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COMPARISON OF QUEEN HONEY BEE COLONY MIGRATION WITH VARIOUS MPPTS ON PHOTOVOLTAIC SYSTEM UNDER SHADED CONDITIONS

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Abstract

Shaded conditions cause a decrease in the performance of photovoltaic (PV) systems. In this situation, the power versus voltage curve shows two maximum power points, namely local (LMPP) and global (GMPP). The main challenge for extracting the maximum power from a PV system during shading conditions is the existence of a false maximum or LMPP along with a true maximum or GMPP. Traditional maximum power point tracking (MPPT) has faced hurdles in overcoming the situation. Therefore, this paper describes the implementation of Queen Honey Bee Migration (or QHBM for short) to track GMPP of PV systems, which called QHBM MPPT. The highlight of this paper is the simulation results of QHBM MPPT on PV systems under various shading conditions.

We implemented QHBM MPPT on a boost converter installed on a 1200 Wp PV system. We conducted a simulation using MATLAB® with five scenarios which aim to show the various shadows that PV systems might encounter in reality. The MPPT QHBM is tested repeatedly and then the average value is taken to measure performance in MPP tracking. The average value is used to calculate tracking efficiency, number of iteration or convergence time. We also compared QHBM with other methods, namely incremental conductance (IC) and Particle Swarm Optimization (PSO). The results obtained show that the QHBM and PSO MPPTs outperform the IC MPPT in terms of efficiency, convergence time and the number of iterations. IC MPPTs oscillate under shading conditions since no knowledge of GMPP. Both PSO and QHBM MPPTs know GMPP from scouts or particles, respectively. Therefore, PSO and QHBM MPPTs are better than IC MPPT in various shading cases.

Keywords: boost converter, convergence time, global MPP, heuristic, IC MPPT, local MPP, PSO MPPT, PV system, QHBM MPPT, tracking efficiency.

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1. Introduction

In recent years, there has been severe environmental pollution due to fossil fuels. If it is necessary to switch to greener energy, then solar energy is one of the main choices, especially for tropical areas, such as Indonesia. Solar energy can be harvested into electrical energy by solar panels or Photovoltaics (PV). Current PV technology has made it possible to be stand-alone or connected to the grid [1–3].

Electrical energy conversion using PV systems is limited by nature, which is sun hours (about 4–6 hours a day), irradiation and surface temperature. In addition, the effect of solar irradiation is not linear, especially when the conditions are shady. Therefore, in PV applications, a device is required to track the maximum power point (MPP), where the technology is called maximum power point tracking (MPPT). The current MPPT methods have been well developed, especially the traditional ones such as fractional open circuit voltage (FOC), fractional short circuit (FSC), and hill-climbing MPPTs [2]. The FOC and FSC MPPTs use a certain constant that multiplies the open circuit voltage, V_{OC} and short circuit current, I_{SC} respectively. Hill-climbing methods commonly use Perturb and observed (P&O) [3], incremental conductance (IC) [4].

The shadow on PV surface has an impact on the harvesting of solar energy into electricity [5]. Several peak points exist on the Power versus Voltage curve or $P–V$ curve during the shadow as shown in **Fig. 1**, namely local maximum power point (LMPP) and global maximum power point (GMPP). In the shading condition, the traditional MPPTs are not smart enough to distinguish the true MPP [3–5]. Moreover, traditional hill-climbing MPPTs such as P&O [3] and IC [4] oscillated around the local peak while shading [5]. These limitations have made many researchers in the literature implement adaptive MPPT [6], hybrid of traditional method with heuristic or soft computing as in [5], combine 2 traditional MPPT such as FOC and P&) [7], or heuristic only.

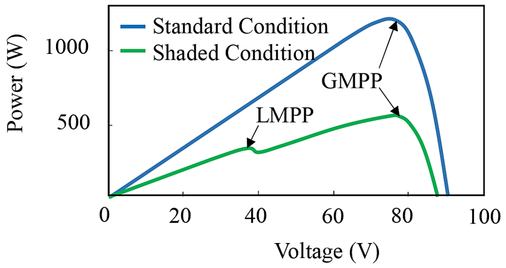


Fig. 1. PV characteristics during the standard and shaded cases

Various heuristic methods, such as artificial neural network (ANN) [8], artificial bee colony (ABC) [9], ant colony (ACO) [10], and many others [11, 12]. The most favorable heuristic MPPT in literature is particle swarm optimization (PSO) [13–16]. PSO MPPT [5] imitates the behavior of a flock of birds in finding food sources [13] thus it has a random speed for each potential solution. In determining the initial value representing the solution, it is important to increase the speed of finding the best solution [14]. PSO-MPPT requires high memories to store the best value for each computation [15]. Moreover, it changes speed each time step to reach the best points by updating the position and velocity of the particles [16]. The PSO MPPT is stable for searching GMPP [17]. In specific, the number of particles that are randomly distributed in the search field has made PSO MPPT not easily trapped at LMPP points or false peaks like the conventional MPPTs [5].

Grey wolf optimization (GWO) [18], firefly [19], intelligent monkey king [20], flying squirrel [21] and queen honey bee colony migration (QHBM) [21–23] were also implement for MPPT. Those heuristics approaches are used to challenge the false peak problem due to shading condition [11].

Discussion about MPPT is not limited to algorithms but also hardware, especially converters. Furthermore, control issues are also important in MPPT and have been discussed in [1, 24]. Most of previous study use dc-dc converters, namely buck, boost, sepic, and etc. [25, 26].

Previous researchers have claimed the superiority of proposal compared to traditional MPPTs [27, 28]. To the best of our knowledge, we have not found a specific comparison of MPPT efficiency in the literature. In specific, QHBM [12] has tested a dc-to-dc converter for MPPT tracking on a stand-alone PV system, where the experiment was carried out in normal cases [23].

The purpose of this study was to test the performance of the KBM as an MPPT under shaded conditions. This research was conducted by computer simulation with real PV data and shaded conditions using the solar irradiation change approach. This paper introduces the capabilities of QHBM in shaded cases which several contributions as follow. We conducted a simulation of QHBM MPPT on PV system consisting of PV panels connected in series and parallel under various shading conditions. IC and PSO MPPTs are represent the traditional and heuristic methods respectively which used as competitors in this paper. Furthermore, the comparison of QHBM MPPT with IC and PSO MPPTs in terms of efficiency, convergence time dan iterations. We describe the tracking points' of QHBM in different shaded conditions.

2. Materials and method

PV system under study is depicted in **Fig. 2**. This system consists of a PV string with a total power of 1200 Wp, a solar charge controller from a boost converter, MPPT algorithm, and a dc dummy load. The PV array is formed by 4 identical PV panels type ZXP6 from ZNSHINESOLAR rated at 300 Wp; connected in series and parallel. The parameters of the PV panel are listed in **Table 1**. **Table 2** shows the parameters of the converter, such as inductance L, capacitance C, switching frequency f_s, etc. The resistance of the dc load is 10 Ω. MPPT block is used for QHBM implementation also the competitors.

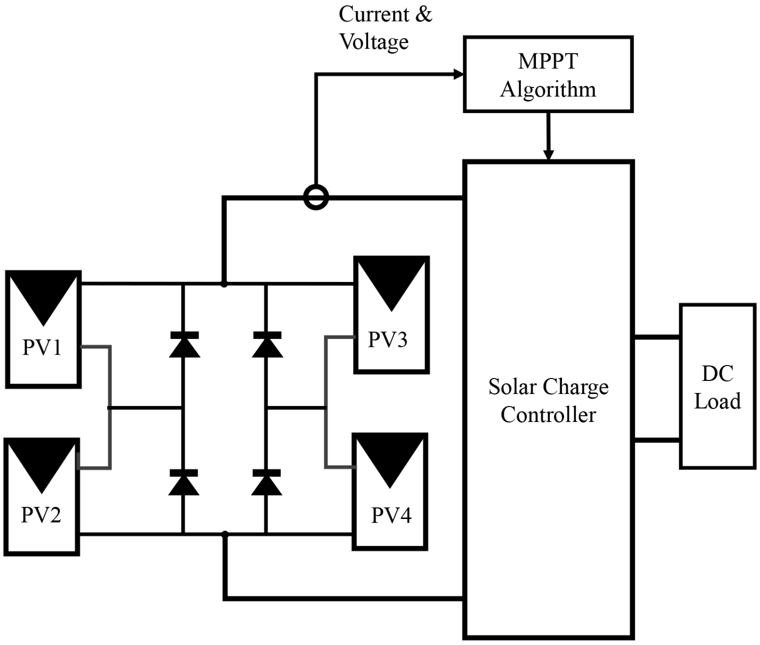


Fig. 2. System Setup

The basic principle of QHBM has adopted the natural migration of the queen honeybee, where queen migrates from the hive guided by scouts. The queen decides its movement according to the sign from scout bees, like cardinal directions, sectors and dance-like behavior. The best place for building a new hive is selected by the Queen based on the highest weight of scout bees. Each journey has natural factors, which are true in real situations like obstacles, predators, etc., see [22] for detail. Finally, the queen computes the migration length for each iteration. In short, QHBM has followed 3 steps in finding GMPP, there are initialization, decision and migration for each iteration which is adopted here for GMPP.

Table 1
PV parameters

Item	**Value**
Model	ZXP6
Manufacturer	ZNSHINESOLAR
Power Output, P_{MPP}	300 Wp
Short Circuit Current, I_{sc}	8.64 A
Open Circuit Voltage, V_{OC}	44.95 V
Current at MPP, I_{MPP}	8.12 A
Voltage at MPP, V_{MPP}	36.95 V

Table 2
Converter parameter

Item	Value
Power	1200 W
Voltage	73.72 V
Current	16.27 A
ΔI_L	0.1 A
ΔV_L	0.1 V
L	6 mH
C	200 mF
f_s	200 kHz

In the beginning, queen and scouts are placed at random points in the *P–V* curve as illustrated in **Fig. 3**. The queen's starting point is (V^{k+1}, P^{k+1}) and the n scouts are also scattered with random *V* and *P* values. The second phase is the decision as shown in **Fig. 4**, where the queen will take into account the probability of each sector. The sector weight is calculated by (2), (3), then queen chooses the direction according to the highest weight, c_j [22]:

$$c_j = \frac{1}{n}\sum_{j=1}^{n} e_{r(j)}, \tag{1}$$

$$s_j = \frac{c_j}{\sum_{j=1}^{8} c_j}, \tag{2}$$

where $e_{r(j)}$, s_j are the weight (information) of scout, and sector probability respectively. And $j = 1, 2, 3\ldots8$ is the number of sectors according to the cardinal direction (North-N, South-S, etc.),

In the final phase, the queen will calculate the migration distance by considering natural factors, according to the following equation [22]:

$$V^{k+1} = V^k + r_m^{k+1} \times \cos\theta^{k+1}, \tag{3}$$

$$P^{k+1} = P^k + r_m^{k+1} \times \sin\theta^{k+1}, \tag{4}$$

$$r_m^{k+1} = (1 - g_m^k) \times r_s, \tag{5}$$

$$g_m^{k+1} = g_m^k \times \text{rand}(1), \tag{6}$$

where r_m, r_s, g_m and θ are migration length, queen radius, natural factor and pole angle respectively. And k *is* 1, 2, 3…n, where n is the iteration number.

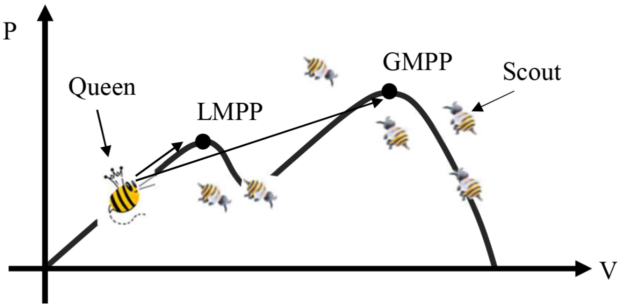


Fig. 3. Queen Honey Bee Migration (QHBM) MPPT

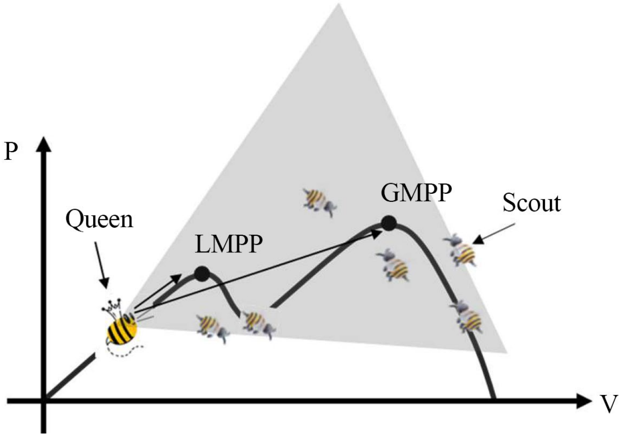


Fig. 4. Queen prepares decision

Fig. 5 shows the logical view of queen while it deciding on pole selection (or easily saying where to go). Queen in the centre of circle of sight, evaluate the weight of each sector s_j. The highest weight of sector is determined by the e_j which visually has the highest group scouts. Then, queen migrates to the selected pole, for example, East (E). QHBM will continue to perform computations and finally stop while dP/dV is equal or close to 0. In the simulation, we use 24 scout bees and a radius of 10 for QHBM parameters.

We assumed that the P_{MPP_REF} is linearly varied only by the irradiation as shown in **Table 3**. Then, the tracking target is the ideal value of the maximum power point, which is defined as P_{MPP_REF}. We conducted simulations using MATLAB for the three types of MPPT algorithms, namely QHBM, PSO and IC, each of which was carried out with 5 different case studies. These cases consist of 1 normal irradiation with 1000 W/m^2 and 4 random irradiations, namely 400 W/m^2, 500 W/m^2, 600 W/m^2, 700 W/m^2, 800 W/m^2, 900 W/m^2 set for possible shaded conditions depicted on **Table 4**. Finally, the simulation is carried out several times for each scenario, and the average values of converge time t_{MPPT}, the number of iterations, and tracking efficiency.

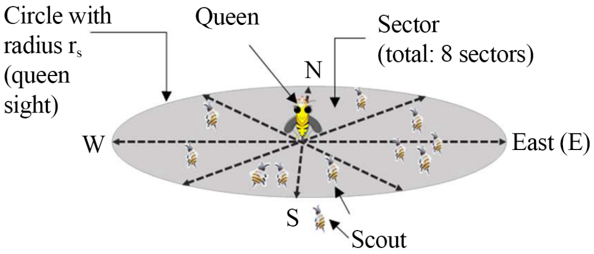


Fig. 5. Logical view of queen during decision of migration pole

Table 3
Case Studies

Irradiation (W/m^2)	400	500	600	700	800	900	1000
Target MPP, P_{MPP_REF} (W)	442	560	691	800	920	1038	1200

Table 4
Case Studies

Case	Irradiation (W/m^2)				Status
	PV1	PV2	PV3	PV4	–
Case 1	1000	1000	1000	1000	Normal
Case 2	1000	700	1000	700	Shaded
Case 3	900	600	700	600	Shaded
Case 4	600	1000	400	800	Shaded
Case 5	700	500	400	400	Shaded (worst case)

3. Results and analysis

We are focused on 3 major terms for the performance indices, such as MPPT efficiency, converge time, and several iterations to show and compare the performance of QHBM and its competitors. These performance indices are grouped twofold. The first indices are the system performance, which is measured by MPPT efficiency both in standard and shaded conditions. MPPT efficiency is a ratio between actual or steady state output power, P_{MPPT} and reference power which is true for GMPP defines as P_{MPPT_REF}. The efficiency η_{MPPT} of tracking GMPP is calculated as follows:

$$\eta_{MPPT} = \frac{P_{MPPT}}{P_{MPP\_REF}} \times 100\ \%. \tag{7}$$

The second indices are the MPP search process by each algorithm both in shaded and normal conditions. This search process is visualized with graphs, converge times, and iterations. Convergence times t_{MPPT} defines the length of time required by the MPPT algorithm to reach the true MPP point or GMPP. The t_{MPPT} is recorded automatically while running the program in MATLAB. Meanwhile, the number of iterations is referred to the number of iterations that have been completed until the MPPT method is converge, where the agent of each algorithm reaches the target P_{MPP_REF} and/or stops the iteration while the condition meets. **Tables 5**, **6** show the simulation results for all cases.

The results of the QHBM MPPT for tracking target GMPP on 1200Wp PV system are shown in **Fig. 6**. **Fig. 6, *a*** shows the result of the MPPT QHBM simulation where is the PV while the irradiation value is 1000 W/m^2. **Fig. 6, *b*** depicts the MPPT QHBM behavior in case 2, where the PV2 and PV4 are 30 % shaded. During the normal case, QHBM MPPT has efficiency up to 99.91 % with P_{MPPT} is around 1199 W. Even though the PV2 and PV4 are shaded, QHBM could rapidly track the GMPP on 758.5 W. In other shaded cases (cases 3 to case 4) QHBM MPPT found GMPP for 645.4 W, and 553.1 W, respectively. Meanwhile, in the worst shaded condition (case 5) where the PV strings are heavily shaded, the power extracted from PV strings drops to 300 W/m^2, and the QHBM MPPT reach the target. The efficiency of QHBM MPPT is 99.95 % with P_{MPPT} being 895.3 W. Thus, the average tracking efficiency achieved by QHBM MPPT for all cases is 99.92 %.

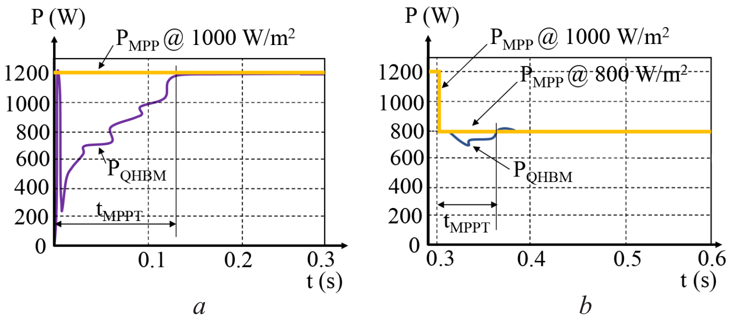
Fig. 7 shows the simulation results of the IC MPPT for tracking MPP on PV system under normal (**Fig. 7, *a***) and under shaded conditions (**Fig. 7, *b***). In normal irradiation (case 1), IC MPPT requires short t_{MPPT} to reach the target, exactly at P_{MPP_REF}. IC MPPT extracts electric power for about 1152 W from PV strings which results in 96 % of efficiency, with only a 3.91 % gap from QHBM MPPT. However, in case 2 as depicted in **Fig. 4, *b***, IC MPPT experienced a decrease in efficiency. Moreover, in the worst case, namely case 5, the efficiency of IC MPPT is dropped to 57.53 % **(Table 6)**. The efficiency of IC MPPT decreases by 2 % for all shaded cases. Previous studies have also concluded that MPPT ICs are inefficient for shaded states [4]. In general, the efficiency IC MPPT is still above 70 % without considering case 5. Therefore, IC MPPT is still popular for commercial applications, especially the low-cost segment.

Table 5
Power and output voltage from various MPPTs

Case	Power (Watt)			Voltage (Volt)		
	QHBM	PSO	IC	QHBM	PSO	IC
1	1199	1197	1152	73.88	73.68	78.44
2	895.3	894.8	575.7	76.86	76.38	38.18
3	758.5	754.7	454.5	75.66	76.8	38.18
4	645.4	642.9	506.2	78.43	76.49	38.17
5	553.1	551.1	318.3	75.61	76.39	39

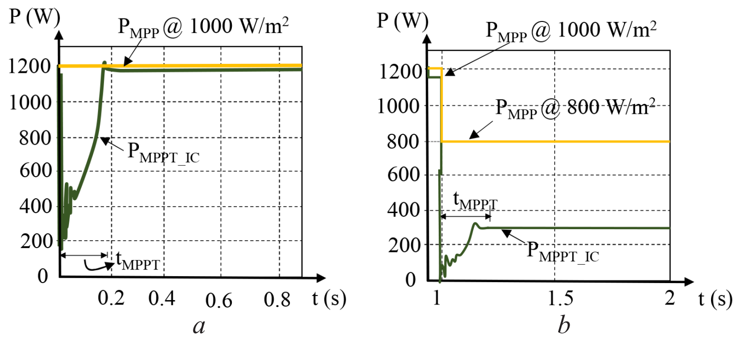
Table 6
Converge time, iteration and efficiency of various MPPTs

Converge Time (s)			Iteration			Efficiency (%)		
QHBM	PSO	IC	QHBM	PSO	IC	QHBM	PSO	IC
0.14	0.57	0.18	5	15	1800	99.91	99.75	96
0.112	0.56	0.13	6	16	1300	99.95	99.90	64.27
0.15	0.57	0.15	8	15	1500	99.97	99.47	59.91
0.3	0.68	0.15	10	17	1500	99.81	99.43	78.29
0.8	0.8	0.17	10	21	1700	99.96	99.60	57.53



a *b*

Fig. 6. QHBM MPPT under different irradiations: *a* – normal; *b* – shaded. Yellow line is defined the P_{MPP} at each irradiation, purple line is P_{MPPT} by QHBM MPPT



a *b*

Fig. 7. IC MPPT under different conditions: *a* – normal; *b* – shaded. Yellow line is defined the P_{MPP} according to irradiation, moss green line is P_{MPPT} by IC MPPT

The results of the PSO MPPT simulation are shown in **Fig. 8**. **Fig. 8, *a*** is the final result of the MPP searching process with PSO for case 1. In the early stage, PSO oscillates due to several particles placed randomly on the field. PSO founds GMPP at 1157 W, which gives 99.75 % of efficiency. Compared with QHBM MPPT (**Fig. 6, *a***), PSO MPPT is only slightly below it. PSO MPPT is 3.75 % better than IC MPPT, which is true as the majority claimed by researchers in the literature [5, 13].

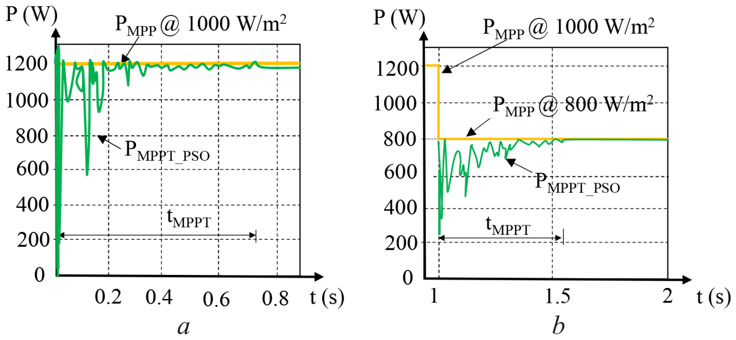


Fig. 8. PSO MPPT under different irradiation: *a* – normal; *b* – shaded. Yellow line is defined the P_{MPP} according to irradiation, light green line is P_{MPPT} by PSO MPPT

PSO MPPT appears to be more sTable (**Fig. 8, *b***) under shaded cases, since PSO has placed the particles from the start so that when there is a shadow effect, PSO MPPT can still know the true MPP (or GMPP) position. The tracking efficiency given by PSO MPPT is quite good in various cases, the average is above 99 %. PSO has been proven to be tough in shaded conditions according to the claims of previous researchers [15]. If we look back at **Fig. 6, *b*** and **Table 6**, it is clear that the MPPT QHBM is capable of achieving above 99 % efficiency just like the PSO MPPT. Furthermore, QHBM proved to be much faster than PSO in terms of convergence due to a smaller number of agents. This means that QHBM can outperform PSO in terms of MPP tracking in PV systems.

The other contributions of this paper, such as convergent time and the number of iterations in various cases are discussed below. The QHBM MPPT searching process is depicted in **Fig. 9**. **Fig. 9**, ***a*** shows the tracking process of the QHBM MPPT for case 1, whereas **Fig. 6**, ***b*** for case 2. In case 1, queen moves very fast and easily found the MPP. Case 2 shows the *P–V* curve has two peaks because of the shading condition. Since scout bees are placed and travel randomly in the field, thus the queen knows these two (LMPP and GMPP). Queen then evaluates the weight of information's brings by the scouts (**Fig. 5**). This condition is repeated, so that and migrates in the right direction approaching the GMPP. Queen migrates upward like climbing a hill similar to what the IC MPPT. The simulation results show that QHBM MPPT requires 5 iterations to converge at 0.14 seconds. In the shaded condition (**Fig. 9**, ***b***), QHBM MPPT reaches a convergence time of 0.15 seconds by 5 iterations. The rest of the QHBM MPPT results are listed in **Table 6**. The highest convergence speed of QHBM MPPT occurs in case 1 and the lowest in case 5. Case 5 makes all PV panels exposed to shadows so that the MPP points shift rapidly. Even so, QHBM MPPT only requires 0.8 s to converge through 10 iterations which means that the queen migrates 10 times until it finally finds GMPP.

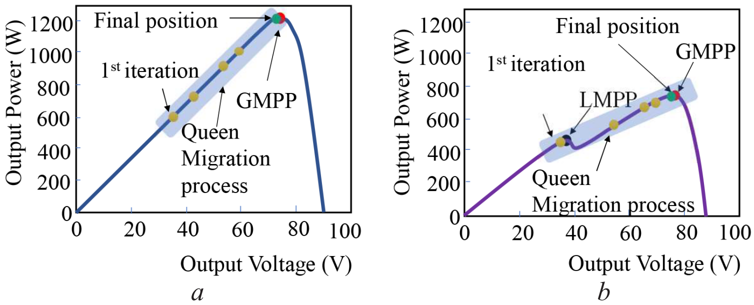
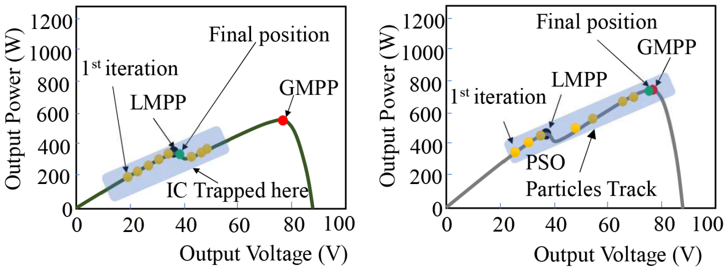


Fig. 9. Tracking GMPP by QHBM MPPT under different cases: *a* – normal, *b* – shaded. The red bullet indicates GMPP, the yellow bullets are queen position, a green bullet is the final position of the queen, and a black bullet is LMPP

In this paper, we examine the ability of MPPT QHBMs to perform GMPP searches on solar panels in the shade as shown in **Fig. 9**, ***b***. We used the IC and PSO simulation results for comparison, which are respectively shown in **Fig. 10**, ***a*** and **Fig. 10**, ***b*** respectively. In general, PSO and QHBM MPPTs are faster than IC MPPT for both normal and shaded cases. Based on **Table 6**, the average convergence achieved by QHBM, PSO and IC in searching for GMPP is around 0.5 seconds, 1 second and 0.26 seconds respectively. Even though the IC MPPT appears to reach convergence faster than PSO and QHBM MPPTs, the results are inaccurate and even stuck at LMPP (**Fig. 10**, ***a***). More specifically, the IC MPPT is constantly oscillating around LMPP while shaded. The average number of iterations required by the QHBM, PSO and IC MPPTs to find the GMPP in all case studies are 8, 16, and over 1500 iterations respectively. The fact that IC MPPT oscillates around LMPP is supported by [4].



a *b*

Fig. 10. Tracking GMPP under shading condition: *a* – IC MPPT; *b* – PSO MPPT.
The red bullet indicates GMPP, the yellow bullets are IC or best particle position, the green bullet is the final position of the IC or best particle, and the black bullet is LMPP

PSO MPPT can overcome shadow state which has already been proven by [15, 17]. If we look back (**Fig. 9, *a*** and **Fig. 4**), it appears that QHBM MPPT uses scouts as agents for searching true peak location on *P–V* curve, whereas PSO uses particles. The QHBM is superior in various cases due to faster computation, less agent compares to PSO. Based on **Table 6**, it is clear that the QHBM MPPT converges faster than the PSO MPPT in all cases. Likewise, the number of iterations of QHBM MPPT is also less than that of PSO MPPT.

The limitation of QHBM is small changes in irradiation, so it doesn't respond as quickly as IC. However, PSO with a higher number of particles is more sensitive and can immediately respond to these changes. Future research potential is the opportunity to modify the QHBM parameters and use them in a larger shaded PV system model. Another research opportunity is implementation during a transient transition, where every heuristic algorithm will face challenges in responding to these changes.

4. Conclusions

The comparison of the QHBM and PSO MPPTs in shaded conditions has been successfully simulated on a power converter in a PV system. In general, the QHBM algorithm has very good performance in both normal and shaded conditions. Both PSO and QHBM MPPTs proved to be better than traditional MPPT, where both found MPP and GMPP.

The IC MPPT works well under normal conditions of the PV system. But it cannot find True MPP when the shaded state changes too fast. The IC MPPT oscillates and gets stuck on false MPP. Compared to QHBM, PSO requires a longer time and many iterations to reach a steady state. In addition, the fact shows that MPPT Efficiency with QHBM surpasses competitors by almost 0.2 % higher than PSO. IC takes longer to converge compared to PSO and QHBM. QHBM takes 3 to 5 iterations while PSO does the same for 3 to 7 more iterations. The computational speed of QHBM opens wide implementation opportunities for low-cost hardware.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

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