Improved Hybrid Salp swarm and Sine-cosine Optimization based MPPT Control for PV Systems Under Partial Shading Conditions

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Abstract. A novel improved meta heuristic method, Hybrid salp swarm using sine cosine algorithm (Hybrid SS-SC) for maximum power point tracking (MPPT) under partial shading condition is proposed in this paper. The proposed algorithm envisages finding the best GMPP. The simulation studies clearly demonstrate that the method compares favourably with the conventional P&O method as well as with some other nature inspired algorithms in tracking GMPP in less time.

Keyword: Hybrid salp swarm algorithm, MPPT, Partial shading, GMPP

1. Introduction
We have entered the twenty-first century, but a reliable twenty-four hour electricity supply is still a pipe dream. Because of the traditional approach to electricity generation, we have been unable to meet the rising demand for energy. So, as we enter the third decade of the twentieth century, we are constantly attempting to produce more electricity from renewable energy sources with more optimised output in order to meet demand. Solar energy is the most promising of all available energy sources. The main advantages of solar systems are their low carbon footprint, low maintenance, lack of noise, and quick installation [1]. Efficiency, cost, type of installation, and complexity are the key features to consider when generating maximum power with solar systems. PV arrays have nonlinear properties, and their output is affected by solar irradiation, ambient temperature, and load. These variables change on a regular basis and have an impact on the output power of PV arrays. Several methods for extracting the most power from PV arrays under changing conditions have been reported. These methods for maximum power point tracking (MPPT) are divided into two categories: traditional techniques and new meta-heuristic algorithms-based techniques. Nature-based algorithms are being used in recent trends to overcome the drawbacks of conventional ones and to achieve better optimised results [2]. This paper is primarily concerned with the performance of MPPT in order to achieve...
maximum power. A novel hybrid method for tracking the maximum power point has been proposed. The MPPT method proposed here incorporates the Salp swarm algorithm as well as an improved sine-cosine algorithm. In this paper, a levy flight with a step size control factor and an improved sine cosine operator are used to improve the traversal and exploration capabilities of search agents and the leader's search efficiency to obtain optimised power and the best global maxima among all available global maximum power point (GMPP) under partial shading conditions.

2. PV SYSTEM MODELLING

2.1. PV Cell Model

The equivalent circuit shown in figure[3] can be used to express a schematic diagram of a basic solar cell. A single diode, a current source, an equivalent series resistor, and a parallel resistor are all part of the PV model[4]. The presence of a parallel resistor is caused by the cell's pn junction leakage current. The Schockley equation determines the diode's V-I characteristic graph. The current of a PV cell can be calculated using the equations presented below:

\[ I = I_{SC} - I_d - I_P \]

\[ I = I_{SC} - I_0 \left[ \exp\left( \frac{q(V + I R_s)}{n k T} \right) - 1 \right] - \frac{V + I R_s}{R_p} \]

(1)

(2)

Here I is the terminal current, \( I_0 \) is the reverse saturation current, \( V \) is the cell voltage, \( I_d \) is the diode current and \( n \) is the ideality factor. Normally, the value of ideality factor is between 1 and 2. The range of ideality factor is dependent on the semiconductor material and fabrication process. Here, it is considered as 1. Here, Boltzmann constant (\( k \)) value is 1.38*10^-23 J/K, PV cell temperature is denoted by the T, electron charge (\( q \)) value is 1.6 * 10^-19 C. The PV module 1 Soltech 1STH-215-P is used in the system. Figure2. shows the V-I and the P-V graph of the PV module 1 Soltech 1STH-215-P.

Table 1: Electrical characteristics of Soltech 1STH-215-P

| Description                  | 1STH-215-P |
|------------------------------|------------|
| Maximum Power \( P_{max} \) (W) | 213.15     |
| Open circuit voltage \( V_{oc} \) (V) | 36.3       |
| Short circuit current \( I_{sc} \) (A) | 7.84       |
| Voltage at maximum power point \( V_{mp} \) (V) | 29         |
| Current at maximum power point \( I_{mp} \) (A) | 7.35       |
2.2. Boost Converter

The boost converter is an essential part of the PV system. It provides required control variable for the regulation of the voltage of PV arrays by adjusting the duty cycle D [5]. D is mainly modulated so that it can adapt $V_{pv}$. The parameters of the boost converter are switching frequency ($f$), output voltage ($V_{out}$), input voltage ($V_{in}$), output capacitance ($C_{out}$), input capacitance ($C_{in}$), inductor ($L$), duty cycle ($D$)[6]. The electrical parameters are calculated using equations (3-7). The complete layout of the PV system is given in the following figure.

$$V_{out} = \frac{V_{in}}{1-D}$$

$$D = \frac{t_{on}}{t_{swt}}$$

$$C_{in} = \frac{D}{0.95 + 0.01 + L}$$

$$C_{out} = \frac{D}{0.02 + F + R}$$

$$L = \frac{D(1-D)R + F}{2 + F}$$

![Figure 3. A complete PV system [4]](image)

3. Hybrid Salp Swarm-Sine-Cosine Algorithm Based MPPT Method

Under partial shade conditions, this research presents a novel study of a hybrid salp swarm model paired with a sine–cosine model to find optimal output in conventional MPPT methodologies. This section provides a quick overview of the salp swarm algorithm, the sine cosine method, and the hybrid algorithm, which is a hybrid of the two.

3.1. Salp Swarm Algorithm

The SSA was created for the aim of optimization. The leader and followers make up the majority of the salp chains. The route and foraging route to the population are primarily determined by the leader. While the followers assist in the quick exploration of search space and exploitation in a localised area for better food consumption, the leader and followers achieve a perfect balance. SSA is implemented for optimising MPPT, taking into account these two properties. In our approach, the duty cycle represents the search space, which accepts values between 0 and 1. The output duty cycle is linked to the position of the salp leader [7].

$$X_j^3 = \begin{cases} F_j + c_1 \left( (u_b_j - l_b_j) c_2 + l_b_j \right) & c_3 \geq 0 \\ F_j - c_1 \left( (u_b_j - l_b_j) c_2 + l_b_j \right) & c_3 < 0 \end{cases}$$

In the above equation, $X_j^3$ shows the leader’s position in the j-th dimension; $F_j$ indicates the position of the food in the j-th dimension; $u_b_j$ is the higher bound and $l_b_j$ is the lower bound of the j-th dimension; These are used to limit leader from exceeding the searching space. $c_2$ is a random number between [0,1], used to control the leader’s path. $c_3$ is a random number between [0,1], used to equally select whether the leader’s moving direction is closer or farther from the food location. But in this case the key parameter is $c_1$ as it helps to maintain the balance between the exploitation and exploration. The value of the parameter $c_1$, can be calculated using the following equation.
Here ‘n’ shows the present iteration number and ‘N’ shows the number of total iteration. The followers’ equation can be studied by taking the help of the Newton’s laws of motion i.e.

\[ X_i^j = v_0 t + \frac{1}{2} a t^2 \]  

(10)

Where, \( X_i^j \) indicates the position of the i-th follower in the jth dimension when \( i \geq 2 \); \( t \) represents time; \( v_0 \) represents the initial speed, the acceleration of the followers’ movement \( a = \frac{v_{final}}{v_0} \); The speed of the follower is \( v = (x - x_0) \). The time variable of the optimization problem is represented by the number of iterations, so the iteration interval represents the time interval, \( t = 1 \). The follower’s initial speed \( v_0 = 0 \). So the equation 10 can be updated as

\[ X_i^j = \frac{1}{2} (X_i^j + X_i^{j-1}) \]  

(11)

### 3.2. Sine Cosine Algorithm

As the name implies, it is a mathematically based approach that optimises results by using both the sine and cosine functions. Again, global exploration and local exploitation play a role in this algorithm. The sine part of the SCA is used for exploration while the cosine part is used for exploitation. SCA is represented by the following equation:

\[
X_i^{t+1} = \begin{cases} 
X_i^t + r_1 \sin(r_2) \cdot |r_3 p_i^t - X_i^t| & \text{if } r_4 < 0.5 \\
X_i^t + r_1 \cos(r_2) \cdot |r_3 p_i^t - X_i^t| & \text{if } r_4 \geq 0.5 
\end{cases}
\]  

(12)

Here, \( X_i^{t+1} \) indicates the position of the individual in the i-th dimension and in the t-th iteration and \( p_i^t \) indicates the position of the current optimal individual in the i-th dimension. \( r_1, r_2, r_3, r_4 \), are the basic four parameters in the SCA algorithm. The role of \( r_2 \) is to control the moving path of the search agents having a range of \([0,2\pi]\). The role of \( r_3 \) is to either strengthen or weaken effect of moving distance of particle whereas, \( r_4 \) is used to control both the sine and cosine search function. \( r_1 \), can be used as a guiding parameter for the search particles. It can be calculated using the following equation:

\[ r_1 = a - t \frac{a}{T} \]  

(13)

In the above equation, \( t \) indicates the current number of iterations; \( T \) indicates the maximum number of iterations; \( a \) is a constant that limits the size of \( r_1 \), generally \( a = 2 \).

Both global exploration and local exploitation must be thoroughly investigated in the ways indicated above. The main focus of MPPT, on the other hand, is on better optimised power output. So, despite local exploitation, our goal is to look ahead to more global exploration, and the salp swarm hybrid algorithm, as well as the sine–cosine algorithm, are being investigated for that reason.

### 3.3. Hybrid SS–SC Algorithm

The improvement in search space and the leader’s position for MPPT under partial shading conditions is implemented in this approach. For a decent optimization, more search space is required, which will be provided by improvements in the levy flight function. It will assist in the strengthening or weakening of space agents. The following is the equation for updating the position of a salp swarm with an enhanced flying function:

\[ X_i^j = X_i^j + a. S \otimes X_i^j \]  

(14)

Where, \( X_i^j \) indicates the position of the i-th follower in the j-th dimension when \( i \geq 2 \); \( S \) is the random step size following the Levy distribution generated by the Mantegna distribution method; \( \otimes \) indicates the dot product between elements; \( a \) is the step size control factor. When the step size control factor is small, the search agent can carefully search in a small range. It is considered as 0.01 here. The leader’s position can be updated using the improved sine operator function which is given in equation (15).

\[
X_i^j = \begin{cases} 
X_i^j + c_1 \cdot \sin(r_2) \cdot |F_j - X_i^j| \cdot e^1, & r_4 < 0.5 \\
X_i^j + c_1 \cdot \cos(r_2) \cdot |F_j - X_i^j| \cdot e^1, & r_4 \geq 0.5 
\end{cases}
\]  

(15)
The effect of the parameter $c_4$ is the same as that of the salp swarm method, while the effects of the parameters $r_2, r_4$ are the same as those of the SCA. The search space range is enlarged to $[2, 2]$ in the approach, allowing for wider global research. Rather than looking for the first GMPP, the algorithm proposed here looks for the best GMPP. It will examine the system’s maximum reference power with
varied power at different iterations, then settle on the best global maximum power with the shortest settling time, as shown in the flowchart in the above figure.

4. Simulation and Results
To test the effectiveness of the suggested method, a simulation study is carried out. Under partial shading conditions, the performance of the system using the suggested MPPT algorithm is compared to the performance of the same system using the conventional P&O method and the HHO algorithm. In the final part of the presentation, a comparison of the system's reported performance utilising alternative meta-heuristic methods for tracking GMPP is offered. Figures 5-8 show the PV voltage and current, as well as the output voltage and current, for systems using P&O, HHO, and the proposed hybrid SS-SC algorithm.

(Figure 5. simulation results of PV cells under P&O algorithm)

(Figure 6. Simulation results of PV cells under HHO algorithm)

(Figure 7. simulation results of PV cells under hybrid SS-SC algorithm)

The maximum power that can be extracted using the above mentioned three methods and their settling times is shown in figure 8.
This study provides two alternative better ways to circumvent the shortcomings of the SSA algorithm. The first technique relies on a step control factor to improve Levy flight. This is used to boost GMPP levels. The enhanced sine cosine operator, which introduces the convergence factor, is the second. This is utilized to improve the leader's efficiency. Both methods aid in the improvement of GMPP and LMPP. This technique outperforms GHO [8], SSO [9], Bat-FLC [10], HHO [11] and P&O in terms of optimization accuracy. Table 2 shows the GMPP tracking time for these approaches.

Table 2 Tracking time of different MPPTs

| MPPT Algorithm                | Tracking time of GMPP (in sec) |
|-------------------------------|--------------------------------|
| 1. The Proposed Method        | 0.089                          |
| 2. GHO [11]                   | 0.13                           |
| 3. SSO [12]                   | 0.19                           |
| 4. BAT-Fuzzy algorithm [13]   | 0.17                           |
| 5. HHO                        | 0.552                          |

The hybrid salp swarm algorithm has the best tracking time among the approaches investigated, as shown in the table. Physical implementation in the best-suited weather conditions can be used to further investigate the performance of the suggested algorithm in an actual context.

5. Conclusion

A hybrid SS-SCO based MPPT technique for extracting maximum energy from a solar PV system is proposed in this work. The proposed method was compared with the conventional P & O method and some nature inspired algorithms already reported to have been used for the same purpose. It produces more GMPP and takes less time to settle than the HHO and the traditional perturb and observe method. The proposed algorithm also demonstrates better GMPP tracking time as compared to other nature-inspired algorithms reported to have been used for this purpose. This method is a suitable candidate for usage in MPPT under partial shading situations because of its fast convergence and higher optimization accuracy.
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