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Development of PSO for tracking Maximum Power Point of Photovoltaic Systems

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***Abstract*— For a photovoltaic system, the relationship of the output voltage and power is usually non-linear, so it is essential to equip a MPPT controller in PV systems. Furthermore, the hotspot problem is a common phenomenon, resulting from the PV system operating under PSC. Partial shading not only damages the PV cells, but also makes it difficult to find the global MPP in the characteristic curves of P-V. The paper proposes a novel version of PSO, namely PPSO in order to detect the global peak among the multiple peaks, known as the true maximum energy from PV panel. For this, the PPSO algorithm makes the velocity of each particle be perturbed once the particles are struck into a local minima state in order to find the best optimum solution in the MPPT problem. The perturbation in the velocity vector of each particle not only helps them tracking the MPP accurately under the changing environmental conditions, such as large fluctuations of insolation and temperature like PSC; but also removes the steady-state oscillation. The proposed approach has been tested on a MPPT system, which controls a dc-dc boost converter connected in series with a resistive load. Moreover, the obtained results are compared to those obtained without any MPPT controller to prove the efficiency of the suggested method. In addition, this novel version gives the highest accuracy of tracking the optimum power in the least iteration number as compared to the conventional PSO.**

***Keywords*— boost converter, MPPT, partially shaded conditions, PSO, PV system.**

I. INTRODUCTION

Vietnam has the potential to develop its available renewable energy resources [1] that can be exploited and used in practice have been identified to date including: hydropower, wind energy, biomass energy, biogas energy, biofuels, solar energy, and geothermal energy [2]. Due to low fuel costs, environmentally friendly and low-cost maintenance, PV systems have an important role in the development of green energy [3]. However, the disadvantage of applying PV array is the high price of installation but the low energy conversion efficiency. Besides, the output power of photovoltaic is varied non-linearly with the voltage because of the changing environmental condition [4]. The recent PV array conversion efficiency only reaches below 20 %, it means an amount of 80% of solar energy is lost in the environment [3], [5]. An effective solution to this problem, a MPPT controller is normally combined with an energy conversion to exalt the operating efficiency of photovoltaic systems [6]. Due to the simple implement and fast computing time, the MPPT controller using the P&O [7], and INC algorithm [8] are the most popular. The P&O algorithm is performed based on the disturbance of the output voltage, leading to the output power variation of PV. For this, the direction of voltage perturbation has changed following to the movement of operating point toward the MPP. However, the oscillation around the balance state has lead to the power losses and the increase of convergence time. To improve the P&O method, the INC is implemented by the comparison between the instantaneous conductance of PV and the derivative rate of conductance. Because of the dynamic characteristic and the size of perturbation step; however, the conventional methods normally suffer the steady-state oscillation, giving rise to the low operating efficiency of PV [9].

To overcome this problems, the FLC has introduced to track accurately the MPP by using three steps: fuzzification, fuzzy rule base table and defuzzification [10]. However, the tracking accuracy depends on the number of the member functions, so the ANN [6], [11] is proposed in order to solute this problem. In spite of the higher operating efficiency, the ANN should be regularly trained because the

PV characteristic varies to its life.

For tracking MPP, the hotspot problem is very important in case of PV systems under PSC and can damage PV cells [12]. To avoid this situation, some of adaptive behaviors algorithms, including GA [13], DE [14], and PSO [15] have been applied to the MPPT controllers. Nevertheless, it is not easy for these methods to determine the global peak because of the appearance of multi-local peaks in the PV characteristic provided.

In this current study, PPSO has been developed to enhance the operating efficiency of PV. The proposed method is based on the perturbation of the velocity whenever the particles move toward the local minimal. In addition, the obtained results are compared to other conventional MPPT methods to demonstrate the superiority of the PPSO- based MPPT controller, even under the varying environmental condition.

II. MATERIALS AND METHODS

Figure 1 shows that the PV system modules are connected to a parallel-series matrix (N_S x N_P) [12]. Nevertheless, at all time, each cell can receive a different amount of solar energy because some modules might be covered by nearby tree, chimney, or cloud, known as PSC [16]. In this case, the sunlight energy received by the shaded cells is lower than that obtained by the non-shaded cells, leading to the hotspot problem. In other words, the hotpot phenomenon is occurred by absorbing the electric power generated by the non-shaded PV cells, giving rise to damage PV systems [17], [18].

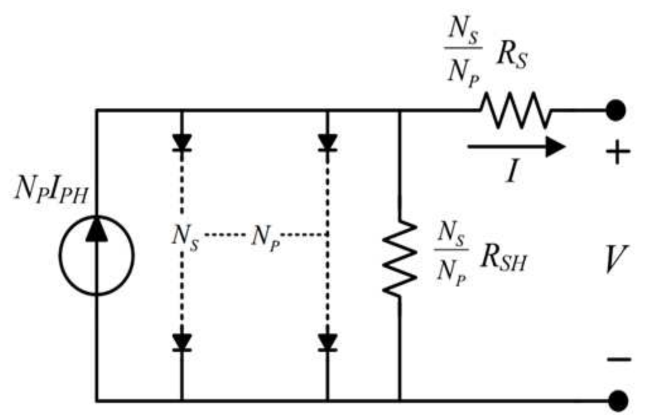

Fig. 1 Series-parallel structure of a PV array

In case of PSC, a PV cell has connected in parallel with a bypass diode to produce other path for the current in order to remove the hotspot problem. However, the disadvantage of inserting a diode is the presence of multiple peaks on the characteristics of the P–V, as shown Figure 2, in which there is only one global optimal point, giving the true MPP [19].

A variety of the conventional MPPT algorithms is proposed to detect this GP during PSC, but they are not effective because of high power loss [20]. To overcome this problem, some approaches are mentioned for finding the true MPP, in which the PSO-based MPPT algorithm is suggested controlling several PV arrays with a pair of voltage and current sensors [10]. However, it is difficult to detect the GP because it is trapped into a local optimum, and hence requires an improved PSO to overcome this problem.

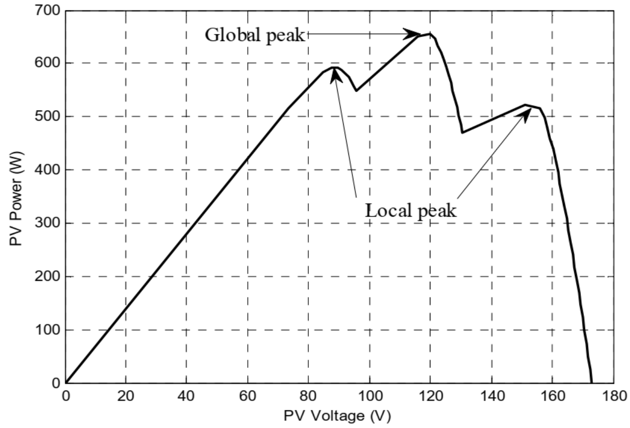

Fig. 2 Characteristic curve of PV modules under PSC

A. A Brief of PSO Algorithm

PSO is considered as a swarm intelligence, which is introduced in the first time by Kennedy and Eberhart in 2002 [21]. At first, each particle is initialized by random solutions and then keeps searching for the optimum solution by updating generations. It can be noted that these particles fly in the search space by P_{best} and G_{best}. Mathematically, the position of each particle is determined in the search space as follows:

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

$$X_{p,q}^{k+1} = X_{p,q}^{k} + V_{p,q}^{k+1} \tag{2}$$

Where:
c_1, c_2: learning factors;
r_1, r_2: random number between (0,1);
w: inertia factor.

P_{best} and G_{best} are determined as stated before. The search mechanism of PSO in a multidimensional search space is illustrated in Figure 3.

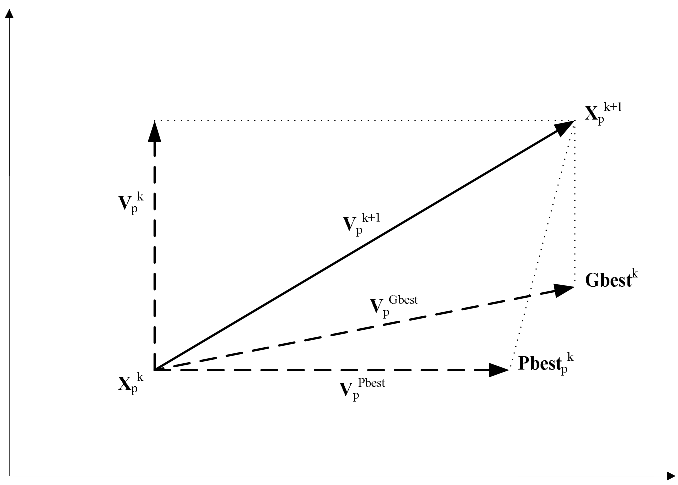

Fig.3 The search mechanism of PSO

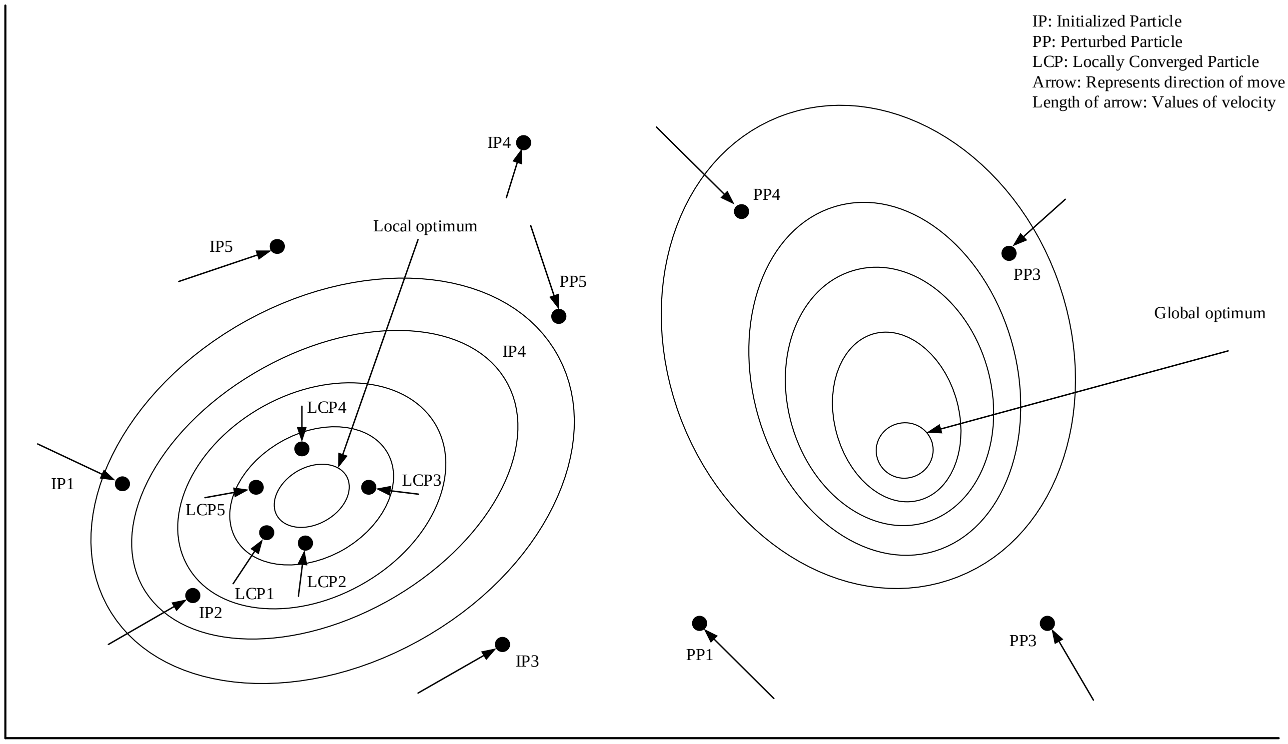

Fig. 4 Dynamics of particle in the multi-dimensional search space in the algorithm based on PSO

Compared to many similar population bionic intelligent algorithms, particles that can converge to the optimum point make the convergence speed of PSO faster. It can be seen from the eqn. (1); however, after a certain number of iteration, a slow decrease for the velocity of each particle can be observed, arising from the effect of the inertia weight w [22], [23]. Therefore, each particle is not capable to reach a position considerably for the smaller velocity; in other words, it is easy for them to be struck into a local optimal state. Figure 4 shows the dynamics of special particles, which have longer arrows in the PSO algorithm's search space.

B. The Improved PPSO Algorithm

The PPSO makes the velocity vector of each particle be disturbed once it reaches to a local peak. In other words, the velocity of each particle should be reset if there is no the best search solution of population after a certain number of iterations. The perturbation of velocity can help particles getting a great thrust to push them escaping from the optimal region with a local property. The perturbed velocity for each particle can be updated by the following equation.

$$V_{i,j}^{m+1} = Pbest_{i,j}^{m} \tag{3}$$

It is noted that the tolerance should be relaxed in order to receive another opportunity to continue the search process for a pre-defined number of iterations. It can be concluded that the particles can keep searching the optimal solution in the multidimensional space to avoid the local peaks by perturbing the velocity of each particle.

Detailed procedures for optimizing using PPSO can be presented in steps:

Step 1: Generate the swarm randomly in search space subject to upper and lower bounds and initialize the parameters of PPSO.

Step 2: Calculate the fitness function of each particle using the equation as following:

$$F_i^m = f\left(X_i^m\right), \tag{4}$$

Step 3: Set $Pbest_i^m = X_i^m$, ∀i and $Gbest^m = X_p^m$

Step 4: After setting the iteration count m = 1 and the tolerance t = 1, the velocity and position of each particle is updated by using eqns. (1) and (2).

Step 5: The fitness values of each particle corresponding to its new velocity and position are calculated as follows:

$$F_i^{m+1} = f\left(X_i^{m+1}\right), \tag{5}$$

where the best particle is indexed by p_1

Step 6: The updated personal experiment and overall experience for each particle are corresponding to:

$$if \quad F_i^{m+1} < F_i^m \quad then \quad Pbest_i^{m+1} = X_i^{m+1} \quad else \quad Pbest_i^{m+1} = Pbest_i^m \tag{6}$$

$$\begin{aligned} &if \quad F_{p1}^{m+1} < F_p^m \quad then \quad Gbest^{m+1} < Pbest_{p1}^{m+1} \\ &and\ set \quad p = p_1 \quad else \quad Gbest^{m+1} < Gbest^m \end{aligned} \tag{7}$$

Step 7: The perturbation of velocity is performed as follows:

$$\begin{aligned} &if \quad t < t_{\max} \quad then \quad V = Pbest \\ &and\ set \quad t = 1 \quad else \quad t = F_p^m - F_{p1}^{m+1} \end{aligned} \tag{8}$$

Step 8: The optimum process is repeated until the pre-defined iteration is met

Step 9: The optimum solution is reached (G_{best}^k)

C. The *PPSO*-based MPPT algorithm for the improvement of the output power

The overall flowchart of the PPSO-based MPPT method is illustrated in Figure 5.

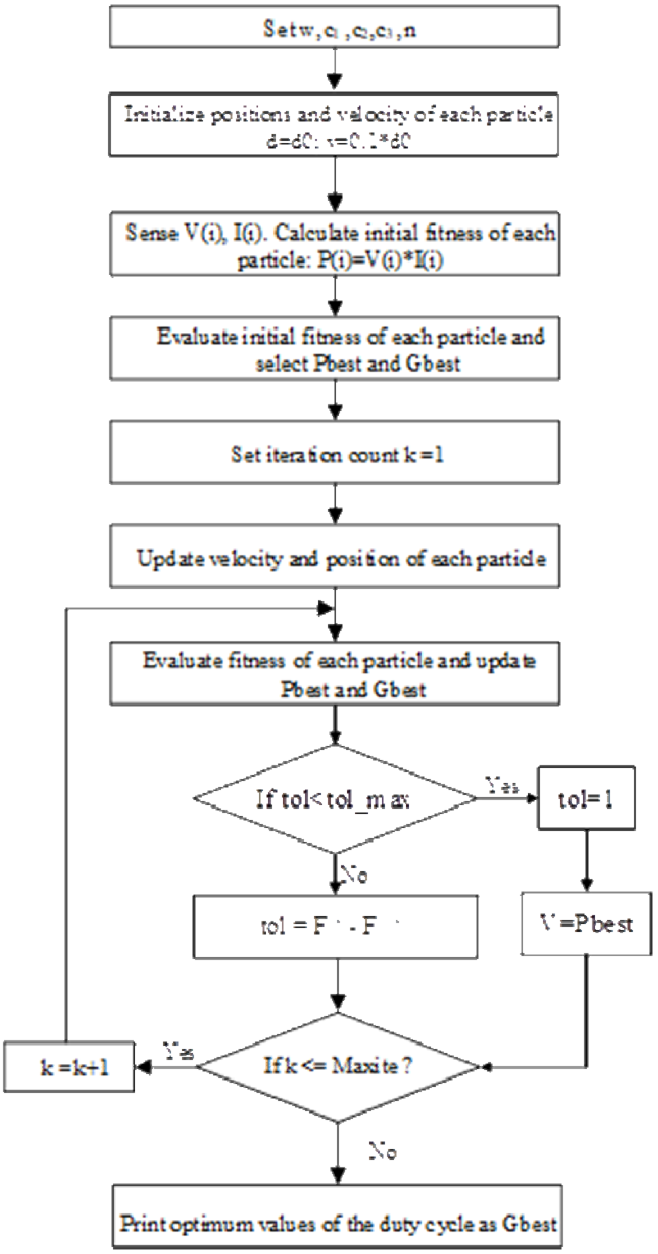

Fig. 5 Diagram of the proposed PPSO_MPPT

Firstly, the initial position of particle is chosen by the random value of duty cycle (d) of a boost converter while the fitness function is determined by the output power (P_{out}) of PV system. The initial value of (d) should be subjected to upper and lower bounds, [D_{min}, D_{max}]. Next, a PWM command corresponding to the duty cycle is sent from a digital controller, the output voltage (V_{out}) and current (I_{out}) are practically measured, P_{out} of PV system is thus calculated. After the fitness of each particle is evaluated, the best initial particle is obtained. Finally, the PPSO algorithm updates the position and velocity of particles based on the personal and overall experience until the optimum value of the duty cycle is obtained. It can be careful that the perturbation of velocity is performed once the tolerance limit has not met.

It can be noted that each PV module is connected in parallel with a by-pass diode in order to remove the hotspot problem. In case of PSC, the PV modules are partially shaped by the different solar irradiances, which are inputted to the tested PV system. V_{out} and I_{out} of the PV system are provided to the PPSO-MPPT block, after that the digital controller generates a PWM duty aiming at controlling the switch of the energy converter with the pre-defined frequency of 30 kHz. The MPPT controller is executed according to the duty cycle generated from the PPSO-based MPPT block. It can be observed from Fig. 6 that the energy converter includes an inductor of 30 mH connected to a capacitor of 10 mF and a switch connected in parallel with a diode.

Firstly, the simulation of a PV array under PSC is performed in case of without any MPPT controllers. The obtained maximum power results given in Table 1 are corresponding to the difference in solar irradiances of four PV modules.

III. RESULTS AND DISCUSSION

The proposed PPSO algorithm has been used for tracking the optimum power during PSC in current study. Achieved empirical results of the case with the MPPT controller are compared with none. It is the basis for demonstrating the reliability of the proposed method. For this, the following parameters have been considered for the novel PPSO variant. In particular, the parameters are selected using a loop to optimize parameters.

- The size of swarm is set as 100
- The inertia weight belongs the range of 0.4 and 0.9
- Acceleration factors $c_1 = c_2 = 2$
- Maximum iteration is set to 1000.

With the support of Core i7 processor with the clock frequency corresponding to 2.66GHz and 8192MB RAM, the calculation program has been developed in MATLAB environment.

For tracking MPP, the suggested PPSO-MPPT algorithm is performed based on a typical system composed of a PV panel and a boost converter integrated with a MPPT controller, as shown in Fig. 6. According to Figure 7, PV modules have been connected in series with the test subjects.

It can be clearly seen in case 1, all of PV modules are provided the maximum solar irradiance of 1000 W/m^2. The maximum output power of PV system reaches to 908.6 W, which is presented by only one peak on the PV characteristic. The case 2, 3, 4 and 5 are tested, in which the solar irradiance supplied for the first PV module is retained, while other modules are shaped by the different sunlight energy. It can be observed in case 2 and 4 that the solar energy of the second and third PV modules is the same, results in there are three optimum points on the P-V characteristic. However, the number of peaks is four in case of 3 and 5 because the four PV modules were shaded by different sunlight energy.

In the case of using the PPSO-based MPPT controller, the variation of solar irradiances supplied for the four PV modules are shown in Table 2. Furthermore, the obtained results are compared to those reached in case of without any MPPT controllers under PSC, as expressed in Table 3. Figure 8 shows the dynamic characteristics of PV.

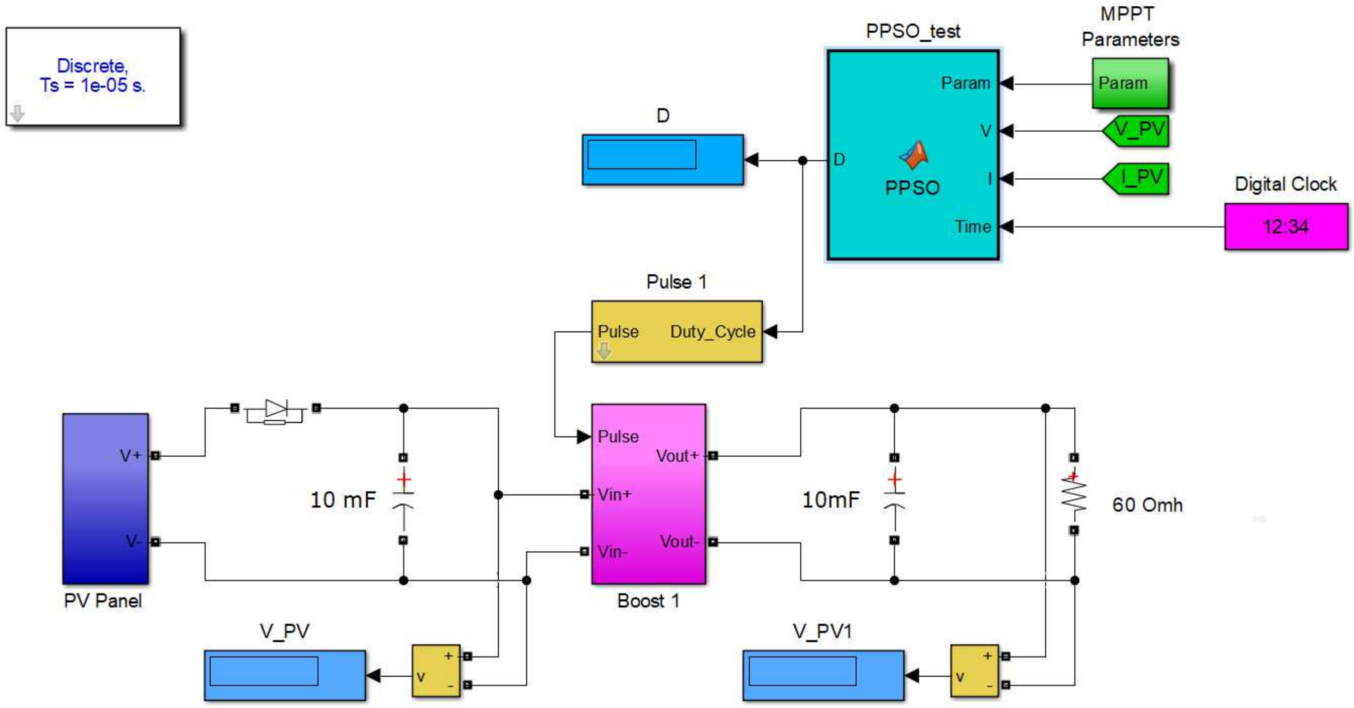

Fig. 1 Simulink model for the system of PPSO_based MPPT

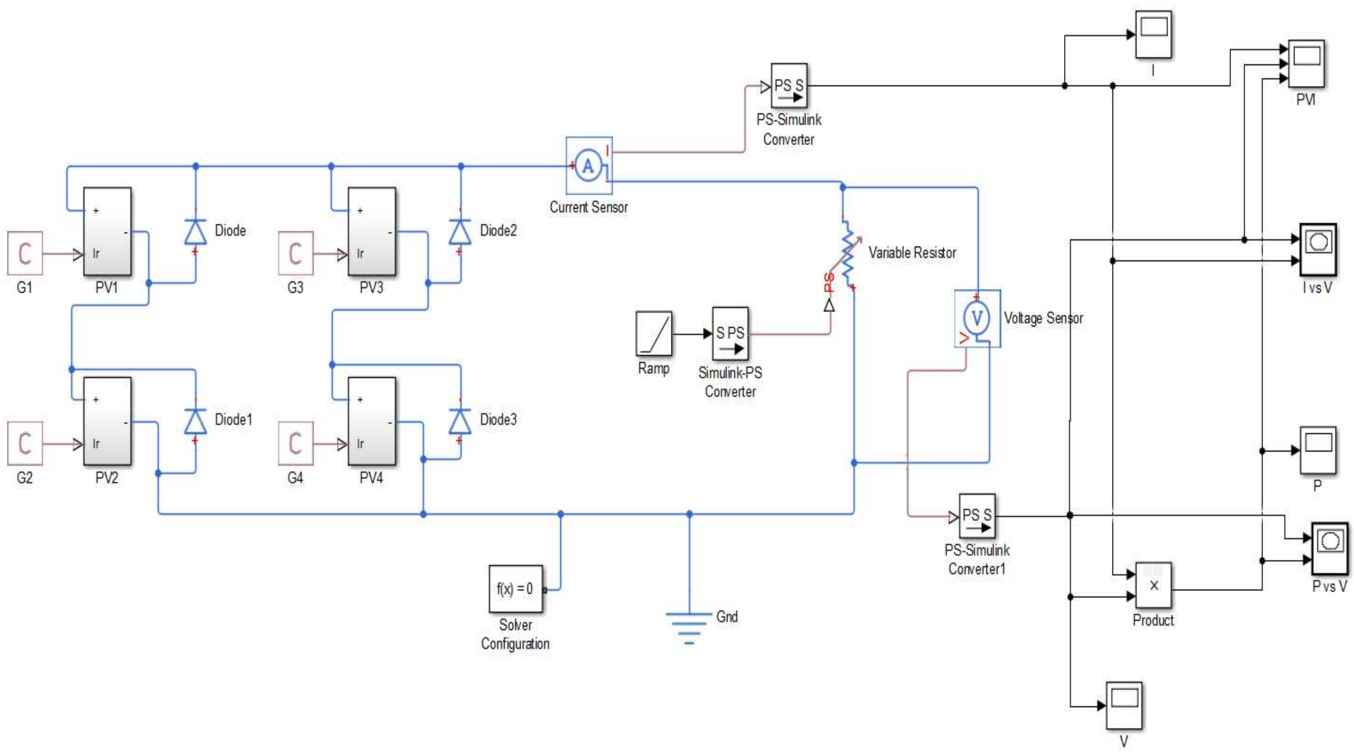

Fig. 2 Simulation model of four PV models connected in series performed in Simulink

Table 5 shows that the accuracy of MPP monitoring when using the PPSO-MPPT controller for all tested cases is more than 90%. Figure 8 shows that the PPSO-MPPT algorithm has the ability to detect relatively good global optimal points in PSC. The accuracy of tracking the optimum power reaches to 99 %, demonstrates the superiority of a suggested method in comparison with the cases of without using MPPT controllers.

TABLE I

THE SOLAR IRRADIANCE FOR G1 TO G4

Case	The solar irradiance				
	G_1 (W/m^2)	**G_2 (W/m^2)**	**G_3 (W/m^2)**	**G_4 (W/m^2)**	**P_{max} (W)**
1	1000	1000	1000	1000	908.6
2	1000	900	900	500	715.4
3	1000	900	800	500	626.5
4	1000	800	800	500	526.7
5	1000	700	600	500	412.6

TABLE II

THE VARIABLE VALUE OF SOLAR IRRADIANCE FOR THE SYSTEM OF PPSO_BASED MPPT

Case	The solar irradiance			
	G_1 (W/m^2)	**G_2 (W/m^2)**	**G_3 (W/m^2)**	**G_4 (W/m^2)**
1	[1000 1000 1000]	[1000 900 600]	[1000 800 500]	[1000 600 300]
2	[1000 1000 1000]	[800 900 900]	[300 800 900]	[300 600 900]
3	[1000 1000 1000]	[1000 900 800]	[800 900 1000]	[400 1000 600]
4	[1000 1000 1000]	[800 900 500]	[800 900 500]	[600 1000 300]

TABLE III

THE VALUE OF MAXIMUM POWER WITH/WITHOUT PPSO-MPPT ALGORITHM

Case	Maximum power (W)	MPPT power (W)	Tracking accuracy (%)
1	[908.6, 725.5, 475.3]	[900, 708, 430]	[99.1, 97.6, 90.5]
2	[528.6, 725.4, 914.6]	[500, 710, 900]	[94.6, 97.8, 98.4]
3	[598.2, 950.4, 771.5]	[560, 900, 740]	[93.6, 94.9, 95.9]
4	[727.5, 950.4, 475.3]	[710, 910, 450]	[97.6, 95.7, 94.7]

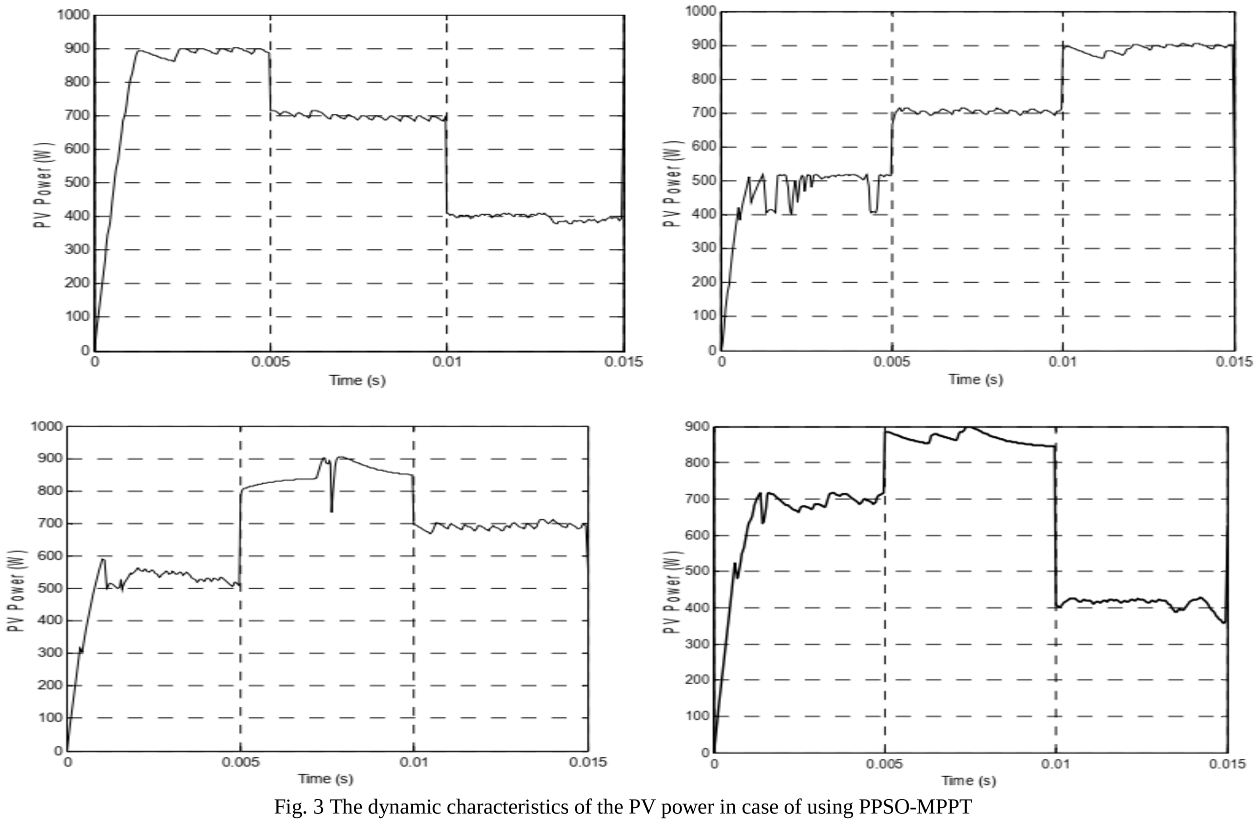

Fig. 3 The dynamic characteristics of the PV power in case of using PPSO-MPPT

IV. CONCLUSION

The PPSO algorithm was investigated aiming to find the global peak of PV systems in this study as well as to enhance the efficiency in the operation process of PV systems. Furthermore, obtained results have been compared to the cases of without using any MPPT controllers. Under PSC, the swarm optimization algorithms can track the optimum power points, but only the proposed PPSO algorithm has the capability of tracking the global optimal (the true maximum among the multiple local minimal). Like the classical PSO, the mentioned PPSO-based MPPT is showed the capability of making the steady-state oscillation with smooth characteristic. Moreover, the MPP accurately under large fluctuations of insolation as well as temperature is found. The novel variant, the PPSO gives the higher tracking accuracy with faster convergence speed as compared to the original PSO.

NOMENCLATURE

ANN	Artificial Neural Network
AI	Artificial Intelligence
DE	Differential Evolution
FL	Fuzzy Logic
FLC	Fuzzy Logic Control
GA	Genetic Algorithm
GP	Global Peak
G_{best}	Overall Experience
LP	Local Peaks
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
NN	Neural Network
P_{best}	Personal Experience
PPSO	Perturbed Particle Swarm Optimization
PSC	Partially Shaded Conditions
PSO	Particle Swarm Optimization
PV	Photovoltaic
INC	Incremental conductance

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