Improving of Maximum Power Point Tracking for Photovoltaic Systems Based on Swarm Optimization Techniques

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Abstract. The photovoltaic system considers one of the important renewable sources of energy that using solar cell. Limitation and crisis of other energy resource make the photovoltaic system is growing. This motivated the researchers to improve and maximize renewable energy sources effectiveness. The optimal operating point is located in the PV voltage curve of the solar cell which is called Maximum Power Point (MPP). This point changes in nonlinear form with varying of solar incandescence, temperature and solar cell properties. Recently more methods are developed to get optimal value of MPPT and one of these methods is the Extremum-Seeking Control (ESC) which is based on filter operation. In this paper different optimization methods are presented such as Genetic Algorithm (GA), Grey Wolf Optimizer (GWO) and Ant Lion Optimizer (ALO). They are used as a tuning tool for ESC controller parameters to improve the MPPT performance. All methods are tested in the MATLAB environment, the result shows that the effectiveness of swarm optimization, especially GWO in term the efficiency and speed of converging.

1. Introduction
In the last years, energy generated from environmentally friendly, renewable, clean and efficient sources becomes one of the important engineering research areas. Solar systems are attracting more research due to their availability. The widespread have been used of photovoltaic systems has reduced the manufacturing cost, but the lower efficiency of a solar cell problem remains. The photovoltaic power of the photovoltaic system depends critically on two variables: cell temperature and sun radiation. This makes the efficiency of solar panels can reach 30-40%. This means that the electrical energy obtained approximately 40% of the total energy. The techniques used effectively in PV are called Maximum Power Point Tracking (MPPT). This technique was implemented to extract the maximum energy available from the solar cell by making it works at the most efficient output. To get MPP, it needed a technique to make the controller to operates at the optimal operating point. Some of tracking techniques have been developed [1]. MPPT algorithm can be classified to two main categories, traditional and non-traditional algorithms. For traditional MPPT methods, many schemes it was suggested; the most popular methods are Hill Climb, Incremental Conductance, and Perturb and Observe which consider most used method. Hill Climbing uses the duty disorder cycle of connected convertor. The Incremental Conductance is based on a photovoltaic voltage derivativition, it must be equal to zero in MPP; it will be positive in the left of MPP, and negative on the right side. Perturb and Observe, can generally be similar in operation to Hill Climbing mode, it is an iterative technique, The MPPT measures PV properties and then the system’s operating point is clogged in order to satisfy the change direction. Biologically inspired (Non Traditional), methods have been arrived more and more
importantly due to ability to manage multi MPP in PV curve, faster convergence ensuring convergence to the global MPP [2]. There are several methods of MPPT algorithm such Extremum Seeking Control (ESC) which is a class of self-optimized control method that can search for the unknown optimal input parameter for a given performance have indicates of the nonlinear factory process. ESC is extracting the derivation information using a signal pair of demodulation and dither with the filters high and low. The control loop is closed with integrator; the signal was run gradient to zero in steady state to reach the optimal solution. As such gradient information have secured to the specified gradient frequency; this scheme is powerful for handling noise and performance map variation. This feature has proved challenging systems [3]. In this work the swarm optimization is mixed with ESC control to achieve the best performance for PV system.

2. Solar System Modelling
The photovoltaic effect can be modelled by the diode, where the cell is connected to a resistance, thus the appearance of an inverted current I as voltage V. In view of the losses caused by manufacturing defects, a resistance Rs must be added equivalent to different connections and contact resistors, Rsh equivalent impedance to distinguish the leakage currents due to the diode as shown in Figure 1, each cell can be designed with the following circuit:

![Figure 1. Photovoltaic System Equivalent Circuit](image)

From electric circuit the following equations can be obtained:

\[ V_p = R_P \times (I_C - I_D - I) - R_S \times I \]  \hspace{1cm} (1)

Where the photocurrent \( I_C \) is derived from the effect of solar radiation and cell temperature, \( I_D \) was represented by Schockley equation, which specifies the ideal characteristic of the diode. \( V_P \) and \( I \) are, single cell voltage and current respectively. Thus, the stationary behaviour of the photovoltaic cell contains the PN silicon is described as follows:

\[ I = \frac{1}{R_P+R_S} \left( R_P \left( I_C - I_D \left( e^{\frac{V_P+R_S I_D}{nV_T}} - 1 \right) \right) - V_P \right) \]  \hspace{1cm} (2)

Where, \( I_D \) is the saturation current of the diode. \( V_T \) is a temperature voltage, and \( n \) is a diode factor [2].

3. Maximum Power Point Tracking Algorithms
The basis of the MPP is based on the following analysis: The output power of PV cells is maximized when the output resistance of the cell is equal to the load resistance. The control algorithm traces the MPP can be affected by climatic conditions such as temperature and radiation. As shown in Figure 2, the relationship between current and voltage is nonlinear. Along the curve, there is a point where the solar cell will produce their maximum capacity; this is called the maximum power point. However, there are many limitations because the oscillations around the MPP while searching for this point [1]. There are different method are developed to track the MPP such Perturb and Observe and Extremum-Seeking Control.
Perturb and have observed the significantly used technique because of its simplicity and general nature. As its name suggest, perturb and observe done by perturbing with the photoelectric voltage periodically and monitors the photovoltaic power to boost or reduction. If the perturbation results in an increase in photovoltaic power, the direction of the perturbation is kept (refer to the operating point is made towards a maximum power point). Otherwise, when the PV power goes down, the system moves away from the maximum power point. Then, reverse the perturbation direction. The power derivative of the voltage function is zero when reaching the maximum power point. Despite the low demand for equipment and its uncomplicated structure, MPPT capture using Perturb and Observe becomes unsuccessful when the radiation of solar on single or multi PV units is unequal because the PV curve becomes distorted and shows multiple peaks (single global and multi Local) [4].

ESC addresses the problem of online optimization to find and improve the input $u$ of the generally unknown and / or variable cost function over time $l(t,u)$, where $u(t)$ is the income parameter vector, Figure 3. show the ESC system. The cost function $l(t,u)$, referred to as $y(t)$, is corrupted by noise $n(t)$. The transfer function $F_I(t)$ refers to linear dynamics of the mechanism that controls parameter $u(t)$. $F_0(t)$ refers to the sensor dynamics transfer function that measures the cost function, which represent a low pass filter to remove noise of the measurement [5].

In MPPT problem, the ESC frame is used in Fig.3 to develop the MPPT scheme of the photovoltaic system, as shown in Figure 4. ESC design contains a determination of the filter amplitude and frequency. At next section the optimization method are introduced to find the optimal filter parameters to maximize the output power.
4. Optimizations Algorithm

The optimization methods can be solved the MPPT problem which has a powerful property such as robustness and rapid calculation capability. Among optimization methods, swarm algorithms correspond to MPPT because of their simple structure, and ability to determine the MPP of the power voltage curve regardless of environmental differences [4].

4.1 Gray Wolf Optimizer (GWO)

A strict hierarchy is implemented in wolf group, this group has a chief called alpha (α), powered by a secondary one called beta (β), which helps a α in the decision making process. The rest of the group members are called δ and ω as shown in Figure 5. The fishing process of gray wolves is: searching for food, briefing food, hunting, and attacking food. The mathematical formula encirclement the food has written by the following equations:

\[ A = |B \cdot P_{pi} - P_t| \]  
\[ P_{t+1} = P_t - X \cdot A \]

Where \( P_t \) is the position of gray wolf, \( P_{pi} \) is the food’s position, \( A \) is the space, \( X \) and \( B \) are vectors calculated as follows

\[ v = 2 - 2 \times i/N \]
\[ X = 2v \cdot rd_1 - v \]
\[ B = 2rd_2 \]

The random numbers rd1 and rd2 have the range 0 to 1. \( v \) is a variable that is linearly decreased from 2 to 0 with increasing of iteration. Search process for position of the food can be achieved by spacing search for entities, when \(|X| > 1\). The process of obtaining food can be achieved through convergence search entities, when \(|X| < 1\). Fishing leads α entity with entities β and δ as shown in (15) - (17). Such as other supra-heuristics algorithms, GWO algorithm can be eliminated for stagnation at the local minimum point but the X and B parameters are used to avoid recession [6].

4.2 Sin Cosine Optimizer (SCO)

In the first stage, the sine cosine optimizer creates a small group and heads towards an optimum solution by updating sine cosine equations.
In order to explore exploration and utilization of the search space, site update equations are used. The sine cosine updating equations are described as:

$$A_{j}^{i+1} = \begin{cases} A_{j}^{i} + \beta \times \sin \alpha \times \left| \rho \times X_{j}^{i} - A_{j}^{i} \right| & \text{if } \theta < 0.5 \\ A_{j}^{i} + \beta \times \cos \alpha \times \left| \rho \times X_{j}^{i} - A_{j}^{i} \right| & \text{if } \theta \geq 0.5 \end{cases}$$

(8)

Where, \(\beta\) is the control parameter of sinusoidal nature, it is defined as,

$$\beta = \mu - n \times \frac{\mu}{N}$$

(9)

Where, \(A_{j}^{i+1}\) is the updated position of the jth individual at ith iteration. \(X_{j}^{i}\) is the ability obtained, corresponding to \(A_{j}^{i}\). \(\rho\) and \(\theta\) are the random numbers have interval from 0 to 1. \(\alpha\) is the random numbers have interval from 0 to 2. \(\mu\) is constant number having natural of sinusoidal. \(N\) is the maximum iteration number. The path of the SCO algorithm individual path addition and the variable position and objective function are shown in Fig. 6. If the sine-cosine function value between -1 and 1 the objective function moves to GMPP and exploits the algorithm search space. However, If the sine-cosine function value out the interval [-1, 1], objective function deviation from GMPP and explore the search algorithm void [7].

4.3 Salp Swarm Algorithm (SSA)

The modeling of swarming manner of salp string have a clustered from salp strings begin with the division of population into two groups, are called leader and successor. Salp leader in the front of the swarm to guide the group and the rest is followed by some of them. In the search area, there is a food source also targets each swarm in and is called TF.

The leader salp’s position is updated according the following equations with regard to targeted food as:

$$A_{i} = \begin{cases} TF_{i} + a_{1}(a_{2}(ub_{i} - lb_{i}) + lb_{i}) & a_{3} \geq 0 \\ TF_{i} - a_{1}(a_{2}(ub_{i} - lb_{i}) + lb_{i}) & a_{3} < 0 \end{cases}$$

(10)
Where, \( A_j^i \), \( TF \) are the salp leader and target food position in \( i^{th} \) dimension respectively, \( a_1, a_2 \) and \( a_3 \) are random numbers. \( a_1 \) parameter balances the searches and exploit the algorithm stages. It is the very important coefficient of SSA and described as following:

\[
a_1 = 2e^{-\frac{4n}{N^2}}
\]  
(11)

Where, \( n \) represents the index of iteration, \( N \) is maximum number of iteration, the range of \( a_2, a_3 \) is \([0,1]\), the other salp update his position as:

\[
A_i^j = 0.5 \times (A_i^j + A_i^{j-1}) \quad \forall j \geq 2
\]  
(12)

From the last equation, it noted that, all salp follow its leader to make the chain of salp[8].

### 4.3 Whale Optimization Algorithm

Whale optimization algorithm is newly proposed optimization method inspired by net bubble hunting humpback whale technology. Describes WOA The behavior of a special follower of humpback whales, in which the whales try to encircle the prey near the water’s surface while creating bubbles present in the figure of a circle. In the technique of catching net bubbles, humpback whale dive nearly 12 meters down and then start to make bubbles in a spiral shape around prey and swimming towards the surface.

![Whale Optimization Strategy](image)

**Figure 8. Whale Optimization Strategy**

During the optimization process, for the typical enclosure mechanism, the following equations are proposed

\[
P_{i+1} = P_i^* - X |B \cdot P_i^* - P_i|
\]  
(13)

Where \( X, P \) are coefficient vectors, \( P_i^* \) the site vector of the optimal solution, \( P_i \) the position vector, \( X \) and \( B \) are vectors calculated as follows

\[
X = v(2. rd_1 - 1)
\]  
(14)

\[
B = 2. rd_2
\]  
(15)

The random numbers rd1 and rd2 have a range 0 to 1. \( v \) is a variable that is linearly decreased from 2 to 0 with increasing of iteration. [9]

### 5. MPPT Based Swarm Optimization Method

In this work, the ESC controller parameters are tuned by using the swarm optimization to achieve the best maximum power point tracking. fig.9 shows that the ESC controller contains low pass filter and high pass filter and these filters can be written as follows:

\[
F_{LP}(s) = \frac{x_1}{s+x_1}
\]  
(16)

\[
F_{HP}(s) = \frac{x_2}{s+x_2}
\]  
(17)

\[
K(s) = x_3
\]  
(18)

For all swarm optimization methods the population is \([x_1, x_2, x_3]\) with fitness function

\[
Max \quad Fitness \quad Function \quad (x_1, x_2, x_3) = V \times I
\]  
(19)
6. Simulation Result
To verify the performance of the proposed method, the photovoltaic system was simulated in MATLAB/Simulink as shown in fig.10. The PV array system contain six cells (SQ85) module that have rated power =85-watt, max power voltage=17.2-volt, max power current=4.95 amper, Voc=22.2 volt, Isc=5.45 ampere, the efficiency of output energy of PV system is consider as performance index to all methods.

\[
\eta = \frac{\int (V \times I) dt}{\int (V_{\text{max}} \times I_{\text{max}}) dt}
\]  

The temperature remains constant at T = 25 °C and the radiation changes from 1000W/m² to 600 W/m² the population size for all method = 20, maximum number of iterations =100 Table.1 shows the energy obtained from the PV system for a different method

| Radiation (W/m²) | GA (%) | GWO (%) | SCO (%) | SSA (%) | WAO (%) | ESC (%) |
|-----------------|--------|---------|---------|---------|---------|---------|
| 1000            | 89.80  | 90.92   | 90.47   | 90.28   | 90.28   | 85.68   |
| 950             | 89.74  | 90.85   | 90.34   | 90.23   | 90.23   | 85.18   |
| 900             | 89.57  | 90.66   | 90.09   | 90.07   | 90.07   | 84.57   |
| 850             | 89.30  | 90.38   | 89.75   | 89.81   | 89.81   | 83.89   |
| 800             | 88.95  | 90.03   | 89.33   | 89.47   | 89.47   | 83.13   |
| 750             | 88.53  | 89.61   | 88.85   | 89.06   | 89.06   | 82.32   |
From the table 1, it can be noticed that, the efficiency of all methods is reduced as the radiation is decrease; also the efficiency of standard ESC controller is reduced to 79% while the tuned ESC based swarm optimization is reduced with low rate as shown in table. Another test is applied by change the sun radiation. Figure 11 shows the tracking speed of all methods. This figure indicates that the swarm optimization track the MPP faster convergence than traditional ESC. Also, they are more robust with the radiation change.

**Figure 11.** Tracking of all methods

**Conclusion**

This paper presents a MPPT method based on tuning ESC controller by using recent swarm optimization methods. These methods are very efficient tuning methods and their solutions are near to the optimal solutions respect to more searching methods. In this paper, output energy considered as a fitness function while the ESC parameter considers as population. Traditional ESC and tuned ESC controllers are applied for MPPT with different sun irradiation and shadow cases. The simulation results was indicated clearly that the tuned ESC has better performance (in term of efficiency and tracking speed) with respect to the traditional ESC . From the result, it can be concluded that, the swarm optimization is a good tool in controller design with suitable objective function. Among all swarm optimization, GWO gives the best result in term the efficiency due to its hierarchy which contains four levels. The swarm optimization can be used in another application such as wind turbine and other.
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