Binary Search Algorithm as Maximum Power Point Tracking Technique for Photovoltaic System Under Partial Shaded Conditions

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***Abstract*— This paper presents an approach to determine the maximum power point (MPP) in photovoltaic (PV) system under partial shaded conditions using Binary Search Algorithm (BSA). The BSA perform MPP tracking by changing the search boundaries to eliminate the region where the MPP cannot lie. In this study, the BSA and particle swarm optimization (PSO) based MPPT were developed in Matlab Simulink with a DC/DC boost converter. Both algorithms were simulated under ten different test cases of partial shading conditions to study the accuracy, speed and tracking efficiency. BSA exhibits a fast convergence with zero steady state oscillation along with the capability of performing MPP tracking under partially shaded PV system.**

Keywords—Particle Swarm Optimization, Binary Search Algorithm, MPPT, Photovoltaic

I. Introduction

Solar photovoltaic (PV) has been widely used as a renewable energy resources for electricity production. The energy from sun's ray is converted into electricity via solar cell. The potential growth of solar PV was mainly due to its inexhaustible energy source as well as causing no pollution to environment while operating. Due to its volatility, it is essential to convert as much energy as possible whenever it is available. The most economic and efficient way is to keep the PV system to operate at its maximum power point (MPP). In order to achieve this, a maximum power point tracking (MPPT) algorithm is necessary to control the DC/DC converter to ensure the PV system always operate at its maximum power operating point.

Due to the non-linear characteristic of the current and voltage (*I-V*) of the PV curve, it poses the challenge of performing MPP tracking. For instance, it requires the MPPT algorithm to react instantly under a rapid changing irradiance condition [1]. It brought to a more complicated challenge to the algorithm when the entire PV array does not receive the same amount of irradiance. Such condition is known as partial shading. Under this condition, the system power loss could be up to 70 % [2]. Besides that, the shaded PV module will also be damaged due to hotspot phenomenon under long term operation. To prevent this, a bypass diode was installed in parallel to the PV modules. The action of the bypass diode has caused the power-voltage (*P-V*) characteristic curve of the PV array to exhibits in multiple peaks, with several local and only one global peak (true MPP). This brought to the conventional MPPT to be trapped at local peak because the algorithm could not differentiate the local and global peak [3]. As a result, the system output power was reduced.

To date, there are numbers of MPPT algorithm being developed and put into study [4]–[8]. Despite having the same objective of tracking for the maximum power operating point for the system, the MPPT techniques differ by its convergence speed, steady state oscillation, robustness, ability to perform tracking during partial shaded conditions as well as the complexity for implementation.

Lately, a computer science based algorithm, binary search algorithm (BSA) was introduced as MPPT algorithm. It has brought to the interest by several researchers and it has been claimed to be effective in performing MPP tracking under rapid changing irradiance condition [9]–[11]. Despite of the potential of the algorithm, there were lack of study for the application of BSA in performing MPP tracking under partial shaded conditions. In addition, the BSA was also having fast convergence time and able to process a large number of dataset in very less iteration [11]. This brought to the study in this paper where the performance of BSA was examined under partial shaded conditions. To evaluate the performance of the BSA, a well-established MPPT algorithm, particle swarm optimization (PSO) was also developed for the same simulation conditions.

II. Maximum Power Point Tracking Algorithm

A. Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a stochastic, population based search algorithm which is modelled after the behavior of bird flocks [12]. The algorithm perform optimization by a swarm of individuals (which is also known as particles), where each of the individual represents a candidate solution. The particles move around in the search space in a simple way which they will emulate the success of neighboring particles and their own achieved success.

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During optimization process, the movement of the particles follow the simple mathematical formulae in (1), where x is the position of the particles and ϕ is the velocity component.

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

The velocity component of the particles can also be calculated by the expression in (2).

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

where ω is the inertia weight, c_1 and c_2 represents the acceleration coefficient, r_1, $r_2 \epsilon$ U(0,1), P_{besti} is the best position of the individual particle i and G_{besti} is the best known position achieved in the entire population.

The dispersed search particles in the search space enable the algorithm to locate and evaluate the fitness of various position effectively. Through successive iteration, the search particles will eventually converge towards a point with the best fitness, which is the maximum power operating point. From the studies carried out by various researchers, the PSO has been claimed to be effective in searching for MPP in multiple maxima situation during partial shaded condition [13]–[15].

B. Binary Search Algorithm (BSA)

Binary search algorithm (BSA) is a search algorithm that is used in computer science application to search for a specific target in a sorted dataset. It is also known as half interval search due to its characteristic that it eliminates half of the elements in the dataset after each search iteration [16], [17].

The search operation of the algorithm begins by comparing the goal value (target) with the middle element in the sorted dataset. The search will be terminated whenever the two values are equal. On the other hand, if the middle element is less than the target value, the algorithm will change its lower boundary to eliminate the lower subset where the target cannot lie on and the search continues on the remaining upper subset or vice versa. In the subsequent iteration, the target value will be compared to the middle element of the remaining set and the process continues until the target is found or the whole dataset has been processed.

For MPPT application, the PV output power is the target value and the PV voltage is the position in the array [11]. In the operation, the target value of the search was also not predefined due to the maximum power point of the system is unknown. Therefore, in accordance to the behavior of the algorithm, the target value will be the next higher value that the search can achieve and it is updated in every iteration.

III. SIMULATION MODEL DEVELOPMENT

A simulation model comprises of a PV string connected to a simple DC/DC boost converter with a MPPT controller was developed in Matlab Simulink. The PV string were made up of three PV modules connected in series configuration. The PV module used in in this study was modelled based on the 245 W multi-crystalline, model MYS-60P/B3/CF-245 manufactured by Malaysia Solar Resources (MSR). The PV module was modelled by using mathematical model with the reference of technique in [18]. The developed model was tested to ensure that it was having the same characteristics as stated in manufacturer datasheet.

For MPPT algorithm development, the algorithms in study, particle swarm optimization and binary search algorithm were developed in Matlab Simulink. To ensure the system has attained the steady state for each search cycle, the sampling time interval of both methods was chosen at 0.05 s [13], [19]. To generate the switching signal for power converter, a direct control strategy method was implemented in this simulation study. The duty cycle for the power converter was computed directly by the MPPT algorithm without the need of conventional PI (proportional-integral) controllers. This control method eliminates the effort of tuning of PI coefficient while maintaining the optimal tracking results[13], [20].

In the study of PSO in MPPT, a simulation model of PSO was developed in Simulink model. To perform MPP tracking, the position of the search particles as described in (1) was represented by the duty cycle of the power converter while the velocity component described in (2) was represented by the change of search duty cycle for the subsequence iterations. In this study, the parameters of PSO used were as follows: $N_p = 3$, $c_1 = 1.2$, $c_2 = 1.6$ and ω=0.4. These parameters were adapted from the study done in [21], [22] and these parameters has also been implemented in similar studies carried out in [13], [23]. Due to the maximum power of the system remained unknown during the search, the objective function for the both method can be described as in (3).

$$P_{\max}(k) > P_{\max}(k-1) \tag{3}$$

where P_{max} is the maximum power located by the algorithm at particular search iteration.

In BSA MPPT, the algorithm core was to changes its search boundaries to locate the MPP. The algorithm in this study was developed by using direct control strategy under the reference of work in [11]. In order to ensure the algorithm to perform effectively, the search boundaries were initialized to include a large search region. In addition, two threshold constant, i.e. th_{reset} and th_{mp} were introduced in the algorithm. The constant th_{reset} was introduced to enable the algorithm to expand its search boundaries whenever the system experienced a large power change due to the weather condition, while the constant th_{mp} was introduced to eliminate the steady state oscillation when the system reached its MPP. For the boundaries expanding, a boundary expanding constant, μ, was introduced to the algorithm so that the search boundaries can be expanded by a predetermined proportion. The parameters of BSA used in this study were as follows: $th_{reset} = 20$ W, $th_{mp} = 2$ W and $\mu = 0.05$. The operational flowchart of the BSA MPPT is shown in Fig. 1.

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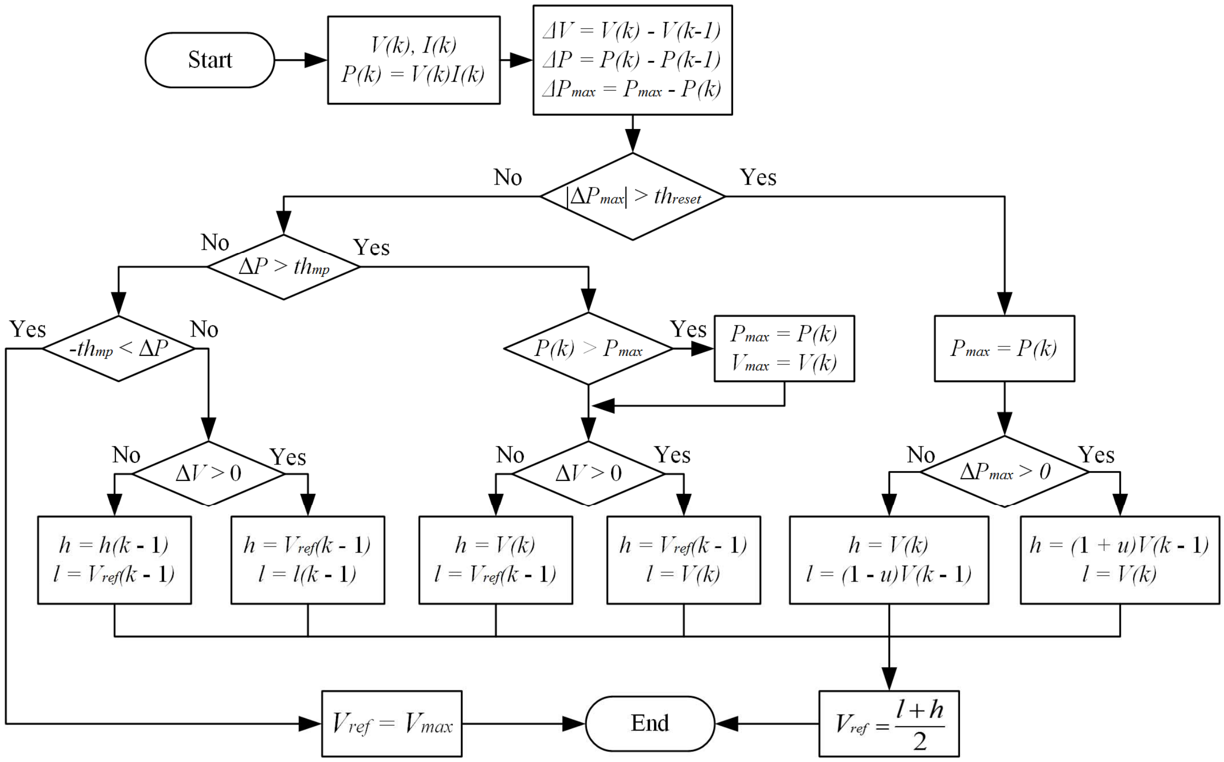

Fig. 1. Flowchart of binary search algorithm maximum power point tracking technique

In order to perform the study of the performance of the techniques, both algorithms were simulated and examined under 10 partially shaded irradiance test cases. For comparison, the theoretical maximum power of the 10 test cases were obtained by sweeping the operating point of the PV module from zero operating voltage (short circuit current) to open circuit voltage. The output efficiency of the algorithm can be described as in (4).

$$Efficiency, \eta = \frac{P_{output}}{P_{theoretical}} \times 100\% \quad (4)$$

where P_{output} is the MPP achieved by the algorithm and $P_{theoretical}$ is the theoretical MPP located from the sweeping process.

IV. Results and Discussion

The simulation of the two MPPT algorithms were carried out in Matlab Simulink. Both of the algorithm were simulated under 10 partially shaded test cases and the maximum power tracked by both algorithm were compared to the theoretical maximum value. The tracking results were summarized in Table I.

From the results shown in Table I, it can be observe that under most of the cases, the MPP of the partially shaded PV system can be tracked by both algorithms. It was observed that out of 10 test cases, PSO was able to locate the true MPP for 9 cases while BSA was 8 cases.

It can be realized that from the performance of PSO, the algorithm experienced a very low tracking efficiency under test case 6. It was discovered that the problem was caused by the error occurred during the sampling for the search particle. This situation happened when the sampling process was performed before the system attained its steady state after the duty cycle has been initiated. In this case, the 0.05 s sampling time used was insufficient for the system to attain steady state during the initialization. This caused the wrong information being logged into the algorithm which affects its tracking performance.

As seen from the results, although in some cases that BSA was able to locate the true MPP correctly, it could not achieve to the highest point at the particular peak. Instead, the system operates at the operating point which was very near to the theoretical maximum power operating point. This causes the system to experience power loss. This could be seen from the tracking of BSA under test cases 7 and 10. This situation happened due to the operating point of the system was capped at the boundary of the algorithm. During the search process, the search boundaries of the algorithm were expanding according to a predefined proportion. As the search approach the MPP, the change in system power (ΔP_{max}) was less than the predefined threshold (th_{reset}), the algorithm will not expand its boundaries. In this case, if the maximum power operating point was near, but outside of the boundaries, the maximum power can be tracked will be capped at the search boundary.

From the results, it can also realized that when the partial shading happened under low irradiance condition, the challenge of tracking for MPP also increases. As seen in test

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TABLE I. TRACKING PERFORMANCE OF VARIOUS ALGORITHM IN STUDY UNDER PARTIAL SHADED CONDITIONS

Curve	Shading Pattern (1 = 1000 W/m2)			Theoretical Output			PSO			BSA			Efficiency	
	A	*B*	*C*	*Vmp*	*Imp*	*Pmp*	*Vmp*	*Imp*	*Pmp*	*Vmp*	*Imp*	*Pmp*	*PSO*	*BSA*
1	0.50	0.35	1.00	97.32	2.86	278.2	97.29	2.86	278.1	98.41	2.82	277.8	99.96	99.86
2	0.65	0.35	0.25	95.64	2.03	194.1	62.27	2.83	176.3	62.38	2.83	176.3	90.83	90.83
3	0.15	0.25	0.10	90.97	0.81	73.7	58.98	1.21	71.3	44.15	1.25	55.3	96.69	74.99
4	1.00	0.90	0.60	98.95	4.87	481.8	98.49	4.89	481.5	97.13	4.95	480.6	99.94	99.75
5	0.90	0.75	0.10	61.65	6.12	377.2	61.49	6.13	377.1	63.11	5.97	376.7	99.97	99.87
6	0.85	0.75	0.65	96.15	5.26	505.4	102.90	4.06	418.1	97.42	5.14	501.1	82.73	99.15
7	0.90	0.80	0.25	62.15	6.42	398.9	62.12	6.42	398.8	64.68	6.01	388.5	99.97	97.39
8	1.00	1.00	0.80	96.73	6.53	631.3	95.80	6.58	630.1	96.67	6.52	630.7	99.81	99.90
9	0.95	0.75	0.25	62.46	6.09	380.6	62.83	6.05	380.2	62.06	6.13	380.2	99.89	99.89
10	0.85	0.65	0.45	96.83	3.69	357.5	96.96	3.69	357.4	101.00	3.35	337.9	99.97	94.52

case 2, both algorithms were trapped at the local peak. This is because under this condition, the value obtained by the search agents does not have a significant difference and this caused the algorithm to converge wrongly towards the local peak. In test case 3, the slight changes of system operating point brought to the large changes of system power, which increases the difficulty for MPP tracking.

Apart from the tracking performance, it can be realized from this study that the BSA was able to track for MPP faster than PSO. This was due to the fact that BSA perform only one sampling in each iteration, while PSO in this case, it needs to carry out three sampling in each iteration. Taking the performance of both algorithm under test case 5 which is shown in Fig. 2, the time taken for PSO to reach the MPP was about 1.25 s while for BSA, it took only about 0.9 s. It can also be observed from Fig. 2 that both algorithm did not exhibit steady state oscillation at MPP.

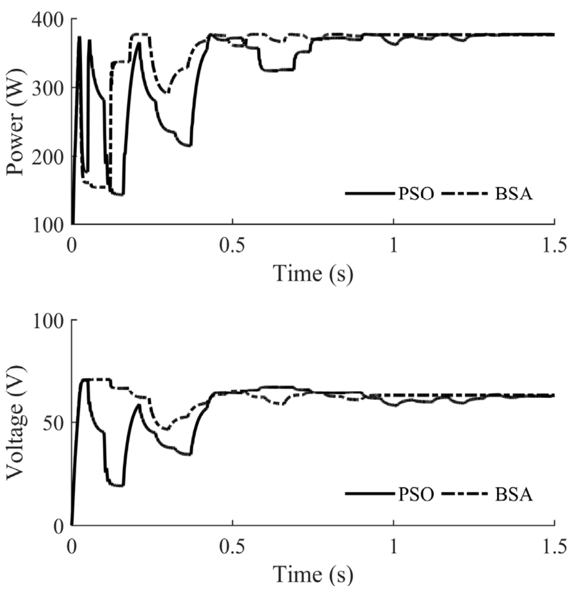

Fig. 2. performance of PSO and BSA under test case 5 shows that PSO and BSA reached their MPP in about 1.25 s and 0.9 s respectively.

V. CONCLUSION

In this study, the binary search algorithm MPPT was implemented in PV system under partial shaded condition. The performance of the algorithm was examined and compared to a well-established MPPT algorithm, particle swarm optimization. From the simulation study, BSA was shown to possess the capability to track for MPP under partial shaded condition although under certain situation, the algorithm did not perform effectively as expected. In addition with the less tuning parameters and fast tracking performance, the algorithm was having the potential to be implemented in tracking for partially shaded PV system.

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REFERENCES

[1] J. Ahmed and Z. Salam, "An improved perturb and observe (P&O) maximum power point tracking (MPPT) algorithm for higher efficiency," *Applied Energy*, vol. 150, pp. 97–108, 2015.

[2] S. Daraban, D. Petreus, and C. Morel, "A novel MPPT (maximum power point tracking) algorithm based on a modified genetic algorithm specialized on tracking the global maximum power point in photovoltaic systems affected by partial shading," *Energy*, vol. 74, pp. 374–388, 2014.

[3] A. Assis and S. Mathew, "Cuckoo Search Algorithm Based Maximum Power Point Tracking for Solar PV Systems," *International Journal of Advances in Electrical Power System and Information Technology (IJAEPSIT)*, vol. 2, no. 1, pp. 20–28, 2016.

[4] Z. Salam, J. Ahmed, and B. S. Merugu, "The application of soft computing methods for MPPT of PV system: A technological and status review," *Applied Energy*, vol. 107, pp. 135–148, 2013.

[5] K. Ishaque and Z. Salam, "A review of maximum power point tracking techniques of PV system for uniform insolation and partial shading condition," *Renewable and Sustainable Energy Reviews*, vol. 19, pp. 475–488, 2013.

[6] M. A. Eltawil and Z. Zhao, "MPPT techniques for photovoltaic applications," *Renewable and Sustainable Energy Reviews*, vol. 25, pp. 793–813, 2013.

[7] J. P. Ram, T. S. Babu, and N. Rajasekar, "A comprehensive review on solar PV maximum power point tracking techniques," *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 826–847, 2017.

[8] M. Al-duliamy, M. Hojabri, H. Daniyal, and A. M. Humada, "Maximum Power Prediction for PV System based on P&O Algorithm," *Journal of Advanced & Applied Sciences (JAAS)*, vol. 3, no. 4, pp. 113–118, 2015.

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[9] N. Shiota, V. Phimmasone, T. Abe, and M. Miyatake, "A MPPT algorithm based on the binary-search technique with ripples from a converter," *2013 International Conference on Electrical Machines and Systems, ICEMS 2013*, pp. 1718–1721, 2013.

[10] C.-T. Phan-Tan and N. Nguyen-Quang, "A P & O MPPT Method for Photovoltaic Applications Based on Binary-Searching," *IEEE International Conference on Sustainable Energy Technologies(ICSET)*, pp. 78–82, 2016.

[11] A. Marquez, J. I. Leon, S. Vazquez, L. G. Franquelo, J. M. Carrasco, and E. Galvan, "Binary search based MPPT algorithm for high-power PV systems," in *2016 10th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG)*, 2016, pp. 168–173.

[12] R. C. Eberhart and J. Kennedy, "A new optimizer using particle swarm theory," in *Proceedings of the sixth international symposium on micro machine and human science*, 1995, vol. 1, pp. 39–43.

[13] K. Ishaque, Z. Salam, A. Shamsudin, and M. Amjad, "A direct control based maximum power point tracking method for photovoltaic system under partial shading conditions using particle swarm optimization algorithm," *Applied Energy*, vol. 99, pp. 414–422, 2012.

[14] K. Sundareswaran and S. Palani, "Application of a combined particle swarm optimization and perturb and observe method for MPPT in PV systems under partial shading conditions," *Renewable Energy*, vol. 75, pp. 308–317, 2015.

[15] T. Sudhakar Babu, N. Rajasekar, and K. Sangeetha, "Modified Particle Swarm Optimization technique based Maximum Power Point Tracking for uniform and under partial shading condition," *Applied Soft Computing Journal*, vol. 34, pp. 613–624, 2015.

[16] B. Arazi, "A Circular Binary Search," *IEEE Transactions on Computers*, vol. 41, no. 1, pp. 109–112, 1992.

[17] A. Francis and R. Ramachandran, "Modulo Ten Search- An Alternative to Linear Search," in *2011 International Conference on Process Automation, Control and Computing*, 2011, pp. 1–4.

[18] G. Walker, "Evaluating MPPT converter topologies using a MATLAB PV model," *Journal of Electrical & Electronics Engineering, Australia*, vol. 21, no. 1, p. 49, 2001.

[19] A. soufyane Benyoucef, A. Chouder, K. Kara, and S. Silvestre, "Artificial bee colony based algorithm for maximum power point tracking (MPPT) for PV systems operating under partial shaded conditions," *Applied Soft Computing*, vol. 32, pp. 38–48, 2015.

[20] K. J. George, "Direct control method applied for improved incremental conductance mppt using SEPIC converter," *Proceeding of the IEEE International Conference on Green Computing, Communication and Electrical Engineering, ICGCCEE 2014*, pp. 1–6, 2014.

[21] M. Miyatake, F. Toriumi, T. Endo, and N. Fujii, "A novel maximum power point tracker controlling several converters connected to photovoltaic arrays with particle swarm optimization technique," *2007 European Conference on Power Electronics and Applications, EPE*, 2007.

[22] M. Miyatake, M. Veerachary, F. Toriumi, N. Fujii, and H. Ko, "Maximum power point tracking of multiple photovoltaic arrays: a PSO approach," *Aerospace and Electronic Systems, IEEE Transactions on*, vol. 47, no. 1, pp. 367–380, 2011.

[23] K. Ishaque, Z. Salam, M. Amjad, and S. Mekhilef, "An improved Particle Swarm Optimization (PSO)–based MPPT for PV with reduced steady-state oscillation," *Power Electronics, IEEE Transactions on*, vol. 27, no. 8, pp. 3627–3638, 2012.

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