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Simulation of MPPT control using an improved particle swarm optimization algorithm of generation system

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ABSTRACT

Because of the difference of environmental conditions, such as temperature and solar radiation quantity of radial, photovoltaic system has the characteristics of nonlinearity and multi-peak. In order to effectively improve the accuracy and speed of maximum power point tracking, the existing circumstances and problems of maximum power point tracking control was analysed in this paper, maximum power point tracking using an improved particle swarm optimization algorithm of photovoltaic system was proposed, duty cycle was initialized after being divided into two parts, and simulated in the environment of MATLAB/Simulink. The comparison of the indexes of MPPT performance and the waveform of output verifies that, the proposed MPPT method has faster tracking velocity for MPP, avoids oscillation around MPP, for variational environment, including partially shading and irradiance lager wave, could always find optimal MPP, and is better than the traditional methods.

KEYWORDS

Photovoltaic system; Particle swarm optimization; Maximum power point tracking; Partial shading.

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INTRODUCTION

Solar energy is a renewable green energy, photovoltaic power generation system has the advantages of being low operation cost, maintenance free, environmentally friendly[1-6]. In order to achieve optimal usage of large array of PV modules, the maximum power point of PV system tracking many scholars at home and abroad (MPPT) method has been extensively studied[1-13]. However, due to the different environmental conditions (such as temperature and solar radiation), the maximum power point in the P-V curve (MPP) is nonlinear and multi peak characteristics of[7-13]. In recent years, researchers have proposed many MPP tracking methods. For maximum power point tracking incremental conductance method, in 2008, F.Liu and S.Duan, with variable step size, have achieved good results, but this method is of high cost and is not suitable for large-scale popularization and application[14]. Literature[15] presented Perturb & amp Observe method, and this method has the advantages of simple structure and being easy to implement, but in steady state accuracy is low and the rapid changes in light intensity will lead to a larger energy loss. Especially when the photovoltaic array is partially obscured, or different parts of the whole array with different illumination, its performance will occur become poor, and P-V curve will show multiple peaks and maximum power point[16]. So it is difficult to obtain the optimal peak in the actual use of the traditional tracking method.

In order to overcome the above disadvantages, many methods to realize MPPT control using artificial intelligence method, such as fuzzy logic controller (FLC) neural network and[17] (NN)[18]. Although these methods to the nonlinear characteristics of the P-V curve is effective, but they require a large amount of calculation. Fuzzy logic controller needs to deal with the fuzzy rule base, fuzzy inference, and defuzzification, and neural network needs to be trained on large amounts of data and constraints. Especially when the environment changes, MPPT is related to temperature and the sun radiation. Obviously, a low cost processor does not satisfy this system.

In view of the existing MPPT problems of the photovoltaic system, this paper proposes an improved particle swarm optimization algorithm (PSO) based maximum power point tracking method, where the duty cycle is divided into two parts to initialize. With modeling in the MATLAB/Simulink simulation environment, we verified the validity and feasibility of this control strategy. According to performance comparison of results before and after improvement, the method has the advantages of fast dynamic response, steady state power fluctuation is small, good robustness etc.

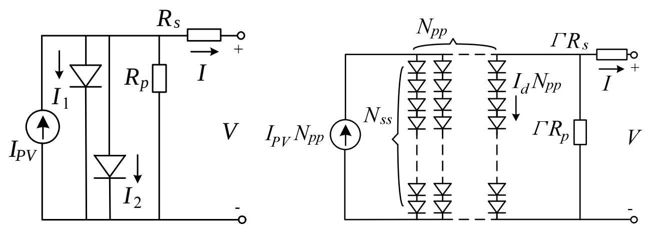
MODEL OF PV ARRAY

The literature[13,19-24] research shows that photovoltaic battery model design with two bypass diodes has more accuracy, as shown in Figure 1a.The output current can be expressed as:

$$I = I_{PV} - I_{o1}\left[\exp\left(\frac{V+IR_s}{\alpha_1 V_{T1}}\right)-1\right] - I_{o2}\left[\exp\left(\frac{V+IR_s}{\alpha_2 V_{T2}}\right)-1\right] - \left(\frac{V+IR_s}{R_p}\right) \quad (1)$$

Where I, I_{o1}, I_{o2} represent photovoltaic cells output current and two bypass diodes dark saturation current; I_{PV} is photocurrent, whose value is influenced by solar irradiance and temperature; V is the output voltage; R_p is photovoltaic parallel resistance (high resistance, the order is kΩ), which can ignore the small current flows through the shunt resistance; R_s is photovoltaic cell serial resistance (low resistance, less than 1Ω); V_{T1}, V_{T2}, composed of Ns photovoltaic cells in series photovoltaic module thermal voltage, which is equal to N_s kT/q, where q is the charge constant (1.602×10^{-19}C), and K is the Pohl Seidman constant (1.381×10^{-23}J/K). T is the absolute temperature of photovoltaic panels; α1 and α2 are ideal constant variables of the two diode respectively. In reference[24], the photovoltaic battery equivalent circuit is simplified and improved, and the output current of the simplified formula can be expressed:

$$I = I_{PV} - I_o\left[\exp\left(\frac{V+IR_s}{V_T}\right) + \exp\left(\frac{V+IR_s}{(p-1)V_T}\right) + 2\right] - \left(\frac{V+IR_s}{R_p}\right) \quad (2)$$



(a) photovoltaic equal circuit **(b) equivalent mode of a photovoltaic array**

Figure 1 : Equivalent circuit of a photovoltaic array

For the large photovoltaic power generation system, general design and installation of a series of PV modules connected in series or parallel are shown in Figure 1b. Photovoltaic system in 1b contains $N_{ss} \times N_{pp}$ photovoltaic modules. In order to improve series parallel structure, output current equation (2) can be used the following amendments:

$$I = N_{pp}\left\{I_{PV} - I_o\left[\exp\left(\frac{V+IR_s\Gamma}{V_T N_{ss}}\right) + \exp\left(\frac{V+IR_s\Gamma}{(p-1)V_T N_{ss}}\right) + 2\right]\right\} - \left(\frac{V+IR_s\Gamma}{R_p\Gamma}\right) \quad \Gamma = \frac{N_{ss}}{N_{pp}} \quad (3)$$

APPLICATION AND ANALYSIS OF FEATURES IN MPPT PSO

Application of PSO in MPPT

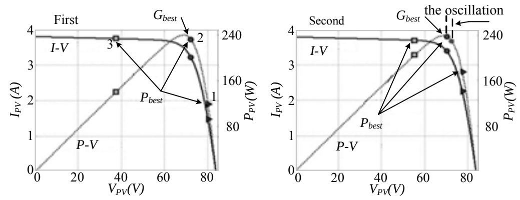
Particle swarm optimization algorithm (PSO) is proposed by Kennedy and Eberhart[25], which is an effective method for multimodal function global optimization and swarm intelligence optimization search[25] guide produced by cooperation and competition among particles in swarm. In order to illustrate that the MPPT controller based on PSO algorithm, we firstly give the solution vector definition with NP particle duty ratio:

$$x_i^k = d_g = [d_1, d_2, d_3, \ldots\ldots, d_j] \quad j = 1,2,3,\ldots\ldots, N_p \quad (4)$$

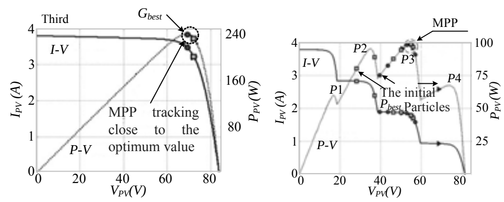
And the objective function is defined as:

$$P(d)_i^k > P(d)_i^{k-1} \quad (5)$$

PSO algorithm combines three duty ratio d_i (i=1, 2, 3) and send them to the power converter to begin the optimization process. Figure 2 triangle, dot and square are three duty ratio d_1, d_2 and d_3. In the first iteration, three duty cycle are all P_{best}, and d_2 is the G_{best}, which is given the optimal value (power of the PV array), as shown in Figure2a. In the second iteration, due to the role of G_{best}, the velocity is only, and in formula (5) the factor ($P_{besti-d(i)}$) is zero, and the ($G_{best-d(2)}$) factor is zero. So the G_{best} particle (d_2) velocity is zero, resulting in zero speed, and duty ratio do not change. Therefore, in the search process, the particle has no effect. To avoid this situation, in the duty cycle a small disturbance is added to ensure that the change in the optimal value, as shown in Figure2b. Figure2c shows the movement of particles in the iteration of third. Because in the first two iterations, the duty ratio obtain better fitness, speed and direction of these particles remain unchanged, then they will be along the same direction towards G_{best}. In the third iteration, all the duty ratio d_i(i=1, 2, 3) are at low speed for MPP. In successive iterations, due to the very low speed, duty ratio is close to a constant, then the system will remain basically stable operating point, to reduce the oscillation of MPP.



a first iteration   b second interation



c third iteration   d MPPT of PSO with shade

Figure 2 : PSO particle movements in searching for the MPP

When photovoltaic array is in partial shade, P-V curve showed multi peak state (i.e. P1, P2 and P4 local poles and a P3 global pole), as shown in Figure 2d. It is shown that, when in partial shade, we also use the above mentioned method, namely, the output of the system with three duty cycle (as P_{best} particles), to begin the optimization process, although the initial duty ratio ($P_{best,i}$) of voltage and current from the global peak (P3), but in the later stages of the iteration, and we successfully found the global peak (P3).

A characteristic analysis

When the change of optical radiation is slow, it is important the PSO algorithm gives the duty ratio appropriate initial value. When tracking MPP, from the front to account for changes in the smaller air ratio, and the initialization, duty cycle variation, range of particle in P-V curve search will increase, the tracking MPP will appear large fluctuations in work as the cost, the PSO algorithm to search the optimal solution in a certain amount of energy waste. Another problem need to be considered, namely tracking MPP need to change fast enough to track speed. However, duty ratio, volatility is not allowed in the PSO algorithm, and not a very accurate tracking to the new MPP. In addition, due to the sun radiation intensity changes, there is a change in the operating point of[27]. In this case, if the duty cycle of small changes, search the MPP might be slow. In the part of the shadow, this situation is more critical. Therefore, as for reasons not empty ratio was used to search the P-V curve in large area, was eventually traced MPP is local rather than global peak peak.

IMPROVED PARTICLE SWARM OPTIMIZATION ALGORITHM MPPT

In order to solve the above two problems, in this paper, the traditional PSO algorithm was improved. The duty cycle is divided into two parts. First of all, the previous duty ratio is of by factor K_1 linearization, increasing or decreasing (according to the change of the array output power). Once the PSO algorithm to search MPP, due to the zero velocity three duty ratio is almost the same value. In order to search for new MPP P-V curve, the second step involves two duty cycle (d_1 and d_3) in the positive, negative direction to K2 constant value perturbation.

Figure 3 gives an estimate method of the value of K_1. As you can see, the array's maximum power and the corresponding PMPP duty ratio, the relationship between G_{best}, P_{best} to DC/DC converter with Δ d_{PMPP} when the corresponding duty ratio. Response by solar radiation from the lambda = 1 is reduced to 0.1, step 0.1. Moreover, there are two equations of the relationship between P_{MPP} and dbest. More importantly, there is between an approximate linear relation between array power and duty, i.e.

$$\mathbf{d}_{new} = \mathbf{d}_{old} - \frac{1}{\mathbf{K}_1}\left(\mathbf{P}_{old,MPP} - \mathbf{P}_{MPP}\right) \tag{6}$$

where D_{old} for G_{best} previous duty ratio, slope $K_1=\Delta P_{MPP}/\Delta d$ for the linear part of th formula (9) is the change of the environment, and the new duty ratio will change according to the operating power and change, and its value is very close to the new optimal duty cycle. Therefore, the initialization duty must search the P-V curve, which will very quickly to keep track of the new MPP.

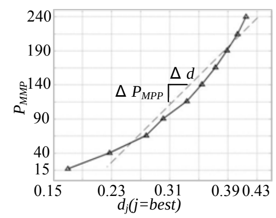


Figure 3 : Relationship between the G_{best} duty cycle and P_{MMP}

It should be noted that, the above analysis is to reduce solar radiation (from the lambda=1 to 0.1) as the foundation, and reduce solar radiation always causes the load line in the photovoltaic array I-V curve of the maximum voltage V_{MPP} to the left, and the load will change greatly, but in fact this is not true. The reason is the increasing sunshine, load line in V_{MPP} right. Between the V_{MPP} and the V_{OC} difference is not large, small change of power. In this case, if the same value of K_1, D_{old} will not be deleted. As a result, the PSO algorithm will need more iterations to obtain MPP. In order to avoid such problems, each of the two cases with two groups of different K_1 values, the value of the following formula:

$$\mathbf{K}_1 = \begin{cases} \mathbf{K}_1 & \Delta P > 0 \\ \frac{\mathbf{K}_1}{2} & \Delta P < 0 \end{cases}$$

where, $\Delta P = P - P_{old}$ **(7)**

In the formula, P>0, P<0 respectively represent decreasing and increasing sunshine sunshine. In order to give the duty ratio of a new perturbation (by formula (9) for d_1 and d_3 respectively), using the following formula for updating the positive, negative direction:

$$\mathbf{d}^{k}_{i,new} = \left[(\mathbf{d}_1 - \mathbf{K}_2), \mathbf{d}_2, (\mathbf{d}_3 + \mathbf{K}_2)\right] \quad \mathbf{K}_2 \geq 0.05 \tag{8}$$

Where the selection principle of 0.05 is to ensure that the PV array power fluctuations will not be too big. However, in partial shade, this value (0.05) may according to the working voltage becomes large, the range of working voltage for the photovoltaic array voltage 30-85%[27]. This is to allow the PSO search algorithm I to V curve more, to track the global peak.

More should also be noted is that, even the formula (9) calculate the duty cycle and the optimal duty cycle difference is big, because the disturbance factor K_2, at least one duty ratio d_i(i=1, 2, 3) will still be close to optimal duty cycle. Therefore, formula (9) and (11) always ensure fast tracking MPP PSO algorithm. PSO algorithm flow chart is shown in figure 4.

From the above analysis, compared with other MPPT control technology, the improved PSO method has the following advantages:

1) the duty cycle of the disturbance is calculated by two different methods: Previous duty ratio $d_i(k)$ and locally optimal particle P_{best}, the difference between i, as well as previous duty ratio $d_i(k)$ and the global best particle among different G_{best}. Therefore, the power converter and tracking the best P_{best}, i and G_{best}. The result is a system with faster search and track the MPP optimal solution.

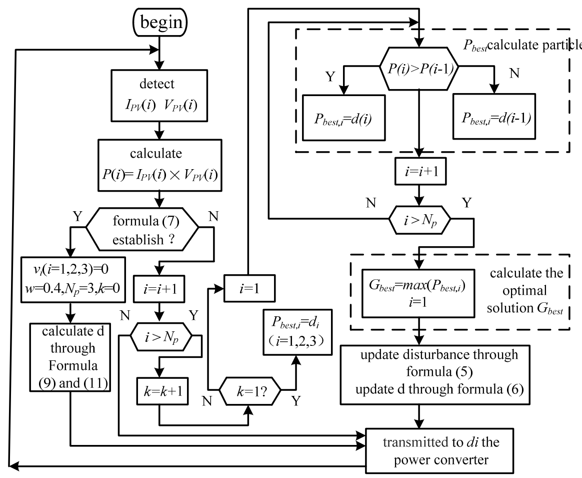


Figure 4 : Complete flowchart of the proposed method

2) Once the particles acquire MPP, the particle velocity is almost zero. Therefore, no oscillation in steady state. The steady state oscillation is very important, because it is[28] one of the main reasons of simplified MPPT efficiency.

3) In the short term fluctuations in environmental conditions, the improved PSO algorithm with three duty cycle. Because the operation power information from three of empty ratio, it never lost direction in the short-term fluctuations in MPP.

4) The improved PSO algorithm is based on the search method, and so on under partially shaded conditions, characteristics of the P-V curve is multi peak state, but it can still be correctly tracking to the global peak.

SIMULATION RESULTS

In order to verify the validity and feasibility of the proposed of the control strategy, in the environment of MATLAB, we constructs an improved particle swarm optimization algorithm (PSO) based on the maximum power point tracking simulation model, as shown in Figure 5.

In the PSO algorithm, the particle dimension is determined by the optimization problem. The maximum speed of Φ_{Max} particles in between the current position and the best location of the region's resolution. If max is too large, the particles may fly over the optimal solution; if a max is too small, the particle cannot adequately search, leading to fall into the local optimal value. Learning factor (coefficient of acceleration) C_1 and C_2 take the lower value, and allow particles to wandering outside the target area; high value leading to particle suddenly over the target area. After repeated tests, the Parameters of PSO algorithm settings are as follows: the population total of 30, dimensions of each particle is 18, the maximum number of iterations is 50, c1=1.2, c2=1.6, w=0.4, P_{thr}=1.5%. The speed of the particle is in the range of [-10, 10]; R_1, R_2 are random numbers in the interval [0,1] uniform distribution. In order to avoid large fluctuations in the array operating point, according to the formula (11) the K_2 value is set to 0.05. Array of K_1 values by Figure 4 estimation, the calculation formula (10), decreasing sunshine, sunshine are increasing approximately 675, 1350.

Performance for maximum power point tracking method is improved with particle swarm optimization algorithm, and the 2 methods are simulated under the same conditions, where the sampling period is 0.1s. In order to test the performance of PSO algorithm, the simulation system adopts three schemes: 1) adding a large order in equilibrium solar radiation jump jump; 2) adding a step change in load; 3) partial shading condition.

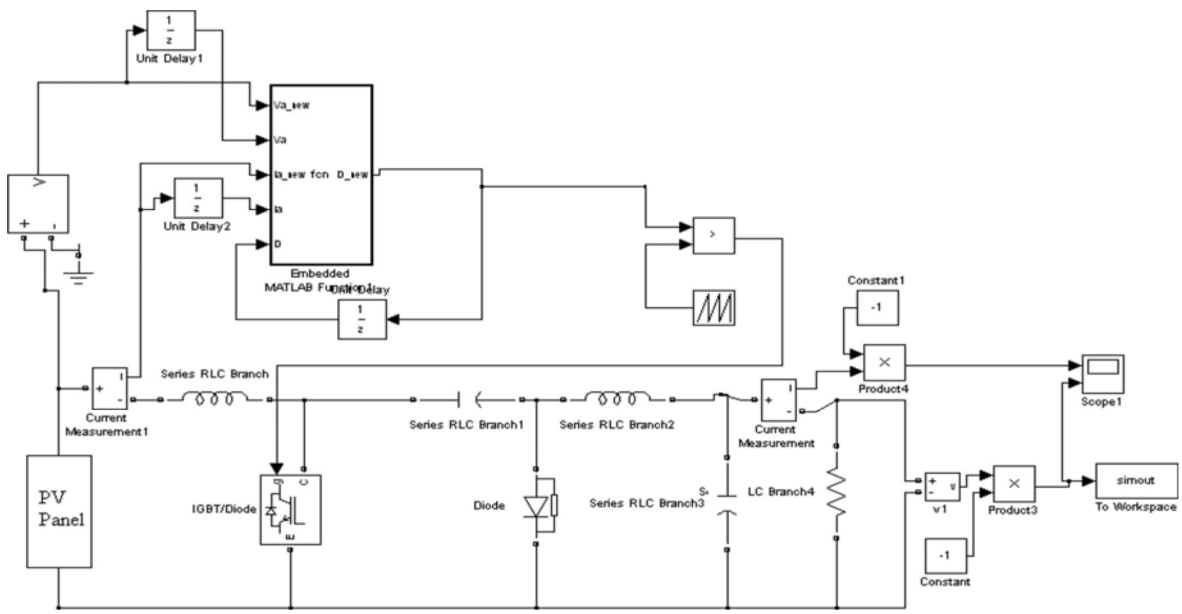


Figure 5 : Improved PSO-based photovoltaic MPPT system

1) Jump

When the sun light uniform changes, the radiosity follow a low-high-low ladder type variation. The initial radiosity value λ =0.4kW/m^2; when t=2s, the first jump λ =1.0kW/m^2; when t=6s, second jump for the lambda =0.4kW/m^2, and the temperature is kept constant value of 25 for C. I-V, the corresponding P-V curve as shown in Figure 6. Figure A for the radiation of the initial value of lambda=0.4kW/m^2 voltage and current. When the radiance appeared first two jumps, voltage and current working point respectively from the A point jump to B, and then from B to C.

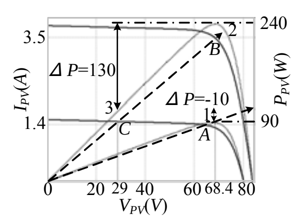


Figure 6 : *I−V* and *P−V* curves that are used in the simulation

Simulation of PSO algorithm and improved results as shown in Figure 7, including voltage, current, total variation curve of air ratio and power. In order to weigh MPP tracking speed and improve the oscillation caused by former PSO algorithm, each 0.1s into a fixed perturbation 0.015 (Figure 7a). From Figure 7a can be observed, when the solar radiation occurred two jumps, MPP tracking is very slow. More importantly, when the solar radiation changes from 1 to 0.4, as the operating point moves from point B to point C, PV array voltage and power decrease. Because of the fixed perturbation added, in order to obtain the optimal power point tracking, MPP requires a longer period (as shown in Figure 7a). More importantly, in the MPP around a corrugated obvious small oscillation. When solar radiation is maintained in a=1.0, the PV array power in (240-231)W oscillation, wave amplitude of 9W. Although, we can reduce the MPP tracking velocity to decrease oscillation (especially when the environment changes greatly), but, when the solar radiation changes very quickly, before the improvement of PSO algorithm will not be able to accurately track the optimal MPP.

Corresponding to the sun'second order radiosity jump, in the improved PSO algorithm three duty cycle were independently calculated (Figure 6). In the first transition (t=2s), duty ratio d_1 in the negative direction change (P-P_{old}), the new particle (i.e. three duty ratio d_1, d_2 and d_3) by formula (9) and (10), and in the d_3 duty cycle after the power is very close to the optimal value (Figure 7b), the improved PSO algorithm can search through three duty ratio to get the new MPP. From Figure 7b, it continue to search the three duty cycles, current and voltage fluctuates. When t=3s, the algorithm correctly search to voltage and current (V_{MP}=68.4V, I_{MP}=3.5A), then MPP is 240W (see Figure 6). The second hopping (t=6s) occurs, power and a big change (negative jump), similar to above-mentioned method, the formula (10) and (11) calculate the new duty cycle, from figure 7b shows by searching the duty ratio d_2 can get the optimal value. When t=7s, the search algorithm voltage and current (V_{MP}=67V, I_{MP}=1.35A), then the correct MPP 90W (see Figure 7). Moreover, from figure 7b, once successful searching to MPP, MPP will be very stable. Using the improved PSO algorithm to track the MPP system dynamic can impove response speed, and steady state accuracy is better. So the system has good tracking performance.

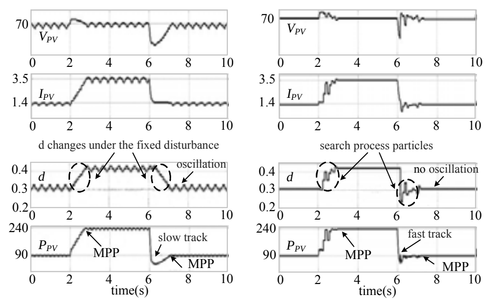


Figure 7 : Simulation results of unproposed and proposed PSO method

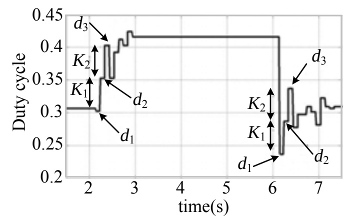


Figure 8 : Duty cycle variations during the exploring phase

2) Load changes and partial shading

In the load step change and shadow conditions, respectively, simulation of PSO algorithm to the improved the tracking results of MPP is shown in Figure 9. Two methods of system initial state of the PV array output power peak was 240W. Figure 9A shows, in t=2s, in the load applied at the end of the 50% step, resulting in a sudden drop in output power. Since then, improved PSO algorithm to the load under the conditions of the new track MPP, and in the 10 MPP cycle after the track to the MPP, and in the vicinity of the maximum power point appeared oscillation. When the t=4s, part shadow, in the P-V curve appeared in the four peak (P1-4), where P1-3 is the local peak, P4 peak (170W) for global. Figure 9A shows that improved PSO method in the MPP maximum power point tracking changes in the vicinity of P3, whose value is 144W, and the final system to work. While the global peak true for P4, the margin between the 26W, resulting in loss of PV system can be seen clearly.

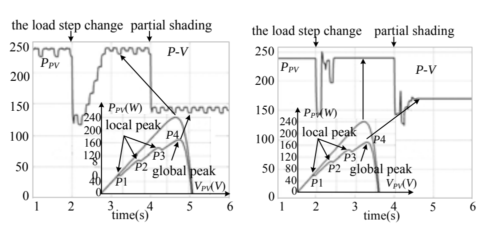


Figure 9 : Tracking performance under load variation and partial shading conditions

On the contrary, the improved PSO algorithm to sudden load changes and partial occlusion handling is appropriate (Figure 9b). When the sudden change of the load, while the result is the sudden drop in output power, but in 5 MPP tracking cycle after traces of the MPP, and there was no big oscillation near the maximum power point. In addition, when the shadows appear, on the P-V curve to search through the improved PSO algorithm, in the 7 MPP cycle after the successful tracking to the global peak real (P4), did not result in the loss of photovoltaic system. Can be seen from the chart, compared with before improvement, the improved PSO algorithm after the system dynamic response speed, steady state accuracy is better, the system has good tracking performance of MPP.

CONCLUSIONS

In order to improve the system for MPP tracking accuracy and speed, this paper designs an improved particle swarm optimization controller, which presents a simple method with high efficiency, namely, the particle swarm is re initialized to search for new MPP. To establish the MPPT model of photovoltaic power generation system, and carried on simulation experiment, simulation and improved results can be seen, the proposed method has the following advantages: 1) has a faster tracking speed of MPP, and improve the dynamic response of the system; 2) to avoid the oscillation in the vicinity of MPP, it improves the steady-state accuracy system; 3) to changes in the environment, including the fluctuating part of the shadow and the sun is big, it can find the best MPP and enhances the tracking performance of the system.

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REFERENCES

[1] L.Bangyin, D.Shanxu, C.Tao; Photovoltaic DC-building-modulebased BIPV system-concept and design considerations[J]. IEEE Trans. Power Electron, **26(5)**, 1418–1429 **(2011)**.

[2] Z.Li, S.Kai, X.Yan et al.; A modular gridconnected photovoltaic generation system based onDC bus[J]. IEEE Trans. Power Electron, **26(2)**, 523–531 **(2011)**.

[3] J.L.Agorreta, M.Borrega, Lo.J.pez et al.; Modeling and control of N-paralleled grid-connected inverters with LCL filter coupled due to grid impedance in PV plants[J]. IEEE Trans. Power Electron, **26(3)**, 770–785 **(2011)**.

[4] J.Young-Hyok, J.Doo-Yong, K.Jun-Gu et al.; A real maximum power point tracking method for mismatching compensation in PV array under partially shaded conditions[J]. IEEE Trans. Power Electron, **26(4)**, 1001–1009 **(2011)**.

[5] Y.Bo, L.Wuhua, Z.Yi et al.; Design and analysis of a gridconnected photovoltaic power system[J]. IEEE Trans. Power Electron, **25(4)**, 992–1000 **(2010)**.

[6] E.Serban, H.Serban; A control strategy for a distributed power generation microgrid application with voltage-and current-controlled source converter[J]. IEEE Trans. Power Electron, **25(12)**, 2981–2992 **(2010)**.

[7] A.K.Abdelsalam, A.M.Massoud, S.Ahmed et al.; High-performance adaptive perturb and observe MPPT technique for photovoltaic-based microgrids[J]. IEEE Trans. Power Electron, **26(4)**, 1010–1021 **(2011)**.

[8] Li Xingpeng, Shi Qingjun, Jiang Quanyuan; Application of double fuzzy control in MPPT of grid-connected photovoltaic generation system[J]. Electric Power Automation Equipment, (in Chinese), **32(8),** 113-117 **(2012)**.

[9] Liu Liqun, Wang Zhixin, Zhang Huaqiang; Fuzzy-immune MPPT control of PV generation system under partial shade condition[J]. Electric Power Automation Equipment, (in Chinese), **30(7)**, 96-100 **(2010)**.

[10] Zhu Yanwei, Shi Xinchun, Dan Yangqing, et al.; Application of PSO Algorithm in Global MPPT for PV Array[J]. Proceedings of the CSEE, (in Chinese), **3(5)**, 42-49 **(2012)**.

[11] Wu Haitao, Sun Yize, Meng Chuo; Application of Fuzzy Controller With Particle Swarm Optimization Algorithm to Maximum Power Point Tracking of Photovoltaic Generation System[J]. Proceedings of the CSEE, (in Chinese), **31(6)**, 52-57.

[12] Liu Lin, Tao Shun, Zheng Jianhui et al.; Improved Maximum Power Point Tracking Algorithm for Photovoltaic Generation Based on Combination of Hysteresis Comparison With Optimal Gradient[J]. Power System Technology, **36(8)**, 56-61(in Chinese).

[13] Kashif Ishaque, Zainal Salam, Muhammad Amjad et al.; An Improved Particle Swarm Optimization (PSO)–Based MPPT for PV With Reduced Steady-State Oscillation[J]. IEEE Trans. Power Electron, **27(8)**, 3627-3638 **(2012)**.

[14] Liu Fangrui, Duan Shanxu, Liu Fei et al.; A variable step size INC MPPT method for PV systems[J]. IEEE Transactions on Industrial Electronics, **55(7)**, 2622-2628 **(2008)**.

[15] N.Femia, D.Granozio, G.Petrone et al.; Predictive & adaptive MPPT perturb and observe method[J]. IEEE Transactions on Aerospace and Electronic Systems, **43(3)**, 934-950 **(2007)**.

[16] N.Femia, G.Petrone, G.Spagnuolo et al.; Optimization of perturb and observe maximum power point tracking method[J]. IEEE Trans. Power Electron, **20(4)**, 963–973 **(2005)**.

[17] B.N.Alajmi, K.H.Ahmed, S.J.Finney et al.; Fuzzylogic-control approach of a modified hill-climbing method for maximum power point in microgrid standalone photovoltaic system[J]. IEEE Trans. Power Electron, **26(4)**, 1022–1030 **(2011)**.

[18] K.Ishaque, Z.Salam; An improved modeling method to determine the model parameters of photovoltaic (PV) modules using differential evolution (DE) [J]. Solar Energy, **85**, 2349–2359 **(2011)**.

[19] Jiao Yang, Song Qiang, Liu WenhuaL; Practical simulation model of photovoltaic cells in photovoltaic generation system and simulation[J]. Power System Technology, (in Chinese), **34(11)**, 198-202 **(2011)**.

[20] Li Chunhua, Zhu Xinjian; Modeling and performance analysis of photovoltaic/fuel cell hybrid power generation systems[J]. Power System Technology, (in Chinese), **33(12)**, 88-92 **(2009)**.

[21] Liu Dongran, Chen Shuyong, Ma Min et al.; A review on models for photovoltaic generation system[J]. Power System Technology, (in Chinese), **35(8)**, 47-52 **(2011)**.

[22] K.Ishaque, Z.Salam, H.Taheri et al.; A critical evaluation of EA computational methods for Photovoltaic cell parameter extraction based on two diode model[J]. Solar Energy, **85**, 1768–1779 **(2011)**.

[23] K.Ishaque, Z.Salam, H.Taheri; Simple, fast and accurate two diode model for photovoltaic modules[J]. Solar Energy Mater.Solar Cells, **95**, 586–594 (2011).

[24] J.Kennedy, R.Eberhart; Particle swarm optimization[C]//Proceedings of IEEE Conference on Neural Networks. Perth: IEEE, 1942-1948 **(1995)**.

[25] Yu Tao, Yu Ji; Progress of Grid-connected Photovoltaic Research[J]. Journal of Shanghai University of Electric Power, (in Chinese), **27(2)**, 110-115 **(2011)**.

[26] K.Ishaque, Z.Salam, H.Taheri et al.; Modeling and simulation of photovoltaic (PV) system during partial shading based on a two-diode model[J]. Simul.Modelling Pract.Theory, **19**, 1613–1626 **(2011)**.

[27] A.Safari, S.Mekhilef; Simulation and hardware implementation of incremental conductance MPPT with direct control method using cuk converter[J]. IEEE Trans. Ind.Electron, **58(4)**, 1154–1161 **(2011)**.

[28] D.Sera, R.Teodorescu, J.Hantschel et al.; Optimized maximum power point tracker for fast-changing environmental conditions[J]. IEEE Trans.Ind.Electron, **55(7)**, 2629–2637 **(2008)**.

[29] You Jun, Zheng Jianyong; MPPT of photovoltaic system with Boost circuit based on fuzzy PI control[J]. Electric Power Automation Equipment, (in Chinese), **32(6)**, 94-98 **(2012)**.