ZIBELINE INTERNATIONAL PUBLISHING

Journal of Mechanical Engineering Research and Developments (JMERD)

ISSN: 1024-1752
CODEN : JERDFO

DOI : http://doi.org/10.26480/jmerd.04.2018.116-121

CrossMark

REVIEW ARTICLE

TRACKING MAXIMUM POWER POINT FOR PHOTOVOLTAIC SYSTEM USING A NOVEL DIFFERENTIAL PARTICLE SWARM OPTIMIZATION

Van Huong Dong[1], Khai Hoan Nhu[1,2], Thi Thom Hoang[2], Thanh Cong Pham[3]

[1]Ho Chi Minh City University of Transport, Ho Chi Minh city, Vietnam
[2] Nha Trang University, Khanh Hoa, Vietnam
[3]Ho Chi Minh City University of Food Industry, Ho Chi Minh city, Vietnam

ARTICLE DETAILS

Article History:

Received 13 September 2018
Accepted 16 October 2018
Available online 7 November 2018

ABSTRACT

In this paper, a new differential particle swarm optimization (DPSO) method is investigated for tracking the maximum power point (MPP) for the photovoltaic (PV) system in order to enhance the operating efficiency of the PV system. The DPSO-based MPPT method is not only able to tract the MPP using few iterations, but also avoids the steady-state oscillation phenomenon. Moreover, the proposed method is capable for extracting the optimization power under varying temperature condition as well as large fluctuations of irradiation. To demonstrate the effectiveness of the proposed, the obtained results are compared to those obtained using the conventional perturb and observation (P&O), incremental conductance (IncCond), and classical particle swarm optimization (PSO). Furthermore, a boost converter supplied by a solar array simulator is done to check the stability of the circuit. Meanwhile, the DPSO-MPPT algorithm is embedded in the PV system simulated by using Simulink software and MATLAB Toolbox. The simulating results show the superiority of the proposed approach in improving the efficiency of the photovoltaic system.

KEYWORDS

Boost converter, maximum power point tracking (MPPT), particle swarm optimization (PSO), photovoltaic (PV) system, solar insolation.

1. INTRODUCTION

In recent decades, the PV energy plays an important role in meeting the rapidly increasing demand of world energy along with development of bio-energy based on bio-based fuels and waste heat recovery technologies to satisfy the ever-stricter regulations in relation to environmental pollution [1-12]. Up to date, many countries on over the world has a PV capacity of more than one gigawatt [13,14]. By the beginning of 2017, the largest PV capacity of 850MW was reached in Longyangxia Dam Solar Park in China [15]. The use of solar energy increases significantly because of low fuels costs, environmentally friendly and low-cost maintenance. However, the cost of PV array as well as equipment for energy conversion is a great challenge in using PV systems. Besides that, the P –V characteristic depends entirely on the extreme environmental condition, including solar insolation and temperature. Therefore, a MPPT controller is often coordinated a power converter to maintain the efficient operation of the PV arrays [16,17]. Traditionally, the MPPT controllers normally use the (P&O) and incremental conductance (IncCond) algorithm because of simple deployment and few parameters [18-23]. In the P&O algorithm, the voltage of the PV array is perturbed by a small increment which results in a variation of output power, P. If the P is improved, the perturbation will move the operating voltage toward the MPP, then the direction of perturbation is retained. In case of a negative P, the system is operated far from the optimal point, thus the direction is reversed accordingly in order to bring the operating point back to the MPP. In the IncCond algorithm; meanwhile, the derivative rate of conductance is compared to the instantaneous conductance to extract the optimization power of PV arrays. However, the main drawback of the InCond and P&O methods is the low efficiency and oscillations around the MPP caused by the dynamics and the perturbation step size [24]. Another method is the hill climbing (H&C), which directly updates the operating point of the PV system by perturbing the duty cycle [25,26]. In spite of simply implement, the H&C also suffers with same disadvantages inherited by two above methods. Furthermore, under PSC and modules irregularities, the results of tracking MPP by using the conventional methods is not accurate due to multiple peaks on the PV curves.

To overcome this aforementioned drawbacks, the artificial intelligence (AI) algorithm, namely fuzzy logic (FL) and neural network (NN) have recently been investigated in order to extract the maximum power in case of non-linear I_V characteristic [27, 28]. Nevertheless, they require an extensive computation with high-cost processors to deal to continuously change in environmental condition. The other new MPPT algorithms, inspired by nature and biological structure, have been proposed for tracking MPP from PV array, including genetic algorithm (GA), differential evolution (DE), and particle swarm optimization (PSO) [29-32]. Among AI algorithms, the PSO has been presented as the best solution for tracking MPP under extreme environmental condition. However, the main drawback of PSO is the significantly decrease of particles' velocity once they find the MPP, thus the operating efficient of the PV arrays is also reduced.

In this paper, the DPSO algorithm has been investigated for the first time to track MPP of PV systems. Compared to the classical PSO, the proposed DPSO is performed by adding one more term in the velocity equation in order to search for a better solution in the search space. The proposed DPSO- based MPPT has a similar structure to the classical PSO and hence it is also capability of avoiding steady-state oscillation and tracking the MPP under partial shading condition (PSC) as well as large fluctuations of insolation. Furthermore, the algorithm has faster tracking speed, simpler deployment using a lower cost controller as compared to other conventional MPPT methods. The rest of this paper is organized as follows. Section II describes research problems, including modeling of the PV module and array. Section III proposed the DPSO algorithm and how to use it for improving the MPPT performance. The simulating results are given in Section IV. Finally, Section 5 presents the conclusion of the work.

2. PROBLEM DESCRIPTION

Various equivalent circuit models are used to describe PV modules, in which the single diode model, as shown in Figure 1, is the most popular [33].

The output current I and the photocurrent I_{PV} for the equivalent circuit in Figure 1 are given by:

$$I = I_{PH} - I_{d1} - \left(\frac{V + IR_S}{R_{SH}}\right) \quad (1)$$

The diode characteristic is given as follow:

$$I_{d1} = I_{RS}\left[\exp\left(\frac{V + IR_S}{\alpha V_T}\right) - 1\right] \quad (2)$$

where I_{RS} is the reverse saturation current of diode 1, α is the diode ideality constant, and V_T is the thermal voltage of PV modules that is expressed by:

$$V_T = k\frac{T}{q} \quad (3)$$

where k is the Boltzmann constant, T is the temperature of the p-n junction in Kelvin and q is the electron charge.

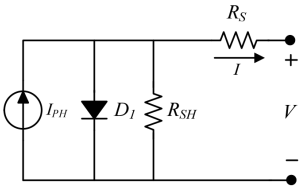

Figure 1: The single diode model of PV module

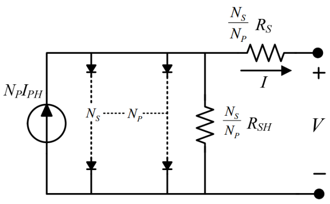

Figure 2: Series-parallel structure of a PV array.

For a PV system, the cells are connected in a series–parallel matrix (N_S x N_P), as shown in Figure 2 [34]. The mathematical equation representing a PV array is given as follows:

$$I = N_P\left[I_{PH} - I_{RS}(I_P + 2)\right] - \left(\left(\frac{V + IR_S\lambda}{R_{RS}\lambda}\right)\right) \quad (4)$$

where

$$I_p = \exp\left(\frac{V + IR_S\lambda}{V_T N_S}\right) + \exp\left(\frac{V + IR_S\lambda}{(p-1)V_T N_S}\right) \quad (5)$$

and

$$\lambda = \frac{N_S}{N_P} \quad (6)$$

Figures 3 and 4 depict the I–V and P–V characteristics of a common PV array. It can be seen that from these figures that photovoltaic cell characteristic is non-linear, whose output power varies as a function of the irradiance and temperature, thus decreasing the operating efficiency of PV system. Also, the efficiency of these photovoltaic modules is not satisfied by the power requirement and hence require an intelligent algorithm to overcome this problem. In this paper, a model using the DPSO assisted MPPT algorithm is designed to enhance the efficiency of PV.

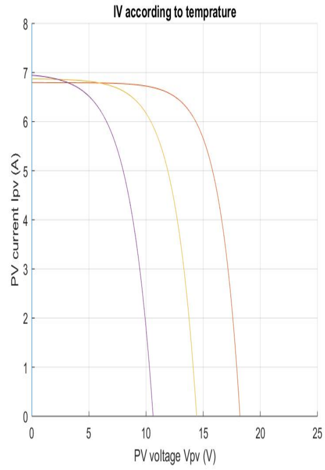

Figure 3: I-V curves for different temperature levels

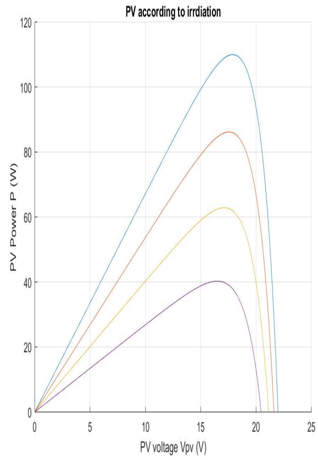

Figure 4: P-V curves for different irradiation levels

3. THE PROPOSED DPSO-BASED MPPT ALGORITHM

In this section, a novel DPSO-based MPPT algorithm is developed for improving the efficient of PV systems. For this, the concepts of DPSO is introduced first.

3.1 DPSO

The DPSO is a modified version of PSO, in which particles are capable of escaping from local minima in order to find a better optimization solution in the search space. PSO is inspired by social and cooperative behavior displayed by various species to fill their needs in a multi-dimensional search space [35]. The algorithm is guided by personal experience (Pbest), overall experience (Gbest) and the present movement of the particles used to decide their next positions in the search space. More details about the basic conceptualization of PSO can be found in [36,37].

The proposed DPSO considers an additional feature in the classical PSO. The additional feature is the opinion of one of the particles selected randomly from the swarm. The randomly-scaled difference of the particle and its opinion-giver particle is included in the velocity equation of the particle necessary to escape from local minima. Mathematically, the concepts of DPSO can be expressed as follows:

$$V_{p,q}^{k+1} = w \times V_{p,q}^{k} + c_1 r_1 (Pbest_{p,q}^{k} - X_{p,q}^{k}) + c_2 r_2 (Gbest_{q}^{k} - X_{p,q}^{k}) + c_3 r_3 (X_{l,q}^{k} - X_{p,q}^{k}) \quad (7)$$

$$X_{p,q}^{k+1} = X_{p,q}^{k} + V_{p,q}^{k+1} \quad (8)$$

In Eq. (7), c_3 is the scaling factor and r_3 is a randomly-generated random number between 0 and 1, whereas l represents the expert particle corresponding to target particle p. In this equation, l varies from 1 to N but l ≠ p. Fig.5 shows the search mechanism of the proposed DPSO in a multidimensional search space.

In Figure 5, $Pbest^k_{p,q}$ represents personal best q^{th} component of p^{th} individual, whereas $Gbest^k_q$ represents q^{th} component of the best individual of population up to iteration k.

Cite The Article: Van Huong Dong, Khai Hoan Nhu, Thi Thom Hoang, Thanh Cong Pham (2018). Tracking Maximum Power Point For Photovoltaic System Using A Novel Differential Particle Swarm Optimization. *Journal of Mechanical Engineering Research and Developments*, 41(4) : 116-121.

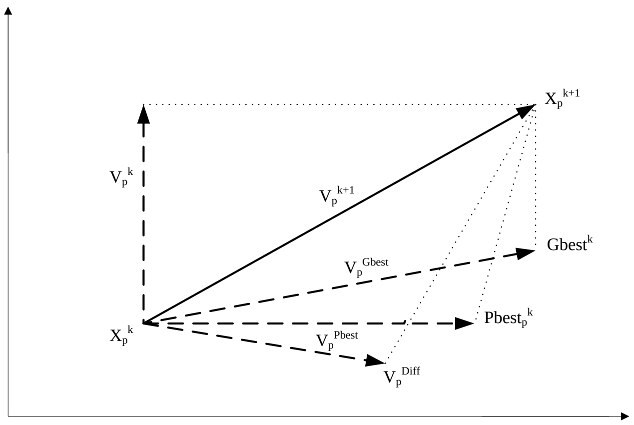

Figure 5: Proposed DPSO search mechanism of pth particle at kth iteration in a multi-dimensional search space

It is found from Figure 5 that the proposed DPSO is performed by adding one more term (V_p^{Diff}) in the velocity equation, thus the MPP can be obtained much sooner than that using the classical PSO. Furthermore, this additional feature allows the particles to escape from a local optimum in order to search for a better solution in the other reasons in the search space.

3.2 Application of DPSO to MPPT

The complete flowchart for the proposed method is shown in Figure 6 and the proposed DPSO assisted MPPT algorithm uses the following basic principles:

Step 1: In this paper, the duty cycle value d of the dc–dc converter is selected as the particle position in the search space. Meanwhile, the PV module output power is defined as the fitness value evaluation function. It can be noted that the number of particles should be is selected as the number of the series connected cells in PV array.

Step 2: The DPSO algorithm will start the optimisation from a random initial value that is determined as follows:

$$D_i^k = [D_1, D_2, D_3, ..., D_N] \tag{9}$$

where N is the number of particles and k is the number of iterations. It means the particles are initialized on random positions which cover the search space [Dmin, Dmax]. Dmax and Dmin are the maximum and minimum duty cycle of the utilized dc-dc converter, respectively.

Step 3 (fitness evaluation): After the digital controller sends the PWM command according to the duty cycle, which also represents the position of particle i, the PV voltage V_{PV} and current I_{PV} are defined. These values are the basis of calculating the fitness evaluation of particle i (the PV module output power). The fitness of each particle is evaluated $F_p^k = f(X_p^k)$,∀p and then finding the best particle index b

Step 4: Select $Pbest_p^k = X_p^k$, ∀p and $Gbest^k = X_b^k$

Step 5: Update the velocity and position of each particle using eqns. (7) and (8)

Step 6: Evaluate the updated fitness of each particle $F_p^{k+1} = f(X_p^{k+1})$, ∀p and find the best particle index b1

Step 7: Update Pbest of each particle∀p and Gbest of population

If $F_p^{k+1} < F_p^k$ $then$ $Pbest_p^{k+1} = X_p^{k+1}$ $else$ $Pbest_p^{k+1} = Pbest_p^k$,

If $F_{b1}^{k+1} < F_b^k$ $then$ $Gbest^{k+1} < Pbest_{b1}^{k+1}$ and set $b = b1$ $else$ $Gbest^{k+1} < Gbest^k$,

Step 8: If $k \le Maxite$ $then$ $k = k+1$ and go to step 5 else go to step 9

Step 9: Optimum solution obtained and hence print the results Gbest.

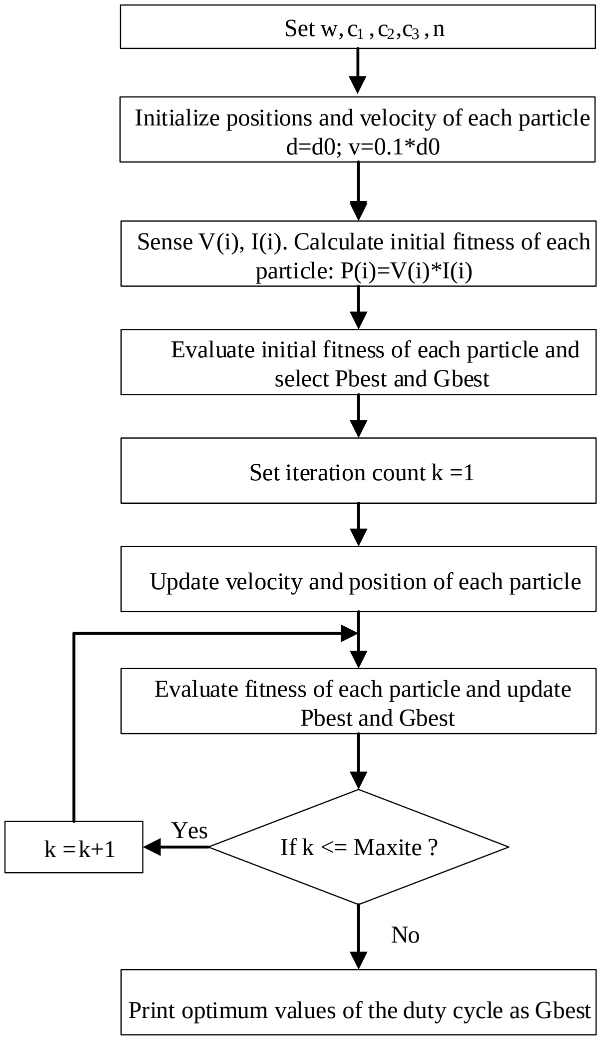

Figure 6: Flowchart of the proposed DPSO_MPPT

4. SIMULATION RESULTS AND DISCUSSION

The proposed DPSO-based MPPT algorithm was developed on a model, which consists of a PV solar panel connected to resistive load through a boost converter with MPPT controller, as depicted in Figure 7. It can be observed that the PV voltage and current from the PV module are sent into the MPPT controller, and subsequently the output of the PWM signal, are used to drive the switch of the boost converter in order to execute the MPPT from the PV module.

To achieve the best performance of the proposed DPSO algorithm, parameter selection plays an important role. During this work, the following procedure is adopted to obtain the best parameters of the algorithm. For different population sizes of 10, the best set of parameters for the DPSO algorithm as follows:

1. Inertia weight is taken in between 0.1 to 0.5 (randomly at each iteration);

2. Acceleration factors (c_1 and c_2) are 1.5 and 2.5, respectively.

3. Scaling factor c_3 is 0.04

4. Maximum iteration is set to 1000.

It can be noted that all the programs were developed in MATLAB environment and executed on an Intel core i7 processor and 2.66GHz clock frequency with 8192MB RAM.

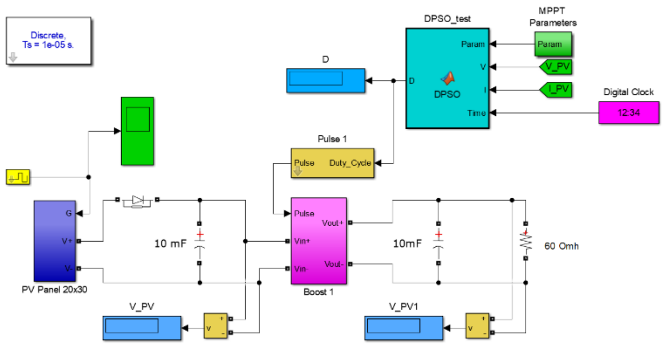

Figure 7: Simulink model of the DPSO_based MPPT system

In this paper, the proposed DPSO-MPPT algorithm has been initially tested with a Matlab/Simulink model under fixed environmental condition. To demonstrate the effectiveness and high efficiency of the proposed algorithm, the output response time was compared to the conventional P&O and IncCond methods. Furthermore, the convergence characteristic of the DPSO-MPPT is compared to the classical PSO-MPPT in order to verify faster and more accurate MPP tracking ability of the proposed method. It is to be noted that the duty cycle d is periodically updated using a fixed step-size of 0.01 for the P&O and IncCond algorithms. The switching frequency of the converter was set to 1 kHz.

Figure 8 shows the response time of output power under constant environmental condition (the solar insolation G = 900 W/m² and the temperature T = 25°C) in case of without MPPT controller, using DPSO and the conventional methods. It can be observed that the maximum capacity of power to be produced by using MPPT controllers is over 7600W, while the power obtained to be 7360 W without any MPPT algorithm. Moreover, the output power value of the proposed DPSO algorithm for the test PV module is 7678 W, which is higher than that obtained by using the conventional methods (7656 W). As can also be seen from Fig. 8 that it only takes 0.57 s to track the optimization power for the proposed DPSO, whereas the P&O and IncCond methods yielded the MPP tracking time of 2.9 s. In other words, the MPPT controllers are capacity of improving the operating efficiency of PV panel, in which the tracking ability of the proposed DPSO algorithm is better compared to two remain methods. Another superior advantage of the proposed algorithm is to eliminate oscillations in a steady state after few iterations.

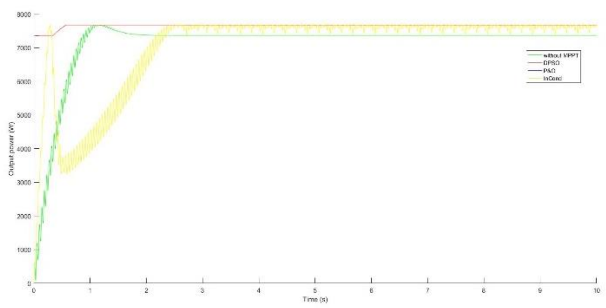

Figure 8: The response time of output power using the DPSO and the conventional methods at G = 900 W/m² and T = 25°C

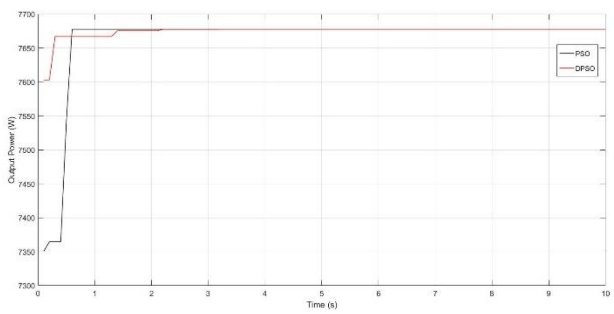

Figure 9: The response time of output power using the DPSO and PSO at G = 900 W/m² and T = 25°C

To demonstrate the superiority of the DPSO, a comparison of tracking the optimization point using the PSO is performed for the test PV system, as shown in Figure 9. It can be clearly seen that both of the AI algorithms can find the optimization of centralized arrays without fluctuation around the MPP, but the improved tracked faster. The optimization time of the DPSO and PSO is 0.57 s and 2.12 s, respectively.

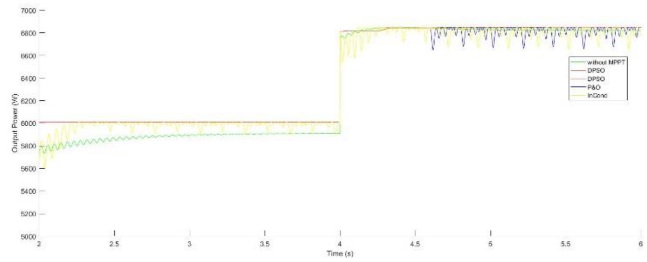

Figure 10: The dynamic characteristic of output power during rapidly increasing radiation values

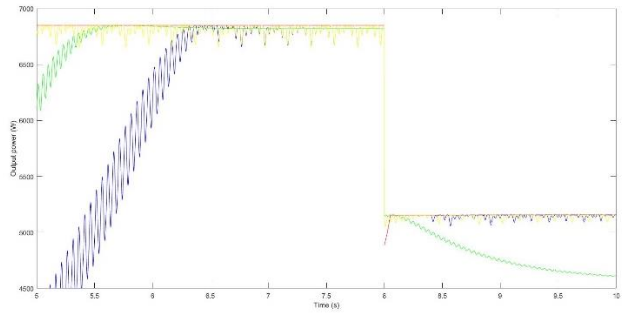

Figure 11: The dynamic characteristic of output power during rapidly decreasing radiation values

Figure 10 shows the dynamic characteristic of the output power under solar radiation varied between 700 W/m² and 800 W/m² at a fixed temperature of 25°C. It can be seen that the maximum power values reached by using the DPSO-MPPT controller are 6009 W for G = 700 W/m² and 6849 W for G = 800 W/m², which are the same to the theoretical value of the MPP. Meanwhile, the dynamic behaviour of the system in case of rapidly reducing irradiation is depicted in Figure 11. When the solar radiation is decrease from 800 W/m² to 600 W/m² at 8 s intervals, the output power obtained by using the DPSO-MPPT controller is 6849 W and 5158 W.

The results for tracking the MPP of the different MPPT controllers under fluctuations of irradiation are summarized in Table 1. It is observed that the power produced by using the proposed algorithm was greater than 99% under all test conditions.

Table 1: The obtained results of output power without/with the MPPT controller

G (W/m²)	Without MPPT	P&O	InCond	PSO	DPSO	the theoretical value of PV
600	4567.0	5137.0	5137.4	5157.2	5157.5	5157.7
700	5913.0	5994.8	5995.0	6009.0	6009.2	6009.7
800	6820.0	6812.0	6812.3	6849.1	6849.5	6850.0
900	7360.0	7655.0	7656.0	7677.2	7678.0	7678.3

5. CONCLUSION

In this paper, a novel DPSO algorithm is proposed by adding one more term in the velocity equation of the classical PSO algorithm in order to improving the operating efficiency of PV system. The DPSO-based technique has been successfully tested on a PV array model connected to a resistive load through a boost converter. The simulating results shows that the output energy of the proposed algorithm is above 99.5% with few iterations under all environmental conditions. Furthermore, these results are compared to the results obtained by the conventional P&O, InCond algorithms to demonstrates the ability of eliminating oscillations around the MPP. In addition, a comparative study of improving the performance of MPPT is carried out by using the PSO in order to faster and more accurate tracking of the proposed method. In short, the DPSO assisted MPPT is a simple and efficient method, which is capable of extracting the optimization power in few iterations under partial shading condition as well as large fluctuations of insolation.

REFERENCES

[1] Hoang, A.T. 2018. Prediction of the density and viscosity of biodiesel and the influence of biodiesel properties on a diesel engine fuel supply system. Journal of Marine Science and Engineering, https://doi.org/10.1080/20464177.2018.1532734.

[2] Hoang, A.T., Pham, V.V. 2018. Impact of Jatropha Oil on Engine Performance, Emission Characteristics, Deposit Formation, and Lubricating Oil Degradation. Combustion Science and Technology, https://doi.org/10.1080/00102202.2018.1504292.

[3] Hoang, A.T., Pham, V.V. 2018. A review on fuels used for marine diesel engines. Journal of Mechanical Engineering Research & Developments., 41 (4), 22-32.

[4] Hoang, A.T., Pham, V.V. 2019. A study of emission characteristic, deposits, and lubrication oil degradation of a diesel engine running on preheated vegetable oil and diesel oil. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects., 41 (5), 611-625.

[5] Hoang, A.T., Tran, Q.V., Al-Tawaha, A.R.M.S., Pham, V.V., Nguyen, X.P. 2019. Comparative analysis on performance and emission characteristics of an in-Vietnam popular 4-stroke motorcycle engine running on biogasoline and mineral gasoline. Renewable Energy Focus., 28, 47-55.

[6] Hoang, A.T., Nguyen, D.C. 2018. Properties of DMF-fossil gasoline RON95 blends in the consideration as the alternative fuel. International Journal of Advanced Science, engineering and Technology, 8 (6), 2555-2560.

[7] Hoang, A.T., Le, A.T. 2018. A review on deposit formation in the injector of diesel engines running on biodiesel. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 41 (5), 584–599.

[8] Hoang, A.T., Pham, M.T. 2018. Influences of heating temperatures on physical properties, spray characteristics of bio-oils and fuel supply system of a conventional diesel engine. International Journal of Advanced Science, engineering and Technology, 8 (5), 2231-2240.

[9] Hoang, A.T. 2018. Waste heat recovery from diesel engines based on Organic Rankine Cycle. Applied Energy, 231, 138–166.

[10] Hoang, A.T., Bui, X.L., Pham, X.D. 2018. A novel investigation of oil and heavy metal adsorption capacity from as-fabricated adsorbent based on agricultural by-product and porous polymer. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 40 (8), 929–939.

[11] Hoang, A.T., Chau, M.Q. 2018. A mini review of using oleophilic skimmers for oil spill recovery. Journal of Mechanical Engineering Research and Developments, 41 (2), 92–96.

[12] Hoang, A.T. 2018. A report of the oil spill recovery and treatment technologies to reduce the marine environment pollution. Int. J. e-Navigation Marit. Econ., 9, 35–49.

[13] Bangyin, L., Shanxu, D., Tao, C. 2011. Photovoltaic DC-building-module-based BIPV system-concept and design considerations. IEEE Xplore: IEEE Transactions on Power Electronics, 26 (5), 1418–1429.

[14] Young-Hyok, J., Doo-Yong, J., Jun-Gu, K., Jae-Hyung, K., Tae-Won, L., Chung-Yuen, W. 2011. A real maximum power point tracking method for mis-matching compensation in PV array under partially shaded conditions. IEEE Xplore: IEEE Transactions on Power Electronics, 26 (4), 1001–1009.

[15] Tim, B., Kashish, S. 2018. Solar is driving a global shift in electricity markets. IEEFA-Global-Solar-Report.

[16] Subudhi, B., Pradhan, R. 2013. A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems. IEEE Xplore: IEEE Transactions on Sustainable Energy, 4 (1), 89-98.

[17] Elgendy, M.A., Zahawi, B., Atkinson, D.J. 2013. Assessment of the incremental conductance maximum power point tracking algorithm. IEEE Xplore: IEEE Transactions on Sustainable Energy, 4 (1), 108–117.

[18] Brunton, S.L., Rowley, C.W., Kulkarni, S.R., Clarkson, C. 2010. Maximum power point tracking for photovoltaic optimization using ripple-based extremum seeking control. IEEE Xplore: IEEE Transactions on Power Electronics, 25 (10), 2531–2540.

[19] Ali, C., Chandra, A. 2015. An Optimal Maximum Power Point Tracking Algorithm for PV Systems with Climatic Parameters Estimation. IEEE Trans. Sustain. Energy, 6 (2), 644-652.

[20] Tang, P., Wa, L. 2005. A single cell maximum power point tracking converter without a current sensor for high performance vehicle solar arrays. In: Proceeding 36th annual IEEE power electronic specific conference, 165-171.

[21] Kobayashi, K.T., Takano, I., Sawada, Y. 2003. A study on a two-stage maximum power point tracking control of a photovoltaic system under partially shaded insolation conditions. In: Presented at the power engineering society general meeting.

[22] Tey, K.S., Mekhilef, S. 2014. Modified incremental conductance algorithm for photovoltaic system under partial shading conditions and load variation. IEEE Xplore: IEEE Transactions on Industrial Electronics, 61 (10), 5384–5392.

[23] Elgendy, Mohammed, Bashar, Z., David, J.A. 2015. Operating Characteristics of the P&O Algorithm at High Perturbation Frequencies for Standalone PV Systems. Energy Conversion, IEEE Transactions, 30 (1), 189-198.

[24] Ishaque, K., Salam, Z., Lauss, G. 2014. The performance of perturb and observe and incremental conductance maximum power point tracking method under dynamic weather conditions. Applied Energy, 119, 228-236.

[25] Xiao, W., Dunford, W.G. 2004. A modified adaptive hill climbing MPPT method for photovoltaic power systems. In: Presented at the proc of 35th annual IEEE power electron spec conf.

[26] Femia, N., Petrone, G., Spagnuolo, G., Vitelli, M. 2005. Optimization of perturb and observe maximum power point tracking method. IEEE Xplore: IEEE Transactions on Power Electronics, 20 (4), 963–973.

[27] Balasubramanian, G., Singaravelu, S. 2012. Fuzzy logic controller for the maximum power point tracking in photovoltaic system. International Journal of Computing, 41, 22–28.

[28] Syafaruddin, E.K., Hiyama, T. 2009. Artificial Neural Network-Polar Coordinated Fuzzy Controller Based Maximum Power Point Tracking Control under Partially Shaded Conditions. IET Renewable Power Generation, 3, 239.

[29] Messai, A., Mellit, A., Guessoum, A., Kalogirou, S.A. 2011. Maximum

power point tracking using GA optimize fuzzy logic controller and its FPGA implementation. Solar Energy, 86, 265–77.

[30] Taheri, H., Salam, Z., Ishaque, K., Syafaruddin. 2010. A novel maximum power point tracking control of photo-voltaic system under partial and rapidly fluctuating shadow conditions using differential evolution. In: Presented at the 2010 IEEE symposium on industrial electronics and applications.

[31] Hsiang, C.K., Chien, L.H. 2013. Maximum power point tracking method based on modiifed particle swarm optimization for photovoltaic systems. International Journal of Photoenergy, 1–6.

[32] Ishaque, K. 2013. A deterministic particle swarm optimization maximum power point tracker for photovoltaic system under partial shading condition. IEEE Trans Ind Electron, 60, 3195–206.

[33] Ramdan, K.B.A., Ahmed, Z.F., Adel, E. 2016. Novel MPPT Algorithm Based on Particle Swarm Optimization for Photovoltaic Systems. IEEE Transactions on Sustainable Energy, 1949-3029.

[34] Shim, E., Zaima, E. 2015. Introduction of Insulation Coordination for UHV AC Systems. Journal of Electrical Engineering and Technology, 10, 1293-1297.

[35] Cho, M.Y., Hoang, T.T. 2017. Feature Selection and Parameters Optimization of SVM Using Particle Swarm Optimization for Fault Classification in Power Distribution Systems. Computational Intelligence and Neuroscience, https://doi.org/10.1155/2017/4135465.

[36] Vapnik, V.N. 1995. The Nature of Statistical Learning Theory. 2nd ed.; Springer-Verlag, New York.

[37] Kennedy, J., Eberhart, R.C., Shi, Y. 2001. Swarm Intelligence, Morgan Kaufmann, San Francisco, USA.