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Maximum Power Point Tracking Algorithm for Solar Photovoltaic System using Moth Flame Optimization with Direct Control Strategy

Meng Chung Tiong[1], Thomas Shan Yau Moh[1], Ling Ai Wong[1], Dennis Wei Sheng Phiong[1]

School of Engineering and Technology, University of Technology Sarawak, Sibu, Malaysia[1]

Abstract: This paper presents a study in maximum power point tracking (MPPT) algorithm in solar photovoltaic (PV). With the increase of the popularity of solar PV as power generation method, the effort of extracting maximum power output from the installed PV system remains a challenge. The study aims to identify the performance of the Moth Flame Optimization (MFO) based MPPT algorithm under constant and rapid change irradiance conditions. A simulation model of MFO MPPT algorithm is developed and implemented with a DC/DC Boost converter in MATLAB Simulink. For comparison, a conventional MPPT method, Perturb and Observe (P&O), together with a well-established Particle Swarm Optimization (PSO) method were also included in this study. All the MPPT algorithms were simulated under 10 constant and 10 step changing irradiance test cases. All the MPPT algorithms in study were showing the ability to achieve the maximum power operating point with output efficiency up to 99 %. The performance of MFO is comparable with PSO in term of tracking efficiency and convergence time.

Keywords: Maximum Power Point Tracking, Particle Swarm Optimization, Moth Flame Optimization, photovoltaic.

I. INTRODUCTION

It is undeniable that energy plays a crucial role in the global development context. In fact, most of the energy are obtained from non-renewable energy resources which might lead to depletion of resources and global warming effect. Thereby, implementation of renewable energy such as hydropower, wind power, solar photovoltaic (PV) and bio-power are important to secure the global energy. At the end of year 2019, it was estimated that renewable energy resources contributed to 27.3 % of global electricity capacity in power generation sector [1].

In this study, solar PV is the main renewable energy to be examined. It operates by converting the energy obtained from sun's ray into electricity through the use of semiconductor (solar cell). In the year of 2019, solar PV has contributed nearly 57.21 % of total 201 GW of global renewable energy capacity [1]. Despite that, there is still room for improvement on the application of solar PV as it has relatively low energy conversion efficiency which might interfered by heavy cloud shading and fast irradiance changes.

In order to maximise the energy generated during the operation, several methods can be carried out for instance, installing PV panels with tilted angle towards the sun, deploying mechanical solar tracking and the implementation of electrical maximum power point tracking (MPPT). In fact, the application of MPPT is considered as one of the most economical and efficiency method to maximise the power generation from the PV system. MPPT device is a converter with ability of altering the operating point of PV module to obtain maximum possible output from the module. In the pass decades, numbers of MPPT algorithm have been developed to ensure that the PV system is able to operates in an optimized condition consistently. With that, three different MPPT algorithms can be given as Perturb and Observe (P&O), Particle Swarm Optimization (PSO) and Moth Flame Optimization (MFO) which will be discussed in this study.

II. LITERATURE REVIEW

A. Perturb and Observe

Perturb and Observe (P&O) is the simplest online MPPT method which has been considered by numbers of researchers [2]–[7]. This is mainly due to the simplicity and requires only low computational power. The P&O algorithm works by sampling the voltage and current from the PV system. With the sensed voltage and current, the corresponding instantaneous output power of the PV system is computed. With the continuous sampling of the voltage and current from the PV system, the algorithm will compare its present output power and operating voltage with the previous output power and voltage which has been stored in the memory. Through the comparison, the algorithm is able to identify the perturbation direction which eventually leads to a higher output power for the PV system. The sampling and comparison

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process continues until the system reached its maximum power point (MPP). The operation flow of the P&O algorithm is shown in the flowchart in Fig 1.

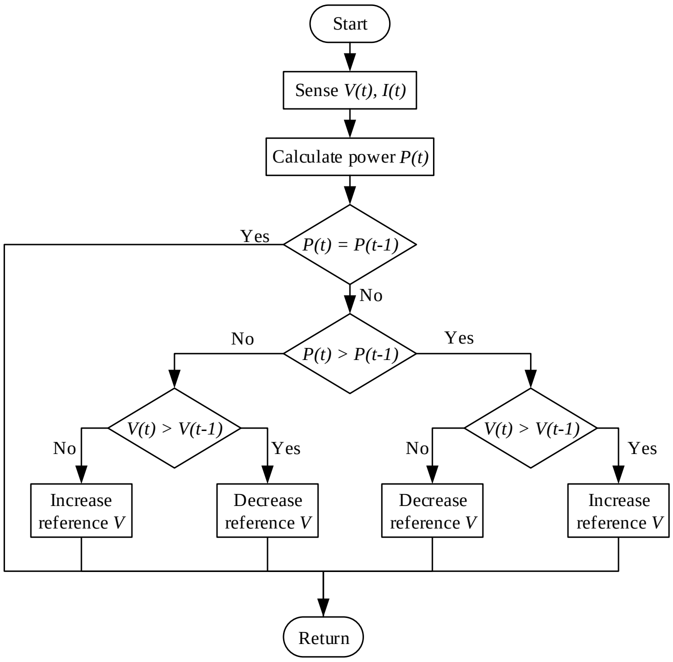

Fig. 1 Flowchart of perturb and observe algorithm

B. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is one of the most popular and well-established optimization technique which has been adopted by researchers in MPPT study[8], [9]. It is a bio-inspired optimization algorithm, modelled after the behaviour of bird flocks[10], [11]. The PSO performs optimization by spreading the search agents randomly in the search space, where each search agent represents a candidate solution. It can be applied to optimize a nonlinear function such as the I-V/P-V characteristic curve in the PV system. The optimization process begins by allocating random positions and velocities to a population array of particles in the search place. With that, the desired optimization fitness function can be evaluated for each particle using the general equation as shown in Eq. 1.

Through comparison between each particle's fitness evaluation, p_{best} can be obtained. At the same time, the particles in the neighbourhood will be examined to obtain a particle with the best fitness evaluation which will be known as g_{best}. As a result, a diversity of response can be obtained from the allocation of responses between p_{best} and g_{best}. Eventually, the population array of particles will be guided to the best-found position. The particles movement can be demonstrated as in Fig 2. PSO process will then be terminated once the termination condition has achieved.

$$x_i^{k+1} = x_i^k + \varphi_i^{k+1} \tag{1}$$

where, φ_i = velocity component, representing the step size

$$\varphi_i^{k+1} = \omega\varphi_i^k + c_1 r_1\{P_{besti} - x_i^k\} + c_2 r_2\{G_{besti} - x_i^k\} \tag{2}$$

where, ω = inertia weight
c_n = acceleration coefficient
$r_n \in U(0,1)$
P_{besti} = personal best position of particle *i*
G_{besti} = best known position achieved in the entire population

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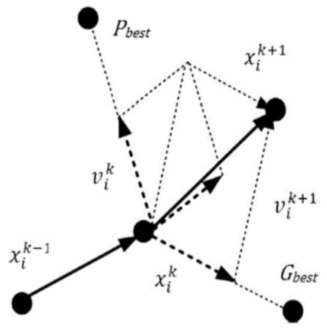

Fig. 2 Particles movement in PSO

C. Moth Flame Optimization

Moth Flame Optimization (MFO) adopted the spiral flying path of moth around the search space as the SC method of optimization. Knowing that moth tends to maintain its flying path in a fixed angle with respect to the moon by utilising a mechanism known as transverse orientation. However, when moth encounter a man-made light source, it will continue fly while maintaining the similar angle with the light which. Thus, causing it to deadly fly in spiral path which in returns, leading the convergence of moth towards the light [12].

During optimization process, moth is the searching agent that move around in the search space while flame is the best position obtained by the moth. The optimizer of MFO is resolved mathematically based on the behaviour of moth. With the presence of flame as centre, the moth will move in a spiral fly path. Such motion can be elucidated in the form of logarithm spiral as shown in Eq. 3. Then, the distance between the moth and flame can be examine through Eq. 4.

$$S(M_i, F_j) = D_i e^{bt} \cos(2\pi t) + F_j \tag{3}$$

where, D_i = distance between i^{th} moth and j^{th} flame
b = constant to define the shape of logarithmic spiral
t = random number in [-1, 1]

$$D_i = |F_j - M_i| \tag{4}$$

D. Direct Control Strategy

To generate the switching signal for power converter in the MPPT application, a control scheme is essential which usually can be carry out by implementing PI (proportional plus integral) controller as control loop. Referring to Fig. 3, the first PI controller is used for voltage control where it outputs the reference voltage from MPPT algorithm to the second PI control loop for current control. Then, the tracking error at MPP will reduced to zero and the final output will determine the operating duty cycle of the power converter.

However, PI controller might not be the most suitable application as MPPT controller considering the unpredictable environmental conditions of the operation of PV system [8], [13]. Thereby, the PI controller can be replaced by the SC (Soft Computing) method where the duty cycle for the power converter will be computed directly from the algorithm as illustrated in Fig. 3. Through the simplification of tracking structure, the computation time for generating switching signal for the overall system can be reduced. Hence, in this study, direct control MPPT method will be implemented.

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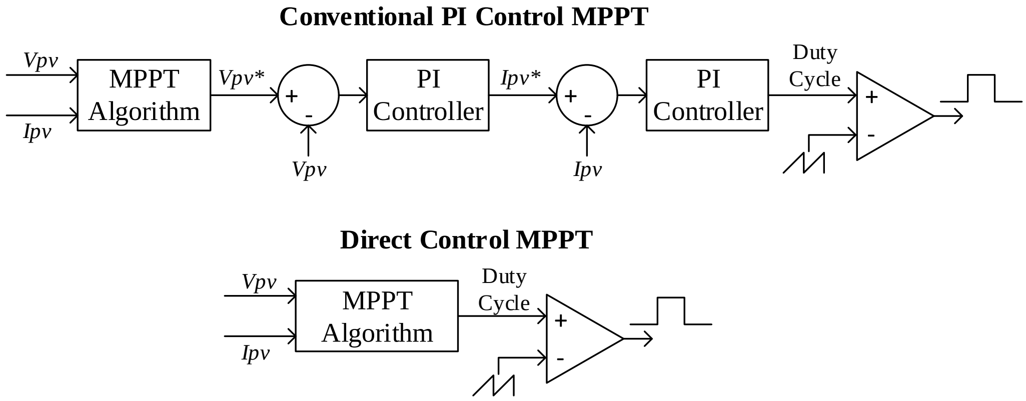

Fig. 3 Comparison of MPPT control method between conventional PI controller and direct control method

III. METHODOLOGY

In order to study the performance of the MPPT algorithms, a simulation model was developed in MATLAB Simulink. The simulation model comprises of a string of PV modules connected to a DC/DC Boost converter which the MPPT algorithms were implemented. The PV string was made up of four 245 W PV modules connected in series, and it was mathematically modelled based on the technique in [14], [15].

One of the factors affecting the P&O operation can be determined as the perturbation step size. A large step size will indeed fasten the algorithm to reach MPP, but in return, causing a greater steady state oscillation around the MPP. Thus, a smaller perturbation size is preferred. In this study, the perturbation step size is allocated at 0.1 % of the duty cycle to minimize the oscillation at MPP.

In this study, the parameters used for PSO were adapted from the studies carried by [16], [17] where $N_p = 3$, $c_1 = 1.2$, $c_2 = 1.6$ and $\omega = 0.4$. Similar studies carried out by [8], [18] implemented the same parameters, which was claimed to be effective. Whereas in MFO, there are two parameters that can affect the MPPT algorithm which are the parameter b and parameter t. In this study, the value of parameter b is maintained at $b = 1$ while the parameter t was a random number in the range between -1 and 1.

Direct control method was implemented to replace the commonly used PI control method to generate switching signal for power converter. Nevertheless, the sampling time for the particular iteration was keep to be as short as possible to ensure the accuracy of the sampled data. However, it is important to ensure that the system has attained its steady state condition which correspond to the particular operating duty cycle during the sampling period. In this study, the sampling time interval was set to be 0.1 s for each search agents in SC methods which the same sampling time interval was claimed to be sufficient as referring to [18], [19].

All MPPT algorithms in this study were investigated under constant irradiance conditions and step changing irradiance conditions. Constant irradiance cases were carried out with 10 test cases. Considering the movement of clouds or the sudden change of weather conditions, the irradiance level received by the PV module might differ from time to time. In order to minimise the power loss from the system, the MPPT algorithms shall be designed with ability to cope with fast changing irradiance conditions. Hence, the MPPT algorithms were also examined under 5 positive step changing and 5 negative step changing irradiance test cases. Moreover, the MPPT algorithms were let to achieve the steady state conditions and followed by the step changing irradiance at the time of 4 s during the simulation.

IV. RESULTS AND DISCUSSIONS

Based on the result shown in Table I, it is noticeable that P&O has the highest output power and efficiency comparing to PSO and MFO. In fact, P&O was able to achieve average tracking efficiency at 99.36 % while the average tracking efficiency for both PSO and MFO were 95.13 % and 90.95 % respectively. By means of that, P&O has greater ability to locate the operating point that allows the system to extract maximum power. In facts, under very low irradiance situation such as case 10, the efficiency of P&O reduced a little by 6.14 % while both PSO and MFO reduced 43.38 % and 42.23 % respectively. Hence, the performance of MPPT algorithms deteriorates under low irradiance conditions.

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TABLE I TRACKING SUMMARY SIMULATED UNDER 10 CONSTANT IRRADIANCE CASES

Case	Irradiance (W/m^2)	Maximum Output Power (W)				Efficiency		
		Theoretical	P&O	PSO	MFO	P&O	PSO	MFO
1	1000	981.12	981.05	981.00	956.41	99.99	99.99	97.48
2	900	878.72	878.67	878.61	878.16	99.99	99.99	99.94
3	800	776.76	776.59	776.64	776.64	99.98	99.98	99.98
4	700	675.14	675.00	675.03	675.01	99.98	99.98	99.98
5	600	574.07	573.95	573.94	573.83	99.98	99.98	99.96
6	500	473.68	473.58	473.57	472.47	99.98	99.98	99.74
7	400	374.19	374.09	374.09	374.09	99.97	99.97	99.97
8	300	275.92	275.82	275.82	275.82	99.96	99.96	99.96
9	200	179.38	179.28	174.77	138.79	99.94	97.43	77.37
10	100	85.60	80.29	46.27	35.14	93.80	54.05	35.14
					Average	99.36	95.13	90.95

The convergence time performance of each case is presented in Table II. Based on the results, P&O has achieved the fastest tracking speed with an average of 0.275 s. On the other hand, PSO and MFO requires longer time of convergence which both of the algorithms achieved an average convergence time at 1.922 s and 2.199 s respectively.

This can be deducted as P&O applies the simplest algorithm which requires a relatively low computational power comparing to PSO and MFO. In addition, the PSO and MFO requires the sampling from each search agents and compute the subsequence position of the search agents accordingly.

This has caused the algorithm to increase the convergence time towards the MPP. Aside from that, the convergence time also increases with the reduction of irradiance conditions which can be explained as the low current output resulting a more oscillation of PV voltage during the tracking process. With that, the movement of the search agents in the search space will be larger and thus, causing a lower efficiency of PSO and MFO in tracking for the MPP.

TABLE II CONVERGENCE TIME SIMULATED UNDER 10 CONSTANT IRRADIANCE CASE

Case	Irradiance (W/m^2)	Time of Convergence (s)		
		P&O	PSO	MFO
1	1000	0.134	1.866	2.792
2	900	0.140	1.873	2.482
3	800	0.147	1.594	2.174
4	700	0.157	1.582	2.172
5	600	0.172	1.572	2.172
6	500	0.193	1.890	1.868
7	400	0.227	1.885	1.753
8	300	0.292	1.682	2.090
9	200	0.460	2.360	2.244
10	100	0.831	2.913	2.247
	Average	0.275	1.922	2.199

The tracking performance of the three algorithms in study under test case 6 is presented in Fig. 4. Under test case 6, the P&O converge towards the MPP at about 0.193 s which is the shortest time among all three algorithms. On the other hand, MFO has a relatively shorter time to converge towards the MPP at 1.868 s comparing to PSO at 1.890 s.

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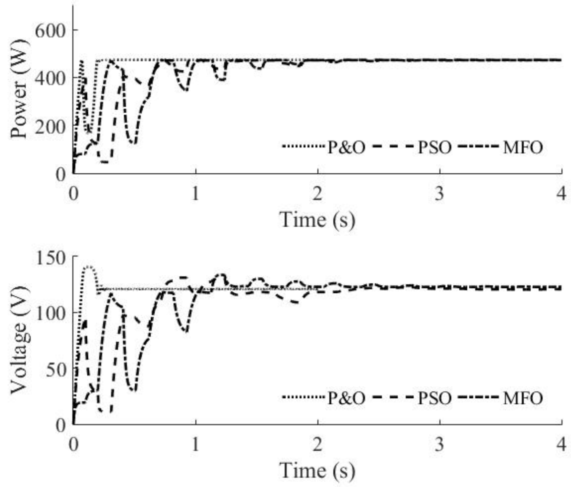

Fig. 4 Tracking performance of constant case 6

To evaluate the ability of the algorithm to cater the drastic operating conditions of the PV system, the response time of each algorithm was investigated. As tabulated in Table III, the three algorithms were simulated under 5 positive step changing (rapid increasing) and 5 negative step changing (rapid decreasing) irradiance condition.

Based on the tracking result, all of the algorithms were able to achieve the average tracking efficiency up to 99 %. From the tracking performance, the P&O has shown the ability to perform the best under step changing irradiance conditions. Whereas for the PSO and MFO, the performance of the algorithm was greatly depended on the ability of the search agents to locate the MPP effectively.

TABLE III TRACKING SUMMARY SIMULATED UNDER 10 STEP CHANGING IRRADIANCE CASES

Case	**Irradiance (W/m^2)**	**Maximum Output Power (W)**				**Efficiency**		
	From / To	Theoretical	P&O	PSO	MFO	P&O	PSO	MFO
1	780 / 350	324.78	324.68	311.95	324.66	99.97	96.05	99.96
2	630 / 460	433.66	433.56	433.35	433.56	99.98	99.93	99.98
3	850 / 640	614.32	614.20	613.93	614.05	99.98	99.94	99.96
4	750 / 500	473.58	473.48	473.48	472.48	99.98	99.98	99.77
5	900 / 650	624.43	624.30	624.33	623.31	99.98	99.98	99.82
6	280 / 700	675.04	674.90	674.94	674.91	99.98	99.98	99.98
7	400 / 850	827.64	827.43	827.49	827.12	99.97	99.98	99.94
8	250 / 600	573.97	573.85	573.86	573.84	99.98	99.98	99.98
9	410 / 750	725.79	725.64	724.73	725.12	99.98	99.85	99.91
10	460 / 650	624.43	624.30	624.32	623.31	99.98	99.98	99.82
					Average	99.98	99.57	99.91

Despite that, the average time of convergence for the algorithms to locate the new MPP was different as shown in Table IV. From the result, P&O has the fastest average response time at 0.023 s followed by MFO at 2.091 s and PSO at 2.447 s. It was found that for the SC methods, the convergence time varies according to different test cases.

The longer convergence time of PSO and MFO was due to the random search from the search agents during the sudden change of irradiance. In spite of that, MFO performs a greater ability to track for new MPP comparing to PSO.

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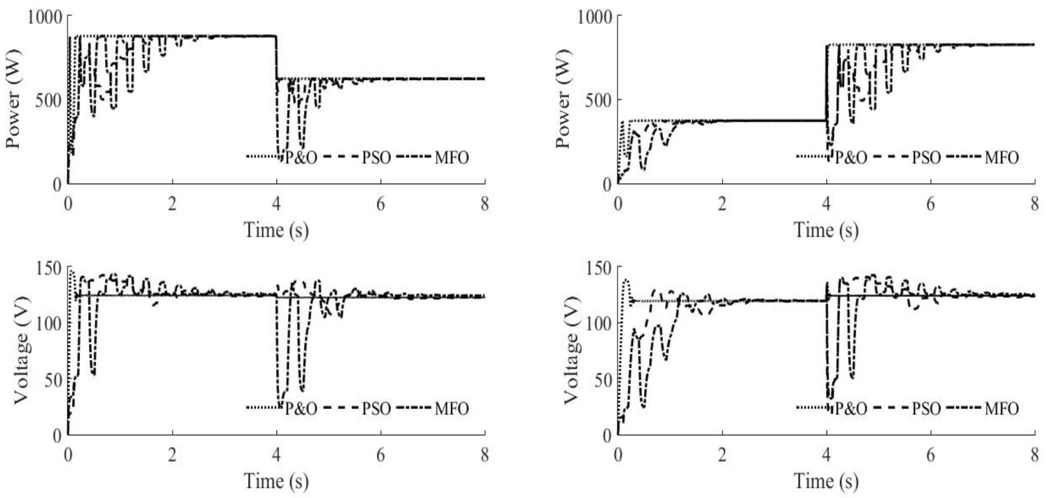
TABLE IV CONVERGENCE TIME SIMULATED UNDER 10 STEP CHANGING IRRADIANCE CASE

Case	Irradiance (W/m^2)	Time of Convergence (s)		
		P&O	PSO	MFO
1	780/350	0.004	3.964	2.186
2	630/460	0.004	1.787	1.568
3	850/640	0.004	3.700	1.871
4	750/500	0.004	1.784	2.181
5	900/650	0.004	1.805	1.874
6	280/700	0.053	1.971	2.184
7	400/850	0.041	2.182	2.494
8	250/600	0.057	1.971	2.184
9	410/750	0.040	3.326	2.494
10	460/650	0.022	1.977	1.874
Average		0.023	2.447	2.091



(a) (b)

Fig. 5 Tracking performance of step changing case, (a) Case 5 and (b) Case 7

V. CONCLUSION

In this study, the performance of MFO on the ability to track for MPP under both constant and step changing conditions has been evaluated. Through comparison between MFO and PSO in terms of tracking efficiency, it was found that MFO required slightly longer tracking time to achieve steady state at MPP under constant condition.

Despite that, in certain cases, for instance case 6, MFO presented a shorter converge time towards MPP compared to PSO. Apart from that, it was also found that MFO has better efficiency and shorter required tracking time to achieve steady state at MPP under step changing condition compared to PSO. In fact, it is believed that MFO is a potential algorithm with space of improvement to achieve a greater MPPT in future.

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