A modified particle swarm optimization algorithm to enhance MPPT in the PV array

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Article Info

Article history:

Received Sep 31, 2019
Revised Apr 11, 2020
Accepted Apr 30, 2020

Keywords:

Accuracy
Efficiency
Maximum power point tracking
Partial shading
Particle swarm optimization
Photovoltaic (PV) system
Solar radiations
Speed

ABSTRACT

Due to the growing demand for electrical power, the researchers are trying to fulfill this demand by considering different ways of renewable energy resource as existing energy resources failed to do so. The solar energy from the sun is freely available, and by using photovoltaic (PV) cell power can be generated. However, it depends on rays fall on the PV cell, climatic condition. Thus, to enhance the efficiency of the photovoltaic (PV) systems, maximum power point tracking (MPPT) of the solar arrays is needed. The output of solar arrays mainly depends on solar irradiance and temperature. The mismatch phenomenon takes place due to partial shade, and it causes to the power output, which brings the incorrect operation of traditional MPP tracker. In this shaded condition, PV array exhibits multiple extreme points. In general, under this scenario, the MPPT approaches fail to judge the MPP, and it leads to low efficiency. The conventional approaches of PSO based algorithms can able to track the MPP under shading condition. However, the optimization process leads to issues in tracking speed. Thus, there a need for an efficient MPPT system which can track MPPT effectively in shaded condition? Hence, the proposed manuscript presents a modified particle swarm optimization (PSO) algorithm is introduced to enhance the tracking speed as well as performance. The outcomes of the proposed system are compared with the traditional PSO system and are found that the tracking speed of MPP, accuracy, and efficiency is improved.

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1. INTRODUCTION

The traditional energy resources are not able to fulfill the needs of current power demands. Hence, renewable energy sources like solar, wind, geothermal, and ocean are the better options to fulfill the growing power demand [1, 2]. Among these, the power generation with photovoltaic (PV) cell has gained a lot of power has recently experienced rapid growth around the world [3]. Solar energy has the advantages of the pollution-free energy conversion process and low maintenance cost [4]. However, in the developing process of solar energy, a number of problems are eager to be solved. One of the problems, experts in the whole world, focusing on, is that the efficiency of the optimization process of maximum power point tracking [5]. The recent past has witnessed the different MPPT techniques towards enhancing the performance of dynamic as well as steady-state tracking [6]. One of the tracking technology is found in perturb and observe (P&O). But, the partial shading may lead to the mismatch among the components and the aging of the solar panel. In that sense, the traditional techniques are failed to provide optimization at maximum points [7]. In order to overcome this problem, a lot of existing researches were come up with significant techniques. Parlak and Can [8] proposed an improved global scanning method which tracks MPPT more accuratelybut consumes a long time in the optimization process leading to power loss. The work of Zhang and Cao [9] has used Fibonacci MPP optimization mechanism which can be adapted for the change in climatic condition, but it also consumes more convergence time. A unique work of Ramaprapha et al. [10] has used the PSO algorithm to select therandom position of particles as an initial value of particles. Also, many other types of research like Shi et al. [11], Gowaid et al. [12], Cheng et al. [13], Sing et al. [14], Yaichi et al. [15], etc. have addressed the issues in MPPT with different approaches. The behavior of the solar WSN under different climatic condition is discussed in Hamili et al. [16]. The work of El malah et al. [17] have discussed a power control mechanisms to reduce the cost and yielding higher performance. In a work of Samosir et al. [18] the fuzzy logic based simulation model is presented to get MPPT for PV application. Thus, in this manuscript, a modified PSO algorithm for MPPT in the PV array is presented to overcome the recent research issue and bring more effectiveness in MPPT. The manuscript is categorized as, section 1 discussing the background of PV circuit, consideration of PSO in MPPT. Section 2 gives research problem, section 3 explains proposed modified PSO algorithm along with algorithm description and implementation, section 4 illustrates the results analysis and section 5 gives the conclusion of the proposed PSO algorithm.

a. The background

From the existing researches of Ishaque et al. [19, 20], Yang et al. [21], Chunhua et al. [22], Dongras et al. [23], found that the PV model with two bypass diodes offers a higher degree of accuracy. The same concept is adapted in designing the PV circuit and has been presented in Figure 1.

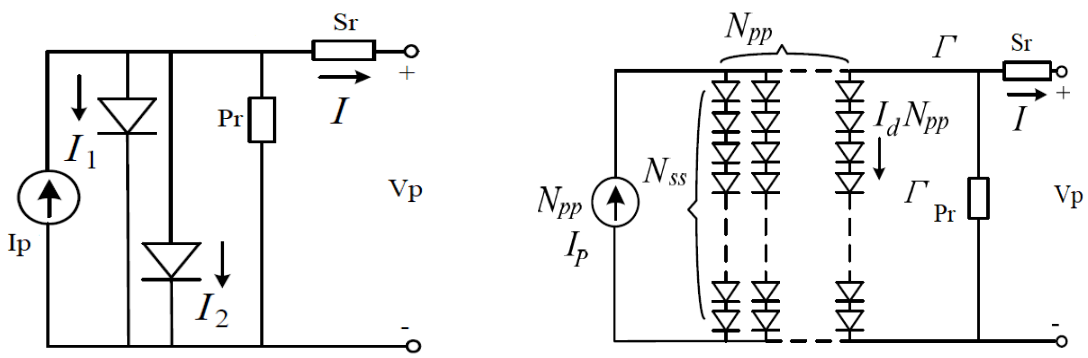

Figure 1. (a) PV circuit, (b) equivalent circuit

The equivalent model of PV array is given in Figure 1(b), where the output current (I) can be obtained as,

$$I = I_p - I_1\left\{\exp\left(\frac{(V+IS_r)}{\alpha_1 \times V_{t1}}\right)-1\right\} - I_2\left\{\exp\left(\frac{(V+IS_r)}{\alpha_2 \times V_{t2}}\right)-1\right\} - \left(\frac{(V+IP_r)}{P_r}\right) \quad (1)$$

where I_p is PV current, I_1 is current across D_1, I_2 is current across D_2,

α_1 & α_2 : Ideal constant variables of two diodes

S_r & P_r : Serial (<1KΩ) and parallel (>1KΩ) resistors respectively

V_{t1} & V_{t2} : Thermal voltages having a number of PV cells (Ns)

$$V_{t1} = V_{t2} = \frac{Ns \times kT}{q}$$

where,

k : Pohl Seidman constant (1.381×10^{-23} J/k)

q : Charge constant (1.602×10^{-19} C)

T : Absolute temperature of PV cell.

The simplified form of the PV module is given in Figure 1(b), and the output current can be taken as,

$$I = I_p - I_1\left\{\exp\left(\frac{(V+IS_r)}{V_t}\right)+\right\} - \left\{\exp\left(\frac{(V+IP_r)}{(p-1)\times V_t}\right)+2\right\} - \left(\frac{(V+IS_r)}{P_r}\right) \quad (2)$$

For large PV based power generation system, the design of Pv is preferred in Figure 1(b). It contains the series of PV modules (Nss) or parallel of PV modules (Npp). The matrix form of PV design can be represented as, [$N_{ss} \times N_{pp}$]. Further, to enhance the structure of a series/parallel circuit, the (2) can be modified as,

$$I = N_{pp}\left[I_p - I_1\left\{\exp\left(\frac{(V+IS_r\,\tau)}{N_{ss}\times V_t}\right)\right\} - \left\{\exp\left(\frac{(V+IP_r\tau)}{(p-1)\times V_t\times N_{ss}}\right)\right\}\right] - \left(\frac{(V+IS_r\tau)}{P_r\tau}\right) \quad (3)$$

where, $\tau = \frac{N_{ss}}{N_{pp}}$

b. PSO in MPPT

The algorithm of Particle Swarm Optimization (PSO) is presented by Kennedy and Eberhart [20]. This is a significant method which can be used for multimodal function optimization and swarm optimization search guide generated from competition and cooperation among the particles in swarm. To illustrate the PSO algorithm for MPPT controller, the solution vector (x_i^k) can be defined.

$$x_i^k = d_j = [d_1, d_2, d_3, ..., d_j] \quad (4)$$

where, d_j is particle duty ratio=1, 2, 3… N_p

The objective function for this duty ratio can be calculated as,

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

The property of PSO is that it adds three duty cycles d_1, d_2, d_3 and forwards then to the power converters to initialize the optimization process. The following Figure 2 gives the movement of particles in search of MPP at different iterations. The triangles represent the duty cycles. In the first iteration as shown in Figure 2(a) of the particle movement, the duty cycles are personal best (P_b) while d2 is global best (G_b) and is the optimal value of PV array.

The movement of particles in the second iteration as shown in Figure 2(b). In this, because of G_b, which is offering optimal value of power (5), the velocity, Pb(di) is zero, and the factor G_b (d_2) is zero. Hence, the velocity of the G_b particle (d_2) is zero, which leads to zero speed and unchanged duty ratio. Thus, in search optimization, the particles do not have any effect. In order to utilize this situation, some disturbance will be added, and it assures the change in optimal value. The movement of particles in the third iteration is presented in Figure 2(c). In first two iterations yield better fitness, speed, and the particle direction is unchanged. Hence, they stay in the same direction along Gb. In the third iteration, all the duty cycles d_1, d_2, d_3 stay at low speed for MPP. At this speed, the duty ratio will be constant, and the system will occupy a stable operating point, which helps in minimizing the oscillations of MPP. If the PV array is in partial shade, the P-V curve faces multi-peak state P1, P2, and P4 local poles while P3 global poles (obtained from 4th iteration as shown in Figure 2(d). The output of the system with duty cycles d_1, d_2, d_3 where Pb is particles, the global peak (P3) is obtained and optimization is initialized at initial duty ratio (P_b, i).

c. Research problem

The work of Yoganandini and Anita [24] have provided an insight into MPPT techniques in PV modules by dealing with existing researches, research gap, and offered a futuristic idea for the research community. From the recent research survey, it is observed that at the slow change in optimal radiations, the PSO need to provide an appropriate value of duty cycle. During MPP tracking, changes in air ratio, initialization, and variation in duty ratio, range of the particles in PV-curve increases. Hence, large fluctuations may appear in providing optimal search solution. This yields high computational cost and energy wastage. Another problem which needs to be considered is that tracking of MPP must be fast enough to track speed but, the duty ratio and volatility are not feasible in the PSO algorithm, and it does not yield proper tracking of MPP. Also, change in the intensity of solar radiation, and it leads to variation in operating point. In this scenario, small changes in duty cycle may lead to slower search in MPP. This is more critical during shadow condition. Hence, the empty ratio is not used to search the PV curve in a large area where the traced MPP may be local peak than the global peak. Thus, there is a need for the modified algorithm to overcome the above-stated problem.Hence, the problem statement is *"to introduce a modified PSO algorithm to enhance the performance of MPPT from PV array."*

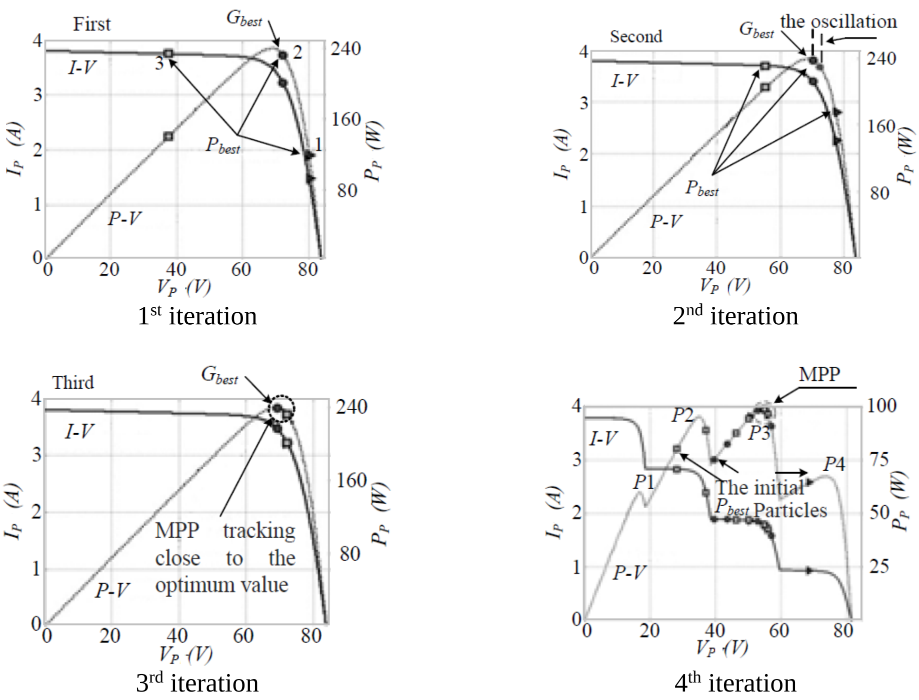

Figure 2. Movement of particles in different iterations

2. MODIFIED PSO ALGORITHM FOR MPPT

The previous work of Yoganandini and Anita [25] have presented a cost-effective MPPT technique for MPPT, where computational time is reduced and achieved cost optimization. This manuscript aims to enhance the performance of the MPP by introducing the modified PSO for the PV array. In the proposed algorithm, the duty cycle is partitioned into two parts. The previous duty ratio exhibits the factor of linearization (K_1) increases or decreases the ratio based on PV array output. Similarly, in providing new PV curve for MPP by using search optimization, two duty cycles d1 and d3 in the positive and negative direction to K_2 constant value perturbation. The following Figure 3 provides an estimation model for K_1 where it can be observed that the maximum power of array and respective power (pMPP), duty ratio, the relationship among P_b, G_b to DC/DC converter having Δd_{pMPP} with respect to duty ratio. The response optimized $\lambda = 1$ can be minimized to 0.1, step 0.1. However, there exist two expressions are considered, which brings the relationship between dbest and pMPP. Also, there exists a linear relationship between array power and duty.

$$d_{new} = d_{old} - \frac{1}{K_1}\left(P_{old,MPP} - P_{MPP}\right)$$

d_{old} is a previous duty ratio for G_b. The slope (K_1) $= \frac{\Delta_{pMMP}}{\Delta d}$ for linear relation changes as per change in operating power and its value is almost equal to the new optimal duty cycle. Hence, the initialization of duty ratio must perform the searching of the P-V curve and will quickly do the tracking of new MPP.

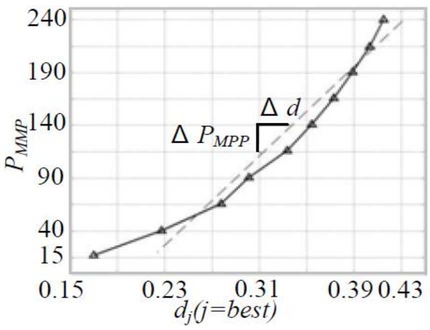

Figure 3. Relation among Gb, duty cycle and pMPP

From the above analysis, it has been found that, the reduction in solar radiation (from wavelength $\lambda = 1$ $\lambda = 0.1$) always leads to load line in PV array I-V gives maximum MPP voltage (VMPP) to the right of plot curve. The increment in sunshine brings load line to the right. The difference between VMPP and output voltage will become small, and it leads to a small variation in power.Hence, the same value of d_{old}& K_1 is not to be deleted. Thus, the PSO algorithm needs to have more iteration to track MPP. To neutralize such type of problems, a simple assumption is made with two different values of K_1.

i.e., $$K_1 = \begin{cases} K_1 & if \ \ \Delta P > 0 \\ \frac{K_1}{2} & if \ \ \Delta P < 0 \end{cases}$$

In this equation, $\Delta P = P - P_{old}$

The value of P>0 & P<0 indicates the decrement and increment in sunshine radiation. In order to get the duty ratio of new perturbation for d_1 and d_3 respectively. The following formula of data ratio updates position, and negative direction.

$$(d_i)_{new} = [(d_1 - K_2), d_2, (d_3 + K_3)] \text{ Where } K_2 \geq 0.05$$

The selection mechanism of this 0.05 helps to manage low power fluctuation but, during the partial shade, the working voltage may increases up to 85%, this helps PSO algorithm to track global peak more. The following section gives the algorithm implementation.

```
Algorithm of modified PSO
Input: Ip, Vp
Output: Gb and Pb
Start
Step-1: initialize & detect Ip and Vp
Step-2: Compute P(i) = Vp × Ip
Step-3: Check if P<0;P>0
             Compute (d) at Vi=(1,2,3)=0, Np=3, K=0
        Else increment i=i+1;
        Check  i>Np
        Increment k=k+1;
        If   K=1;
        Pbest=di
        Else check i=1;
Step-4:  Compute Pb&Gb
Step-5: Update→ disturbances
End
```

The algorithm is initialized by detecting the PV current (Ip) and PV voltage (Vp) (Step-1). Further, the initial power of the PV cell is computed by using the general formula of power $P_{(i)} = V_p \times I_p$ (Step-2). Later, the condition of P>0 or P<0 is verified (Step-3). If the condition is satisfied, the duty ratio (d) is calculated at duty cycles (1,2,3) of voltage Vi(1,2,2)=0 number of particles (Np)=3, constant k=0. If it is not satisfied, then the number of iterations will be incremented by 1. Further, it is checked for "i>Np" and if it is satisfied, then ‘k' value is incremented by 1. If k=1, the "Pb" value will be duty cycle (di) i.e., Pb=di. Similarly, if ‘k=1' is not satisfied, it will be checked for i=1. Then, the value of Pb can be computed after varying the condition P(i)>P(i-1). In case, the condition is satisfied, then “Pb=di” else “Pb=d(i-1). ”. Similarly, to calculate global best (Gb) same procedure of incrementing (i=i+1) and checking "i>Np." Based on this condition, Gb is computed as,

$$G_b = \max(P_b)$$

Finally, the disturbance among Pb, output voltage, and Gb is updated. The duty cycle of disturbance is computed by using previous duty ratio di(k) and local Pb. The difference between ‘i’ and previous di(k) and Gb. Hence, the power converter and tracking best Pb, Gb and I are possible in the proposed algorithm.

The significance of proposed PSO is that it yields faster search and tracks the MPP optimal solution. After acquiring the MPP by particles, the velocity almost becomes zero. Hence, no oscillations will be observed in steady state. The steady state oscillation is necessary as it is helpful in getting the efficiency of MPPT. Another significant feature of modified PSO is that it exhibits 3-duty cycles, and hence, it does not lose direction in short term fluctuations. The proposed PSO effectively able to track the global peak.

3. RESULT ANALYSIS

The proposed system model is simulated using MATLAB. In the optimization process, the fitness value is updated by PV array output power. The performance analysis of the modified PSO is done with traditional PSO under partial shading condition aiming with accurate MPP tracking. Figure 4 represents the tracking result of traditional PSO, where it is observed that a large range of fluctuations exists in optimization. This misjudges the MPP and takes ~0.045sec for tracking the MPP.

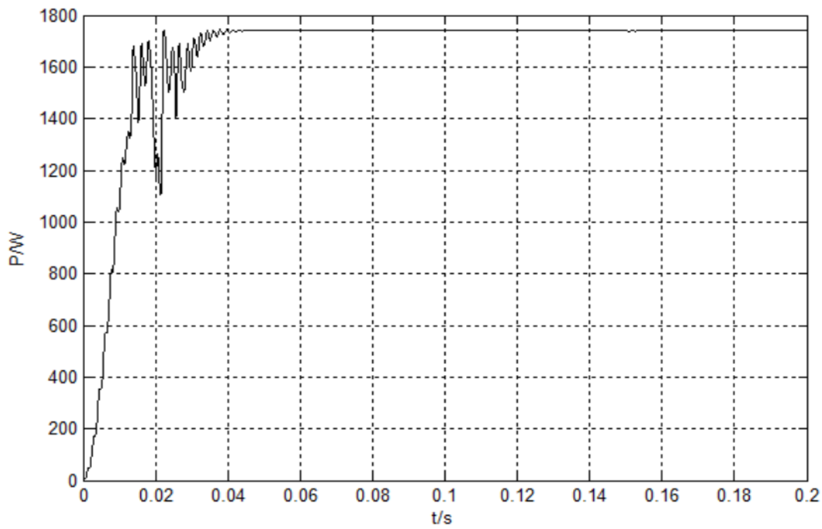

Figure 4. Tracking of MPP with traditional PSO

The proposed, modified PSO considered search-based optimization uses 3-duty cycles and does not lose its direction in short term fluctuation. Figure 5 shows the power Vs. time curve obtained from proposed PSO is smoother than traditional PSO, and it takes only ~0.038sec for MPP tracking, which is improved about 0.08secs. Hence, the modified PSO makes the process more stable and improves the MPP performance.The proposed PSO improved the dynamic response speed tracking accuracy in a steady state.

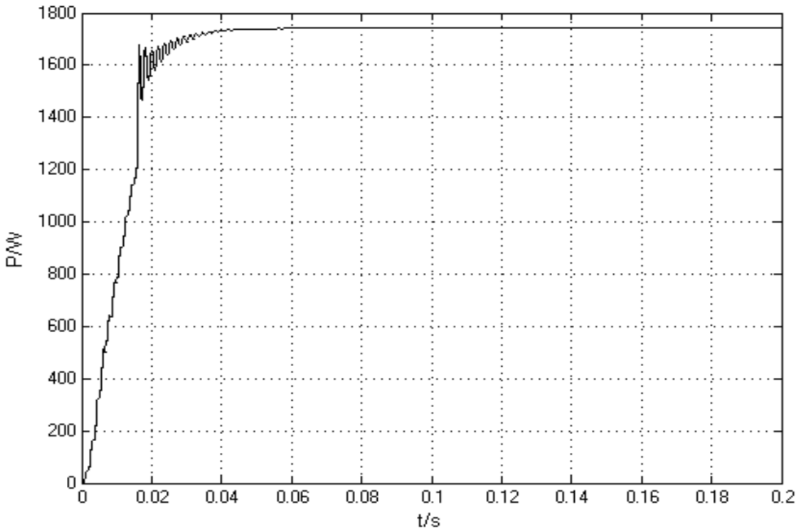

Figure 5. Tracking of MPP with proposed PSO

4. CONCLUSION

In this research, the proposed MPP tracking system is aimed to enhance the tracking accuracy and speed. The proposed system introduced an MPPT technique based on the modified PSO algorithms which bring high efficiency. The search based method is considered with 3-duty cycles and does not lose its direction in short term fluctuation in steady state. Another significance is that the proposed PSO has taken less time (0.038secs) to track the MPP than traditional MPP (0.045sec) found improvement of 0.008secs. This gives that the performance of the MPPT is enhanced with an efficiency of 99%. The scope of the proposed study is that it can be considered with other machine learning approaches under different environmental condition. Further, the research can be carried out with different types of PV arrays.

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