

GMPP Tracking of Solar PV system using Spotted Hyena and Quadratic Approximation based Hybrid Algorithm under Partially shaded conditions

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ABSTRACT The demand for clean and renewable energy is increasing due to environmental concerns. Photovoltaic (PV) system is very popular from the renewable sources and its usage is increasing. The PV system power transfer efficiency depends on several factors such as electrical characteristics of loads, solar irradiation, shading condition and panel temperature. The process of transferring maximum possible power to load from PV system by adjusting the system parameters is called maximum power point tracking (MPPT). Under the partially shaded conditions, multiple power peaks are created in the PV curves and makes the MPPT is a non-convex problem. It is a challenging problem to track the global maximum power point (GMPP) under partially shaded conditions. It is essential to recognize the GMPP and restart the string as early as possible to prevent the physical as well as economical damage. In this paper, a new hybrid algorithm for MPPT is proposed and called as QASHO, a combination of Spotted Hyena optimization (SHO) and Quadrature approximation (QA) technique. The QASHO is used to track the GMPP under different weather conditions such as partial shading. The simulation results are compared with Perturb and Observe (P&O) algorithm and Cuckoo Search optimization (CSO) algorithm and promised for better performance in tracking GMPP. The experimental results are provided to validate the proposed MPPT methodology.

INDEX TERMS Solar PV system, partial shading, global maximum power point, Optimization, Spotted Hyena optimization, Quadrature approximation.

I. INTRODUCTION

In the modern world, the energy demand is increasing exponentially due to industrialization and population growth. The same trend will continue in the future. The demand increase is more in the developing countries [1]. All the countries are planning to reduce the pollution due to power generation and pledged to become net zero by 2050 [2]. Renewable energy resources are the solution to achieve this goal. Solar PV gaining popularity [3] due to its abundance, pollution free nature, maintenance free, limitlessness and noiselessness. Solar PV systems are subject to draw backs such as low efficiency and highly uncertain nature due to dependence on weather conditions. Solar PV output power varies according to changes in weather conditions and irradiance level [4]. The output power of the PV system reduces due to different factors and partial shading is one of the main concerns. Authors in [5] discussed different shading conditions and cell configurations. PV characteristics has several peaks called as local maximum power point (LMPP) under partial

shading and global maximum power point (GMPP) is one of them [6].

The system parameters are modified to get the MPP and the process is called as maximum power point tracking (MPPT). Researchers used several MPPT algorithms for solar PV system to get maximum power [7]-[9]. The algorithms are differing from each other due to cost, complexity, required sensors, effective range, convergence speed and hardware implementation. The Perturb and Observe (P&O), Incremental conductance (IC) and hill climbing algorithm (HCA) are very common and efficient methods to find MPP. These methods are simple to use but losses the tracking path under rapid change of climate and partial shading conditions [10], [11] low efficiency and convergence speed. The issues are solved to some extent using advanced version of the conventional algorithms, like improved IC, adaptive IC [12], self-predictive IC [13], momentum based P&O [14], fixed zone P&O [15], and drift free P&O [16] etc.

In the literature, different optimization techniques are used such as Genetic Algorithm (GA) [17], Particle Swarm

Optimization (PSO) [18], Cuckoo Search Optimization [19], adaptive jaya algorithm [20], Bat algorithm [21], Spotted Hyena optimization [22] etc. It is mentioned that metaheuristic optimization techniques have the capacity to track the GMPP but takes more time to do the same. The researchers are hybridized the metaheuristic methods by combining with conventional methods. Authors in [23] developed two hybrid algorithms by combining IC and P&O with PSO to track MPP. In ref [24], HCA is combined with PSO to utilize the benefits of both the methods. IC is combined with bio-inspired Dragonfly Optimization (DFO) and is proved effective for partial shading [25]. The hybrid methods discussed in the literature uses the features of fast tracking of conventional algorithms and capacity to achieve the GMPP of heuristic algorithms under partial shaded condition. However, every method has its own drawbacks and limitations in terms of convergence, settling time, MPPT efficiency etc.

In this work, a new hybrid algorithm is presented to track the GMPP under partially shading conditions. A novel hybrid algorithm developed in [26] based on the Spotted Hyena Optimization (SHO) and Quadrature Approximation (QA) technique and called as QASHO. The effectiveness of QASHO is proved in [26] by comparing the optimization results with benchmark problems. The PV system used in this study consist of five modules in series which gives the four peaks in the PV curve. The complexity of tracking GMPP is increases with more number of peaks in the PV curve. In this work, the performance of presented MPPT algorithm is validate under uniform irradiance and partial shading while keeping the cell temperature constant. A typical boost converter is used for MPPT control. The methodology is tested under standalone condition. The contributions in this paper are as follows:

- A novel hybrid algorithm i.e., QASHO based MPPT is developed and tested under uniform and partial shading conditions.
- The effectiveness of the proposed QASHO based algorithm is validated by comparing other existing MPPT algorithm.
- Different performance parameters are presented to check the effectiveness of the MPPT algorithms.
- Simulation results are validated with experimental results.

The remaining sections are organized as follows: The PV system modelling is discussed in section II which includes PV cell design, boost converter modelling, PV module configuration and IV and PV curves under different conditions. Section III describes the proposed algorithm along with conventional algorithms. The simulation results and experimental results are discussed in Section IV. Finally, Section V concludes the work.

II. PV SYSTEM DESIGN

The typical PV system consist of PV panel, DC-DC converter, MPPT algorithm, PWM pulse generator and loads. In this work, boost converter is used as DC-DC converter. The typical representation of the PV system is shown in Fig. 1.

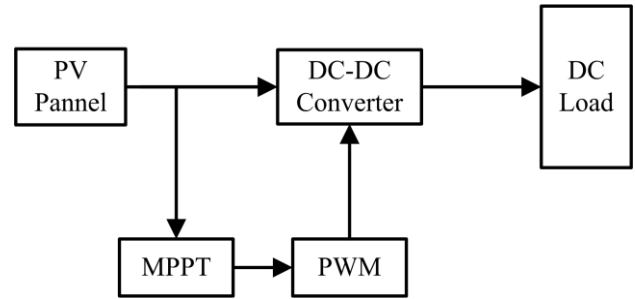


FIGURE 1. Typical PV system representation

A. PV MODELLING

The required power and voltage rating of the PV module is achieved by connecting the PV cells in series and parallel combinations. The series connection increases the voltage and parallel connection increases the current rating of the PV module. Total power depends on the number PV cells used in the PV module. Different equivalent circuit models are available and single diode model (SDM) is very commonly used model. The SDM equivalent circuit of PV cell is shown in Fig. 2.

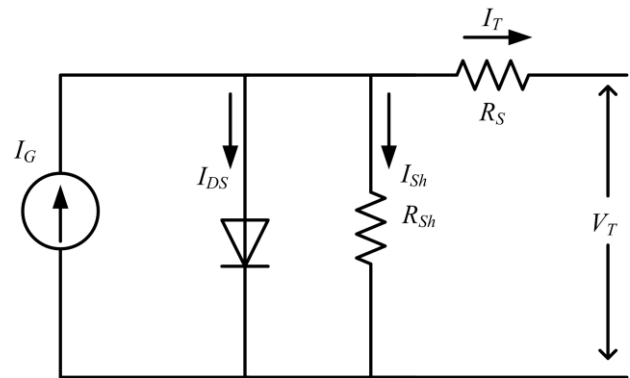


FIGURE 2. Single diode equivalent circuit of PV cell [27]

The cell current has linear relationship with solar irradiance. The current generated in cell is evaluated by [27]

$$I_G = \frac{G}{G_{ref}} \left[I_{sc} + k_i (T - T_{ref}) \right] \quad (1)$$

Where, I_{sc} = short circuit current of the cell, G =solar irradiance, G_{ref} = solar irradiance under ideal conditions, T = cell temperature under working conditions, T_{ref} = cell temperature under ideal conditions, k_i = temaprature co-efficient.

The current flowing through diode is expressed as [28]

$$I_{DS} = I_O \left[\exp\left(\frac{v_{DS}}{V}\right) - 1 \right] \quad (2)$$

$$v_{DS} = V_T + I_T \cdot R_S \quad (3)$$

$$I_O = \frac{I_{sc} + k_I (T - T_{ref})}{\exp\left(\frac{V_{oc} + k_V (T - T_{ref})}{a \cdot V}\right) - 1} \quad (4)$$

Where, I_{DS} and v_{DS} are the current and voltages of the diode respectively. I_O is the diode saturation current.

V is defined as

$$V = \frac{k_B T}{q_e} \quad (5)$$

From the Fig. 2, resultant solar PV cell current is expressed as [28]

$$I_T = I_G - I_{DS} - I_{Sh} \quad (6)$$

$$I_T = \frac{G}{G_{ref}} \left[I_{sc} - k_i (T - T_{ref}) \right] - I_O \left[\exp\left(\frac{v_{DS}}{V}\right) - 1 \right] - \frac{V_T + I_T \cdot R_S}{R_{Sh}} \quad (7)$$

The variation of cell output current with change of temperature and radiation is evaluated using equation (7).

B. CONVERTER MODELLING

The PV panels are connected to load through DC-DC converter. The DC voltage is controlled in such a way that PV system is operated at MPP. Boost Converter is the commonly used converter for MPPT applications. In this work, boost converter is operated in continues conduction mode and designed accordingly. The typical boost converter is shown in Figure 3.

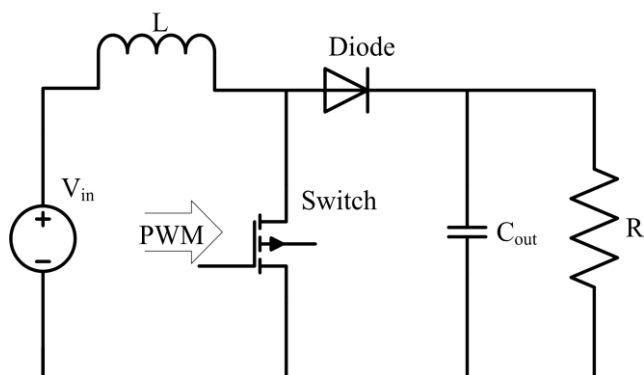


FIGURE 3. Typical circuit for boost converter

Boost converter is simulated using state space equation and are expresses below [14]

$$\frac{dI_L}{dt} = \frac{V_{in} - (1-D)V_{out}}{L} \quad (8)$$

$$\frac{dV_{out}}{dt} = \frac{(1-D)I_L}{C_{out}} - \frac{V_C}{RC_{out}} \quad (9)$$

Here, D = duty cycle

The output voltage equation of the boost converter is expressed as

$$V_{out} = \frac{V_{in}}{1-D} \quad (10)$$

C. PV MODULE AND CONFIGURATION

Atlantis Energy Systems SS156LM module is used for simulation in this work. The module parameters and values are given in Table I.

TABLE I PV MODULE PARAMETERS

Parameter	Value
Maximum power (P_{MPP})	22 W
Short Circuit Current (I_{SC})	8.5 A
Open Circuit Voltage (V_{OC})	3.7 V
Current at P_{MPP} (I_{MPP})	8 A
Voltage at P_{MPP} (V_{MPP})	2.75 V
I_{SC} temperature coefficient (k_I)	0.015
V_{OC} temperature coefficient (k_V)	-0.297

I-V and P-V characteristics of a single module under different conditions is shown in Figure 3 and Figure 4 for constant temperature and constant irradiance respectively.

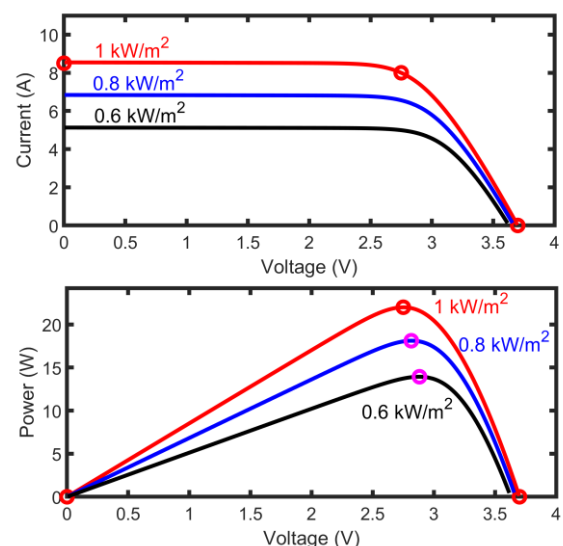


FIGURE 4. PV module I-V and P-V curves for different irradiance and constant temperature $T = 25$ °C.

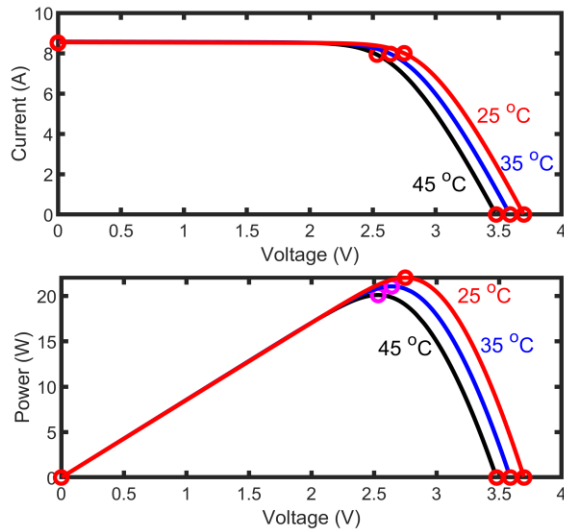


FIGURE 5. PV module IV and PV curves for different temperature and constant irradiance $G = 1000 \text{ W/m}^2$.

Five PV modules are connected in series to form PV array and used to analyze the partial shading effect. The modules are protected using bypass diode. The PV module configuration is shown in Fig. 5.

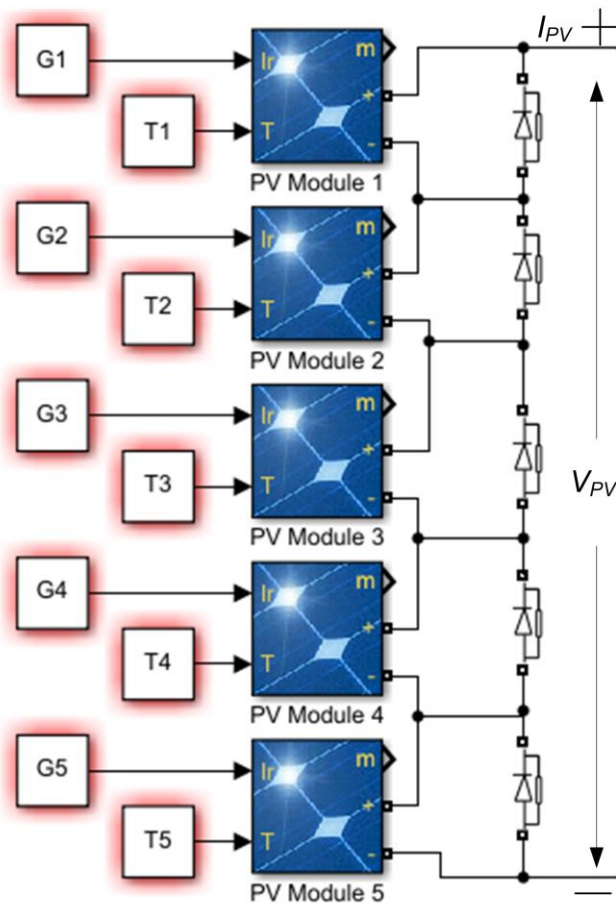


FIGURE 6. PV system configuration for partial shading conditions

Different scenarios are considered to validate performance of the proposed MPPT algorithm. Scenario 1: Solar irradiance for all modules is 1000 W/m^2 and PV cell temperature is 25°C . Scenario 2: All five modules have different irradiance i.e., 1000 W/m^2 , 900 W/m^2 , 800 W/m^2 , 700 W/m^2 , 600 W/m^2 respectively and PV cell temperature is same and is 25°C .

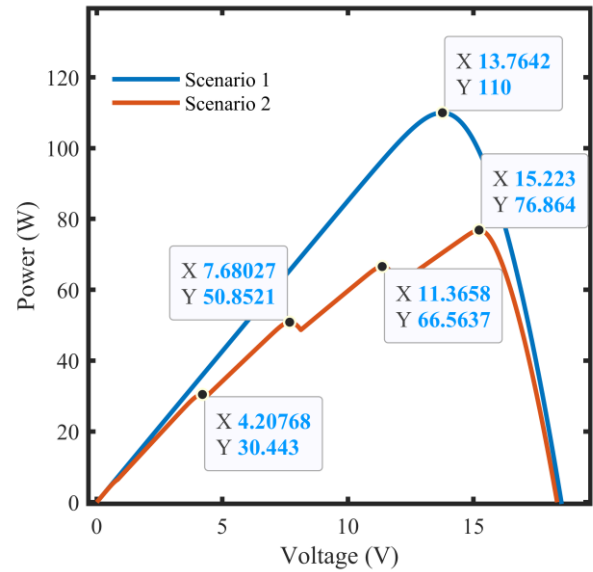


FIGURE 7. PV system PV curves for different scenarios

IV and PV curves for PV system for all two scenarios is shown in Fig. 6 and Fig. 7 respectively. From the Fig. 6, it is observed that partial shading gives multiple peaks in the PV curve. The voltage at MPP is increased compare to uniform irradiance scenario. For Scenario 1, the PV array output power, voltage and current at GMPP are 110W, 13.76V and 7.99A respectively. For scenario 2, the power, voltage and current at GMPP are 76.86W, 15.22V and 5.05 respectively. In scenario 2, other than GMPP, three more peaks are there and called as local MPP (LMPP). The power, voltage and currents at LMPPs are (66.56W, 11.37V and 5.86A), (50.85W, 7.68V and 6.62A) and (30.44W, 4.21V and 7.24A).

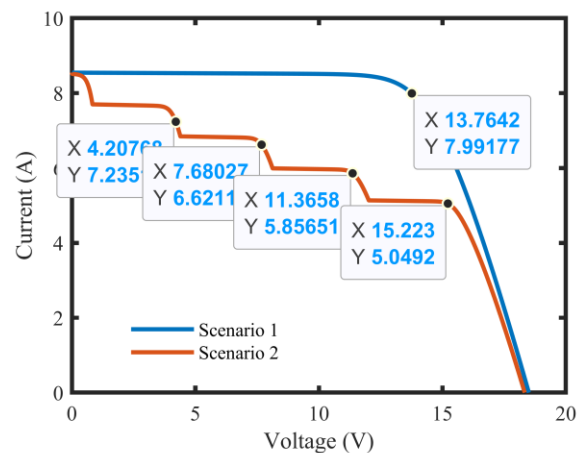


FIGURE 8. PV system IV curves for different scenarios

D. Performance Evaluation of MPPT algorithm

The performance of MPPT algorithm is described using different factors such as tracking time, efficiency and average output power. The tracking time (T) is the time taken to reach the stable output power from zero.

The efficiency (η) of the MPPT algorithm is evaluated by [9]

$$\eta = \frac{p_s}{p_T} \times 100 \quad (11)$$

Where, p_s is the stable output power, p_T is theoretical maximum output under given conditions and extracted from the PV curves and also called as theoretical maximum power.

The average output of the PV array before MPP is tracked is a very important factor to describe the performance of the MPPT algorithm. The average output power (p_{avg}) is evaluated by

$$p_{avg} = \frac{\int_0^T p(t)dt}{T} = \frac{\sum_{k=1}^{N_s} (p_i \cdot \Delta t)}{N_s \cdot \Delta t} \quad (12)$$

Where, $p(t)$ is time varying power, p_i is instantaneous power, Δt is constant time sample, N_s is the number of time samples.

III. PROPOSED HYBRID ALGORITHM

A. Conventional Spotted Hyena Optimizer

Spotted Hyena Optimizer (SHO) is developed based on the behavior pattern of spotted hyenas [29]. The prey position in the SHO is considered as instantaneous best for the consideration of near to optimal as search region is unexplored beforehand. Other search agents changes their positions after adjusting the best search agent around the finest optimum solution. The mathematical modeling of spotted hyena behavior is expressed as [29]:

$$\overrightarrow{DI}_{th} = \left| \overrightarrow{B}_{cov} \cdot \overrightarrow{P}_{IV} \cdot I - \overrightarrow{PS}(CUI) \right| \quad (13)$$

$$\overrightarrow{PS}(I+1) = \overrightarrow{P}_{IV}(I) - \overrightarrow{E}_{cov} \cdot \overrightarrow{DI}_{th} \quad (14)$$

Where, $\overrightarrow{DI}_{th}$ = space between hyena and prey, CUI = progress repetition, $\overrightarrow{P}_{IV}$ = prey vector position, $\overrightarrow{PS}$ = hyena vector position, $\overrightarrow{B}_{cov}$ and $\overrightarrow{E}_{cov}$ = coefficient vectors and are calculated by

$$\overrightarrow{B}_{cov} = 2 * \overrightarrow{ar}_1$$

$$\overrightarrow{E}_{cov} = 2 * \overrightarrow{Ir}_1 * \overrightarrow{ar}_2 - \overrightarrow{Ir}_1$$

$$\overrightarrow{Ir}_1 = 5 - \left(\text{repetn} * \left(\frac{5}{\max \text{repetn}} \right) \right)$$

Where, $\overrightarrow{ar}_1$ and $\overrightarrow{ar}_2$ are randomly generated vectors

The tracking and hunting pattern are mathematically formulated, the prey location is considered as optimum location. The other hyenas assemble on credible camp and grasps the superior magnitudes attained till that the point to change their spaces. The mathematical expression of transforming hyenas position is given by

$$\overrightarrow{DI}_{th} = \left| \overrightarrow{B}_{cov} \cdot \overrightarrow{F}_{sa} - \overrightarrow{PO}_{rs} \right| \quad (15)$$

$$\overrightarrow{PS}_{rs} = \overrightarrow{F}_{sa} - \overrightarrow{E}_{cov} \cdot \overrightarrow{DI}_{th} \quad (16)$$

$$\overrightarrow{A}_{om} = \overrightarrow{PS}_{rs} + \overrightarrow{PS}_{rs+1} + \dots + \overrightarrow{PS}_{rs+TP_{sh}} \quad (17)$$

Where, $\overrightarrow{F}_{sa}$ = optimum hyena, $\overrightarrow{PS}_{rs}$ = position of remaining hyenas, $\overrightarrow{A}_{om}$ = pool of total finest consequences. TP_{sh} = spotted hyenas population size and is calculated by

$$TP_{sh} = \text{Calc}_{grs} \left(\overrightarrow{F}_{sa}, \overrightarrow{F}_{sa+1}, \overrightarrow{F}_{sa+2}, \dots, \left(\overrightarrow{F}_{sa} + \overrightarrow{RV} \right) \right)$$

The optimum outcome can be evaluated by

$$\overrightarrow{PS}(CUI+1) = \frac{\overrightarrow{A}_{om}}{TP_{sh}} \quad (18)$$

B. Quadratic Approximation Operator

Quadratic Approximation Operator (QAO) is the extended version of confined linearization. The basic concept is to exhibit closer approximation of any task. The QAO generates a new agent by considering the 3 different individuals which are picked from the population. One of three is the best individual and picked first from the population and remaining are picked randomly. The point of optimum evaluated using quadrature surface [30]. The generation of new individual is expressed as [30]:

$$Z_{QA}^D = \frac{0.5 * \left(\left[(Z_3^D - Z_2^D)^2 + F(Z_1) \right] + \left[(Z_1^D - Z_3^D)^2 + F(Z_2) \right] + \left[(Z_2^D - Z_1^D)^2 + F(Z_3) \right] \right)}{\left(\left[(Z_3^D - Z_2^D) + F(Z_1) \right] + \left[(Z_1^D - Z_3^D) + F(Z_2) \right] + \left[(Z_2^D - Z_1^D) + F(Z_3) \right] \right)} \quad (19)$$

Where, Z_1 , Z_2 and Z_3 are the selected three individuals and represented as

$$Z_1 = (Z_1^1, Z_1^2, Z_1^3, \dots, Z_1^D)$$

$$Z_2 = (Z_2^1, Z_2^2, Z_2^3, \dots, Z_2^D)$$

$$Z_3 = (Z_3^1, Z_3^2, Z_3^3, \dots, Z_3^D)$$

$F(Z_1)$, $F(Z_2)$ and $F(Z_3)$ are fitness values for Z_1 , Z_2 and Z_3 are respectively.

C. QASHO Algorithm

The integration of QAO with SHO increases the exploration ability of conventional SHO. The QAO is a superior tool to search for local region. Hence, QAO integration gives better global optima by exploiting local region, without losing the search ability in the global region. In the process of hybridization, one best hyena and two random individuals are picked from the hyena population. The new candidate is evaluated as explained above using eq. (7). The new candidate is compared with poorest candidate in the population. If new candidate is superior then poorest candidate is replaced with new candidate. The steps in the proposed hybrid QASHO algorithm is shown in Fig. 9 as a flow chart.

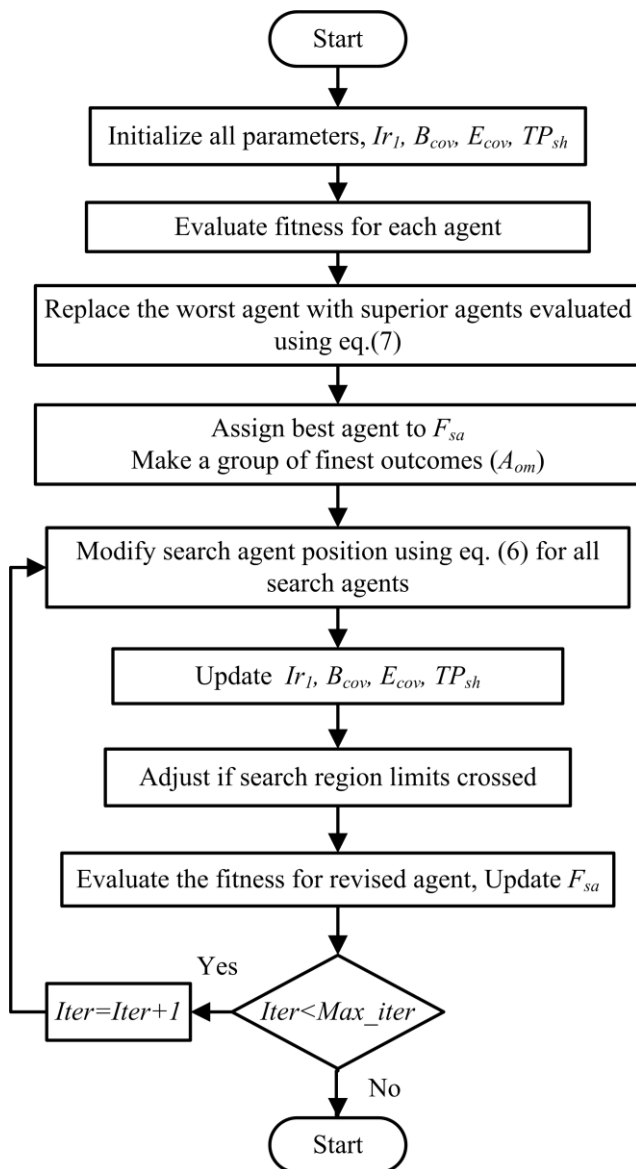


FIGURE 9. Flow chart of proposed hybrid QASHO algorithm

IV. RESULTS AND DISCUSSIONS

A. Simulation Results

The proposed QASHO based MPPT algorithm is validated by simulating the in the MATLAB/SIMULINK and simulation results are validated by comparing with other MPPT algorithms such as P&O and CSO. The PV array output power for scenario 1 is shown in Fig. 10 for three MPPT algorithms. The performance parameters of three MPPT algorithms is given in Table II. The observations from the Fig. 8 and Table II are as follows, the proposed QASHO algorithm took less time to track the GMPP and has lessor oscillations during the initial stage. The tracking efficiency is almost same for QASHO and P&O but P&O taking more time to track the GMPP and the output power contains considerable ripples during stable region.

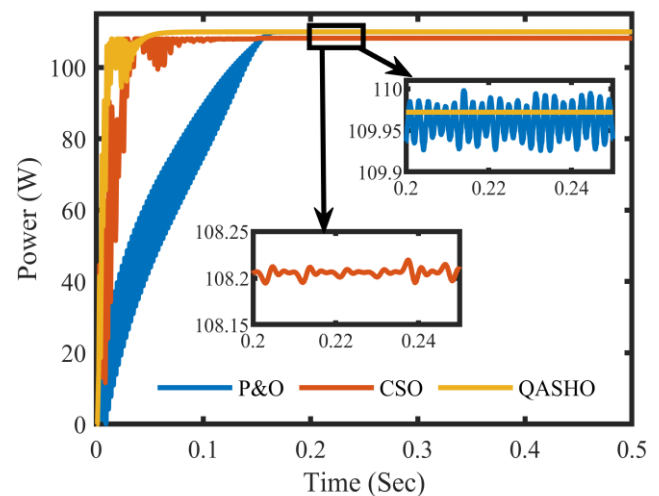


FIGURE 10. PV array output power under scenario 1

During oscillating region, the average power output is more in the proposed QASHO followed by CSO with lessor margin. The tracking time is 0.236 Sec, 0.167 Sec and 0.06 Sec for P&O, CSO and QASHO respectively. The maximum power tracked by the three algorithms is 109.98W, 108.22W and 109.97W respectively against the 110W of theoretical GMPP. It is clear that under uniform irradiance, P&O and QASHO tracking efficiency is almost same and average power during the tracking of GMPP is almost same for CSO and QASHO. However, if all performance parameters are considered then the proposed QASHO dominates other algorithms.

TABLE II MPPT ALGORITHM PERFORMANCE PARAMETERS FOR SCENARIO 1

Algorithm	P_{max} (W)	P_{avg} (W)	η (%)	T (Sec)
P&O	109.98	80.82	99.99	0.236
CSO	108.22	98.05	98.39	0.167
QASHO	109.97	99.93	99.98	0.06

The voltage and current of PV array are shown in Fig. 11 for all three algorithms under scenario 1. The voltage and current at MPP for QASHO are 13.63V and 8.07A respectively. The ripples are almost negligible during stable region for both voltage and current. It is also witnessed in the Fig. 10, that PV panel output power has negligible ripples. The initial tracking phase has oscillation in the voltage and current. Like the power, the voltage and currents for P&O algorithm are oscillating around 13.63V and 8.07A respectively during the stable region. The voltage and currents at MPP for CSO algorithm are 14.36V and 7.53A respectively. Lesser oscillations are found in voltage and current with CSO algorithm compared to P&O algorithm. However, QASHO shows it's superiority over other algorithms by stabilizing the voltage and currents with negligible oscillations. From the Fig.11, it is also observed that P&O and QASHO have almost same values but voltage and current are reached to stable region in QASHO earlier than P&O.

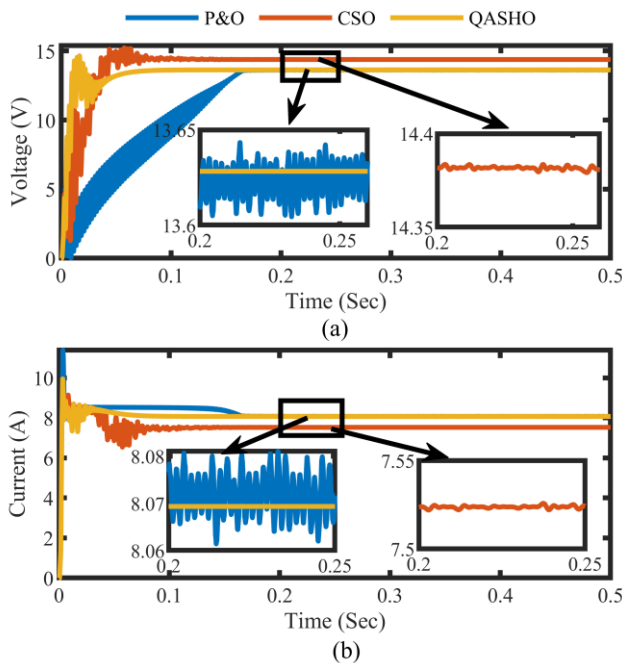


FIGURE 11. PV array voltage and currents under scenario 1 a) Voltage b) Current

The load power, voltage and current are shown in Fig. 12 for all three algorithms. It is seen from the Fig. 12; the load power has ripple content and changes between 105.5W and 107.5W for QASHO algorithm. Like power, the ripples also found in the load voltage and current. The maximum load power is less than the PV array power output due to the losses in the boost converter. The load voltage and current are having ripple around 32.6V and 3.26A respectively. It is observed that P&O algorithm is giving almost same results as QASHO but taking more time to reach the maximum values. The CSO algorithm is as fast as to reach the MPP but ended with slightly lesser MPP values than P&O and QASHO algorithms. Unlike the panel voltage, the deviation in the

load voltage and currents are negligible. The load voltages are 32.6V, 32.6V and 32.4V for P&O, CSO and QASHO respectively. The load currents are 3.27A, 3.27A and 3.24A for P&O, CSO and QASHO respectively.

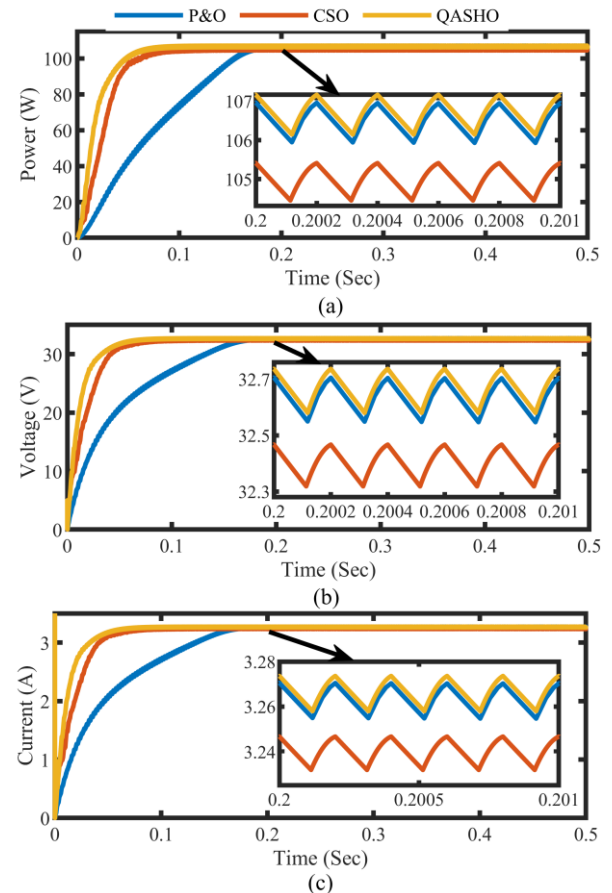


FIGURE 12. Load power, voltage and current with proposed QASHO under scenario 1 a) Power b) Voltage c) Current

The PV array output power for scenario 2 is shown in Fig. 13 for different algorithms. The performance parameters for different algorithms are given in Table III for scenario 2. The proposed QASHO tracked the GMPP with 99.93% efficiency, while CSO tracked GMPP with 98.28% efficiency. However, P&O failed to reach the GMPP and trapped in the LMPP. The tracking times are 0.102 Sec, 0.11 Sec and 0.068 Sec for P&O, CSO and QASHO respectively. Compared to scenario 1, tracking times are reduced in the scenario 2. MPPT algorithm efficiency is slightly reduced in scenario 2 for CSO and QASHO but there is drastic reduction in case of P&O. It clearly shows that P&O fails to track GMPP and trapped into LMPP. The ripples in the PV array output power are more for P&O and are negligible for QASHO algorithm.

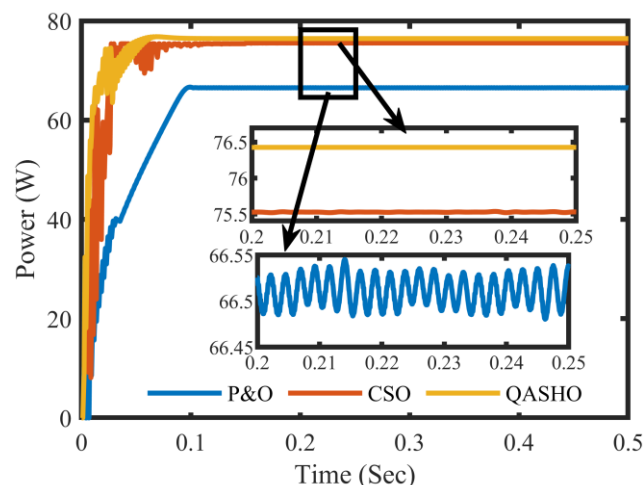


FIGURE 13. PV array output power under scenario 2

Observations from the Table III, The average power during the tracking phase is more with proposed algorithm. The average power is almost same for CSO and proposed QASHO algorithm. The data in the Table III is proves that proposed QASHO MPPT algorithm fully dominated other algorithms to track GMPP and is most efficient in all ways.

TABLE III MPPT ALGORITHM PERFORMANCE PARAMETERS FOR SCENARIO 2

Algorithm	P_{max} (W)	P_{avg} (W)	η (%)	T (Sec)
P&O	66.51	44.42	86.53	0.102
CSO	75.54	64.87	98.28	0.11
QASHO	76.81	64.96	99.93	0.068

The PV array output voltage and current are shown in Fig. 14 for all three algorithms under scenario 2. The voltage and current at GMPP are 15.39V and 4.96A respectively. The ripples are almost negligible during stable region for both voltage and current. It is also witnessed in the Fig. 13, that PV panel output power has negligible ripples. The initial tracking phase has oscillation in the voltage and current like in the scenario 1. The P&O algorithm has lot of ripples in the panel voltage and current during stable region. The voltage and currents oscillates around 11.5V and 5.77A respectively. The CSO algorithm has lessor oscillations in the stable region compared to P&O algorithm.

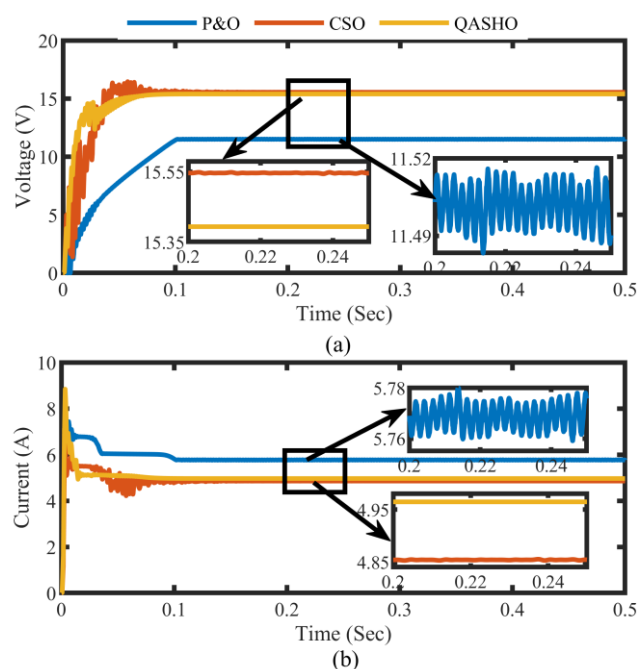


FIGURE 14. PV array voltage and currents under scenario 2 a) Voltage b) Current

The power, voltage and current of load is shown in Fig. 15 for the proposed QASHO algorithm and also compared with P&O and CSO algorithms. The ripple content is negligible during stable output region. The maximum load power is 74.2W against the tracked PV array power 76.81W due to boost converter losses. The load voltage and current with QASHO are 27.2V and 2.7A respectively. Like the scenario 1, in scenario 2 also has ripple content in power, voltage and currents. There is a considerable difference is found in the load voltage and currents among the different algorithms. The load voltages are 32.6V, 35.1V and 27.2V for P&O, CSO and QASHO respectively. The load currents are 1.9A, 2.1A and 2.7A for P&O, CSO and QASHO respectively.

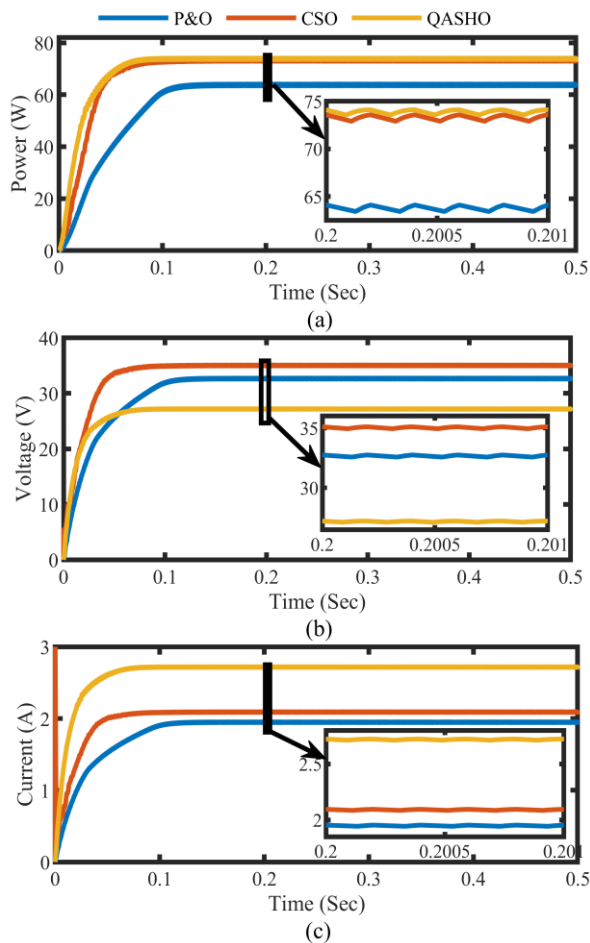


FIGURE 15. Load power, voltage and current with proposed QASHO under scenario 2 a) Power b) Voltage c) Current

B. Experimental Results

The proposed methodology is tested and validated with experimentation. A laboratory prototype is developed for testing purpose. The PV array consist of 5 modules which are connected in series. In order to implement, QASHO based MPPT algorithm, a dc-dc boost converter is design as shown in Fig. 3 and design parameter is given in Table IV.

TABLE IV DESIGN PARAMETERS OF BOOST CONVERTER

Parameter	Value
Switching Frequency	5kHz
Inductor	0.275mH
Capacitor	300V, 2.5mF
Load resistance	10 Ω

The MPPT algorithm is executed using ARDUINO UNO controller. In the prototype, real-time interfacing is done between PV array and boost converter is shown in Fig. 16

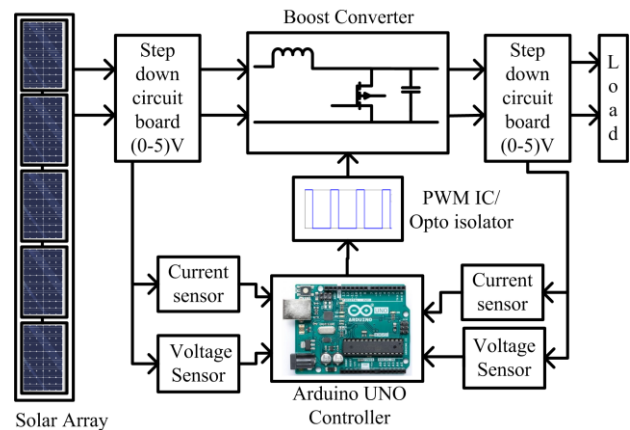


Figure 16. Schematic diagram of hardware prototype

The experimental results for uniform irradiance are shown in Fig. 17. The scenario 1 is considered for experimental validation i.e., the irradiance and temperature are taken as 1000 W/m² and 25 °C respectively. The proposed MPPT algorithm is tracked the maximum PV panel power 109 W and panel voltage and current are 13.5 V and 8.07A respectively.

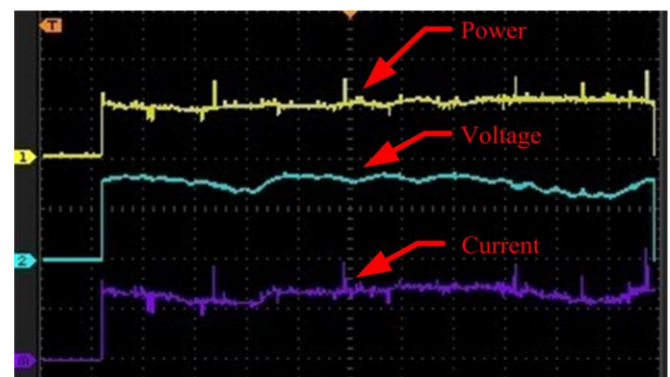


Figure 17. Experimental results under scenario 1

V. CONCLUSIONS

In this paper, a hybrid algorithm is presented which is developed based on the spotted hyena optimization and quadrature approximation operator is called as quadrature approximation-spotted hyena optimization (QASHO). The QASHO based MPPT algorithm is developed to address the issues with conventional and metaheuristic based MPPT algorithms while tracking the GMPP under partial shaded conditions. The performance of the proposed QASHO MPPT algorithm is validated results with P&O and CSO based MPPT algorithms. The results validation is done by considering two different scenarios. In scenario 1, uniform irradiance is considered for all PV modules in the PV array and in scenario 2, all five modules have different irradiance value. The temperature is kept constant at 25 °C for both the scenarios. The performance of the MPPT algorithms is

described with the help of performance parameters such as maximum power tracked, average power during tracking phase, tracking efficiency, tracking time and ripple in the output waveforms during the stable region. For, scenario 1, all three algorithms are performed equally with few performance parameters, however, QASHO has shown its superiority when all parameters are considered. But scenario 2, P&O failed to achieve GMPP and trapped at LMPP. The proposed QASHO dominated in the performance parameters under scenario 2. The proposed MPPT algorithm is also tested and validated using hardware prototype. The scenario 1 is considered for experimental validation and results are matched with simulation results.

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