swarm is defined by (7) and (8).

$$v_i^{k+1} = \omega.v_i^k + c_1.r_1\left(p_{best_i} - x_i^k\right) + c_2.r_2\left(G_{best} - x_i^k\right) \quad (7)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (8)$$

where

i: Variable of the optimization vector;

k: Number of iterations;

v_i^k, x_i^k: Velocity and position of the *i^th^* variable within *k* iterations;

ω: Inertia that maintains a balance between the local and global search;

c_1, c_2: Acceleration constants;

r_1, r_2: Two generated random numbers.

The particle velocity of the basic sub-swarms is updated at the end of iteration and the particle velocity for the adaptive sub-swarm can be described by the following equations:

$$v_i^{(1/2)}(k+1) = \omega.v_i^{(1/2)}(k) + c_1.r_1\left(p_1^{(1/2)} - x_i^{(1/2)}(k)\right) + c_2.r_2\left(G_{best} - x_i^{(1/2)}(k)\right) \quad (9)$$

$$v_i^3(k+1) = \omega\left[\frac{\gamma}{\gamma_1}v_i^{(1)}(k+1) + \frac{\gamma}{\gamma_2}v_i^{(2)}(k+1) + v_i^{(3)}(k+1)\right] + c_1.r_3\left(p_i^{(3)} - x_i^{(3)}(k)\right) + c_2.r_4\left(G_{best} - x_i^{(3)}(k)\right) \quad (10)$$

where

γ_1, γ_2: Fitness numbers of the particles in sub-swarms S_1 and S_2;

r_3, r_4: Random values that are uniformly distributed on [0; 1].

The nonlinear factor weight improvement adjustment presented in [16] is described by (11):

$$\omega = (\omega_m - \omega_M)\arctan h\left(\delta\left(1 - \frac{K}{K_{\max}}\right)^m\right) + \omega_m \quad (11)$$

where

ω_m, ω_M: Minimum and maximum bounds of the inertia weighting factor;

γ, m: Parameters of the control factors;

$K, K_{\max}$: Current iteration of the algorithm and maximum number of iterations respectively.

The velocity and the position of the i^{th} particle in exploration sub-swarm are updated based on the following equations:

$$v_i^{(4)}(k+1) = v_i^{(1)}(k+1) + v_i^{(2)}(k+1) - v_i^{(3)}(k+1) \quad (12)$$

$$x_i^{(4)}(k+1) = \alpha_1 x_i^{(4)}(k) + \alpha_2 p_i^{(4)}(k) + \alpha_3 G_{best} + v_i^{(4)}(k+1) \quad (13)$$

where α_1, α_2 and α_3 are the impact factors which must satisfy the following relations:

$$\alpha_1 + \alpha_2 + \alpha_3 = 1 \quad (13)$$

4. Simulations Results

The proposed Multi-Swarm Particle Swarm Optimization algorithm with Factor selection strategy based Maximum Power Point Tracking (FMSPSO-MPPT) has been verified by simulations under MATLAB/Simulink with 5µs sampling period. The FMSPSO-MPPT control scheme is illustrated in Fig. 6. During the simulation, the system will be exposed first to a rapid dynamic irradiance profile at a fixed temperature (T=25°C), and then to a slow dynamic irradiance profile and temperature as illustrated in Figs. 7 and 8.

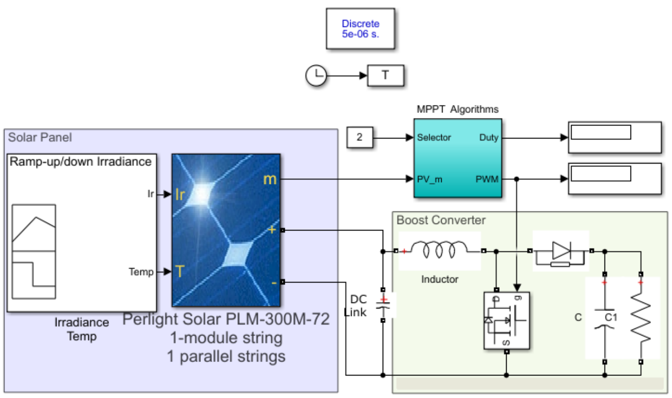

Fig. 6 block diagram of the photovoltaic system

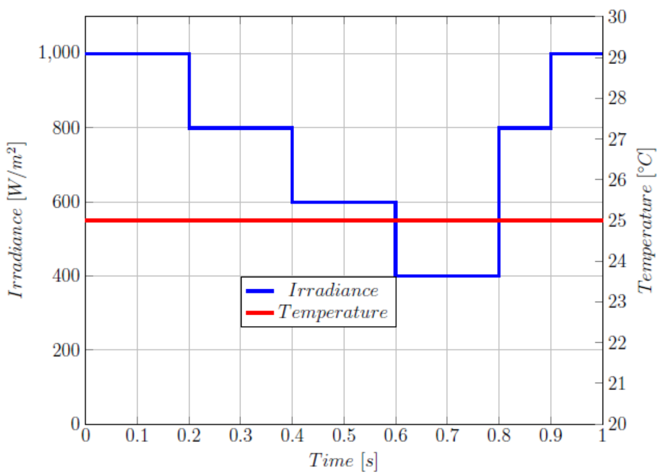

Fig. 7 rapid irradiance and temperature profile

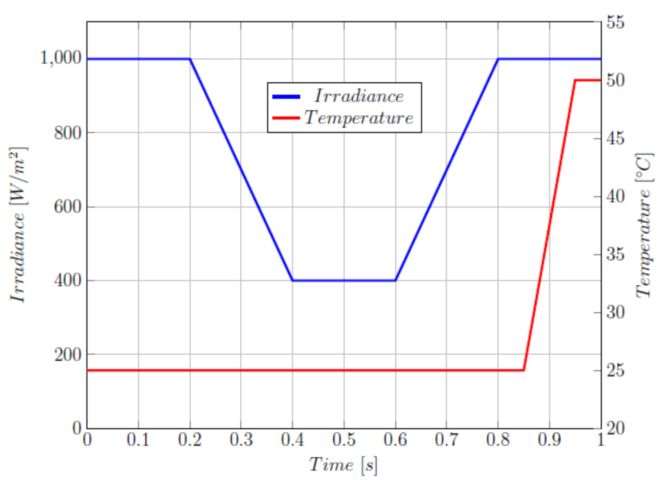

Fig. 8 slow irradiance and temperature profile

The parameters of the proposed (FMSPSO) MPPT algorithm are presented in Table II. The boost converter parameters are listed in Table III.

Table II. parameters values of the FMSPSO algorithm

Parameters	Values
c_1, c_2	2
γ_1, γ_2	0.45
m	2
K_{max}	25
ω_m	0.41
ω_M	0.78
$\alpha_1, \alpha_2, \alpha_3$	0.15, 0.35, 0.5
r_1, r_2, r_3, r_4	0.21, 0.3, 0.5, 0.15

Table III. parameters values of the boost converter

Parameters	Values
Input voltage	20 to 150V
Rated output voltage	200V
Rated output current	9A
Rated output power	1800W
Switching Frequency	50KHz
C	66µF
Q	IRFP460
L	2mH
D	STPS20150CT

Fig. 9 and 10 shows the panel power extracted for the FMSPSO-MPPT, PSO-MPPT and P&O-MPPT. One can observe that whenever there is a change in climatic conditions, the proposed FMSPSO-MPPT algorithm succeeded in extracting the maximum power in a very short time compared to the other three algorithms.

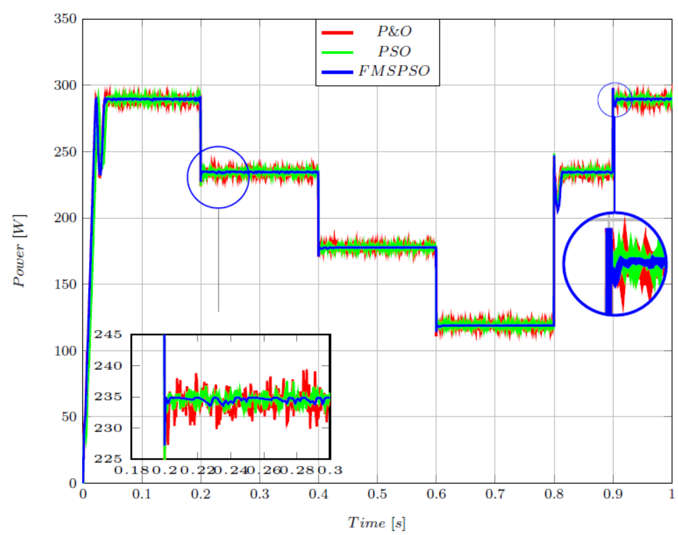

Fig. 9 simulation results of the FMSPSO-MPPT, PSO-MPPT and P&O and MPPT (slow profile)

As shown in Figs. 9 and 10, the FMSPSO and PSO algorithm take around 35ms to track the MPP, and the P&O

algorithm about 40ms. It can also be noted from Fig. 11 that the voltage and power are sensitive to temperature variation.

In case of PSO algorithm, the control produces satisfactory results with a global efficiency which does not exceed 97% for the used irradiance and temperature profile. The P&O algorithm can track the MPP but with significant ripples.

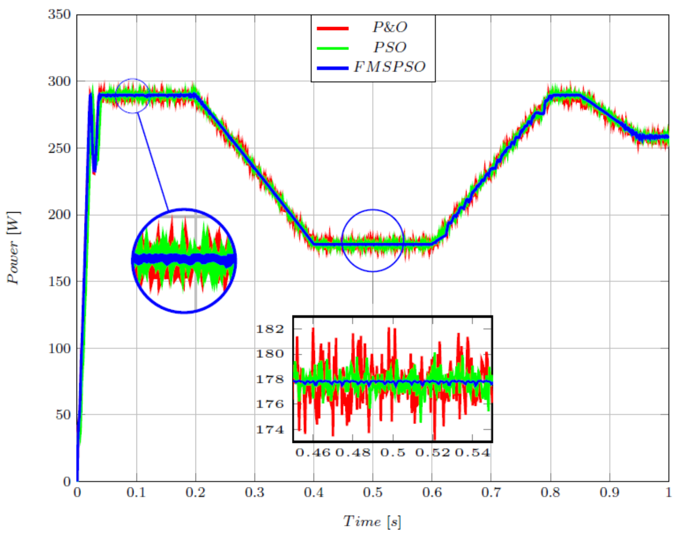

Fig. 10 simulation results of the FMSPSO-MPPT, PSO-MPPT and P&O and MPPT (slow profile)

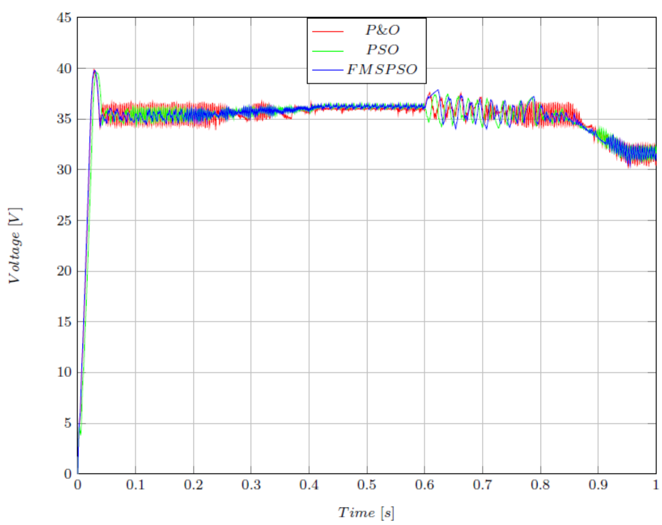

Fig. 11 output voltage of the FMSPSO-MPPT, PSO-MPPT and P&O and MPPT

The value of the MPP, the actual PV voltage and power captured for the proposed climatic condition from the PV energy system is also given in Table V for the three used algorithms. Comparing with the P&O and PSO MPPT techniques, the proposed FMSPSO algorithm appears as one of the most powerful algorithms that can perform very efficiently under variable climatic condition, with an efficiency that reaches 99.5%.

Table V. comparison of the different used MPPT algorithms.

MPPT Algorithm	Maximum Power Point	PV Voltage	Efficiency
FMSPSO	288.5W	36.37V	99.5%
PSO	286.5W	36.01V	98.8%
P&O	283W	35.5V	97.6%

5. Conclusion

A MATLAB Simulink model of a solar PV panel was built in order to examine the effects of changing in climatic conditions. Existing algorithms such as P&O and PSO suffer from weak robustness caused by strong oscillations around the MPP with a longer convergence time. In this paper, FMSPSO based MPPT control method is proposed for PV array. The proposed method has been analyzed by simulation using MATLAB/Simulink. A PV module and a boost converter were simulated to test the FMSPSO algorithm for various climatic conditions. As a result of the analysis, the proposed MPPT algorithm tracks the MPP more precisely and accurately than the P&O and PSO algorithms. In addition, efficiency is increased to reaches 99.5% in comparison with classical P&O, and PSO. The simulation results showed that the proposed FMSPSO algorithm has better performance in tracking the MPP effectively with a short convergence time and small oscillations.

References

[1] M. Brahmi, B. R. Chiheb, H. Hamdi and Z. Abderrahmen (2022), “Comparative Study of P&O and PSO Particle Swarm Optimization MPPT Controllers for Photovoltaic Systems”, 2022 8th International Conference on Control, Decision and Information Technologies (CoDIT).

[2] H. Hamdi, B. R. Chiheb and Z. Abderrahmen (2019), “Performance improvement of a photovoltaic system with a radial basis function network based on particle swarms optimization”, 2019 International Conference on Signal, Control and Communication (SCC).

[3] G. Abelaziz, H. Hamdi, B. R. Chiheb and G. Rached (2021), “Shading effect on the performance of a photovoltaic panel”, 2021 IEEE 2nd International Conference on Signal, Control and Communication (SCC).

[4] Z. A. Yahya, N. Nayeff, M. Ahmed, M. Mohammed and M. Souaad (2021), “Design and simulation of PV grid-connected system considering senstivity analysis”, 2021 IEEE 48th Photovoltaic Specialists Conference (PVSC).

[5] E. Salman S, A. Xin and W. Zhouyang (2018), “Design of a P-&-O algorithm based MPPT charge controller for a stand-alone 200W PV system”, Prot Control Mod Power Syst 3, 25 (2018).

[6] M. Saibal and K. A. Ashok (2021), “Comparative analysis of various P & O MPPT algorithm for PV system under varying radiation condition”, 2021 1st International Conference on Power Electronics and Energy (ICPEE).

[7] M. A. Hamam, A. A. Emad, M. J. Abdulhamed and M. A. S. Ahmed (2019), “Incremental Conductance Algorithm

Optimization for a Photovoltaic System with Fast Response Under Fast-Varying of Solar Power", 2019 10th International Renewable Energy Congress (IREC).

[8] S. Liqun, G. Hangchen and Z. Weiwei (2020), "An improved MPPT control strategy based on incremental conductance algorithm", Prot Control Mod Power Syst 5, 14 (2020).

[9] S. K. Jae, H. Jun-Ho and K. Jong-Chan K (2020), "Overview of Maximum Power Point Tracking Methods for PV System in Micro Grid", Electronics 2020, 9, 816.

[10] P. Neeraj, K. R Vigna, P. Sanjeevikumar and A. Farooque (2019), "An Ant Colony Optimized MPPT for Standalone Hybrid PV-Wind Power System with Single Cuk Converter", Energies 12, no. 1:167.

[11] H. Hichem, B. R. Chiheb and Z. Abderrahmen (2019), "Real-time study of a photovoltaic system with boost converter using the PSORBF neural network algorithms in a MyRio controller", Solar Energy, Volume 183, 1, May 2019, Pages 1-16.

[12] K. Farag, M. Alaaeldin and Y. Almoataz(2019), "MPPT-Based Particle Swarm and Cuckoo Search Algorithms for PV Systems, Modern Maximum Power Point Tracking Techniques for Photovoltaic Energy Systems". Green Energy and Technology. Springer.

[13] G. Ke, C. Lichuang, M. Mingxuan, Z. Lin and Z. Qianjin (2020), "An Improved Gray Wolf Optimizer MPPT Algorithm for PV System With BFBIC Converter Under Partial Shading", in IEEE Access, Volume 8, pp. 103476-103490, 2020.

[14] Chrouta J, Farhani F and Zaafouri A (2021) A modified multi swarm particle swarm optimization algorithm using an adaptive factor selection strategy, Transactions of the Institute of Measurement and Control. July 2021, pp. 1-10.

[15] Cheung N J, Ding X M and Shen H B (2014) A convergent heterogeneous particle swarm optimization algorithm for takagi–sugeno fuzzy modeling, IEEE Transactions on Fuzzy Systems, Volume 22(4), pp. 919–933.

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Author Contributions: Please, indicate the role and the contribution of each author:

Example

Chiheb Ben Regaya conceived the FMSPSO-MPPT algorithm.

Chiheb Ben Regaya, Mahbouba Brahmi and Hichem Hamdi carried out the simulation using MATLAB-Simulink.

Chiheb Ben Regaya and Abderrahmen Zaafouri performed the analysis.

Chiheb Ben Regaya, Mahbouba Brahmi, Hichem Hamdi and Abderrahmen Zaafouri wrote the paper.

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