Investigation of Binary Search Algorithm as Maximum Power Point Tracking Technique in Solar PV System

Meng Chung Tiong, Hamdan Daniyal, Mohd Herwan Sulaiman and Mohd Shafie Bakar

Abstract This paper describes a study in maximum power point tracking (MPPT) technique for photovoltaic (PV) system using binary search algorithm (BSA). The aim of this study is to identify the effectiveness of BSA in performing MPPT under constant irradiance and rapid change irradiance conditions. The BSA MPPT model, together with a well-established particle swarm optimization (PSO) algorithm were developed and implemented with a DC-DC boost converter in MATLAB Simulink. Direct control strategy was implemented to simplify the development of the controller which generates the switching duty cycle of the power converter. In order to examine the performance of both algorithms, five different constant irradiance test cases and four rapid changing irradiance test cases were imposed to the PV system to examine the capability of the both algorithms. BSA exhibits a faster convergence speed with zero steady state oscillation. Both of the algorithms have shown the capability to adapt the rapid change irradiance condition effectively with tracking efficiency up to 99%.

Keywords Maximum power point tracking · Particle swarm optimization
Binary search algorithm

1 Introduction

Solar photovoltaic (PV) is no longer a new topic as a renewable energy source for power generation. Solar PV has become a popular choice of renewable energy due to its inexhaustible source from the sun, environmental friendly as well as the application is almost maintenance free. However, due to the relative high installation cost and low power conversion efficiency, it is necessary to maximize the power extraction from the installed system [1]. One of the most economical way is to

M. C. Tiong · H. Daniyal (✉) · M. H. Sulaiman · M. S. Bakar
Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang,
26600 Pekan, Pahang, Malaysia
e-mail: hamdan@ump.edu.my

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ensure the PV system is always operating at its maximum power point (MPP). One of the easiest way to achieve this is to implement maximum power point tracker into the PV system.

Due to the nonlinear characteristic of the current and voltage (I–V) of PV curve, the MPP tracking remains challenge where it requires the MPPT algorithm to react instantly under rapid changing irradiance. Although the aim for MPPT algorithms are to track for maximum power operating point, the performance of different MPPT algorithms are differ by the convergence speed, steady state oscillation and cost effectiveness. In this study, the performance of binary search algorithm MPPT technique was compared with a well-established particle swarm optimization algorithm. The performance of both algorithm was evaluated and examined under constant irradiance and step changing irradiance conditions.

2 Maximum Power Point Tracking Algorithm

2.1 Particle Swarm Optimization

Particle swarm optimization (PSO) is a stochastic, population based search algorithm which is modelled after the behavior of bird flocks [2, 3]. The algorithm utilizes a swarm of individuals (also known as particles), where each of the individual represents a candidate solutions. The search particles move around in the search space to improve their search position which follows a simple behavior where it emulate the success of the surrounding particles and its own achieved successes. The movements of the particles follow the equation below:

$$x_i(k+1) = x_i(k) + v_i(k+1) \tag{1}$$

where x is the position of the particle while the velocity vector v_i can be calculated by:

$$v_i(k+1) = \omega v_i(k) + c_1 r_1 \left\{ P_{best_i} - x_i(k) \right\} + c_2 r_2 \{ G_{best} - x_i(k) \} \tag{2}$$

where ω is the inertia weight, c_1 and c_2 are the acceleration constants, r_1, $r_2 \in$ U(0, 1), P_{besti} is the personal best position of particle i and G_{best} is the best known position achieved by the entire population. The typical movement of the particles in optimization process is shown in Fig. 1. In MPPT application, the position of the particles can be represented by the duty cycle of the power converter while the velocity component, v, can be represented by the change of duty cycle for the subsequence iterations.

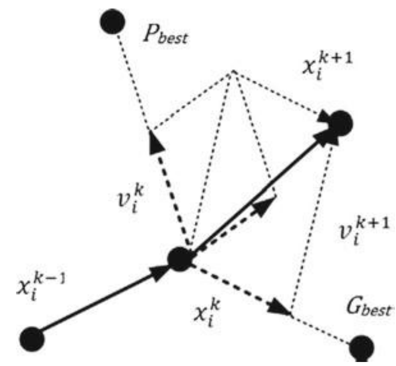

Fig. 1 Movement of search particle in particle swarm optimization process

2.2 Binary Search Algorithm

Binary search algorithm (BSA) also known as half interval search or logarithmic search, which it is a search algorithm that is used in computer science application to search for a specific target in a sorted set [4, 5]. In each iteration, the algorithm will compare the targeted value with the middle element of the dataset. If the two values were equal, the search operation will be terminated, else, the algorithm will eliminate the half set of the element in the array which the target cannot lie on. The search will then continue with the comparison of the targeted value with the remaining dataset until the target is found or the whole dataset has been processed. Throughout the process, the elements in the dataset will be reduced by half for each iteration, hence it is effective in processing a large dataset.

For MPPT application, the targeted value in the search will be the output power from the PV system while PV operating voltage is the position in the array [4]. Unlike the computer science application where the targeted value was predefined, the targeted value in MPPT application was not predefined due to the maximum power point of the system is unknown. Therefore, the targeted value will be updated in every iteration to which it will be the next higher value that the search can achieve. In order to eliminate the steady state oscillation at MPP, a predetermined constant, th_{osc}, was introduced in the algorithm to terminate the search process when the change of power tracked is sufficiently small. In addition, another predetermine threshold value, *th*, was included so that the algorithm will expands its search boundaries accordingly whenever the system experienced a large power changes due to weather conditions. The flowchart of the operation of binary search algorithm is shown in Fig. 2.

3 Simulation Model Development

A simulation model comprises of a PV string connected to a DC/DC boost converter together with a MPPT controller was developed in Matlab Simulink. The PV string

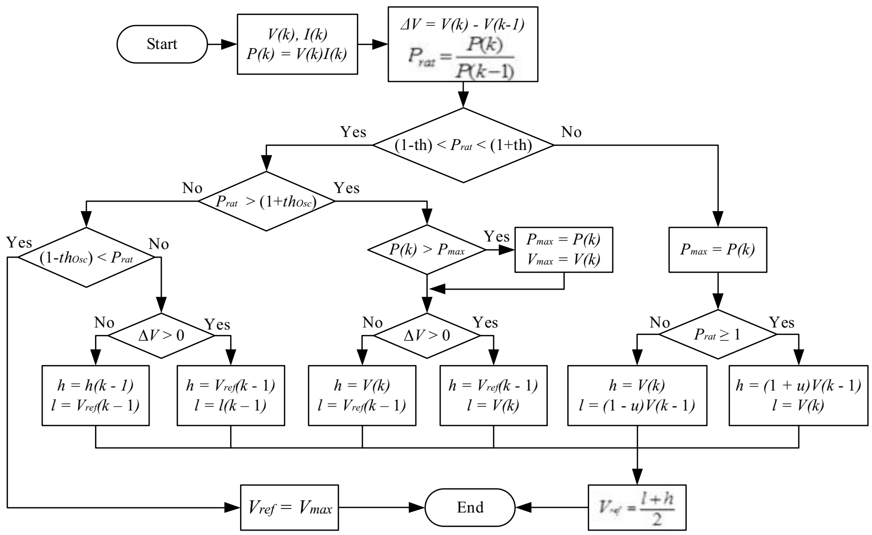

Fig. 2 Operation flowchart of flowchart of the operating flow of binary search MPPT technique

was made up of three series connected 245 W multicrystalline PV modules manufactured by Malaysia Solar Resources (MSR), model MYS-60P/B3/CF-245. The PV module was mathematically modelled with the reference of the technique introduced in [6]. The mathematical model of the PV module was examined so that it will have the same characteristics as stated in manufacturer datasheet.

The MPPT algorithms in study were implemented in the MPPT controller which it controls the operating point of the PV system by adjusting the duty cycle of the DC/DC boost converter. Both the algorithms in study were developed and simulated with the PV system in Matlab Simulink. In order to ensure the search agents had obtained their steady state during sampling process, the sampling interval for both methods was chosen at 0.05 s [3, 7]. The switching duty cycle of the power converter was also computed directly by the MPPT algorithms through direct control strategy which it simplifies the design of the system while maintaining the optimal tracking results [3, 8].

In PSO MPPT algorithm, three search particles were implemented in this study while the other parameters were chosen as $c_1 = 1.2$, $c_2 = 1.6$ and $\omega = 0.4$. These parameters were adapted from the study which has been done in [9, 10], where the same parameters were also implemented in similar case study as in [11, 12]. For BSA, the search boundaries were initiated to include a large search region so that the maximum power operating point can be located effectively. In addition, the two predetermined threshold, which is to eliminate the steady state oscillation at MPP (th_{osc}) and to enable the algorithm to expand the search boundaries during drastic weather change (th) were chosen at 0.003 and 0.05 respectively. For boundaries expanding as described in Fig. 2, the constant was chosen at $u = 0.05$.

To examine the performance of both algorithms, both techniques were simulated and examined under 5 constant irradiance conditions and 4 rapid changes irradiance conditions. For comparison, the MPP tracked by both algorithms were compared to the theoretical value which is obtained through sweeping the operating point of the PV string from zero operating voltage (short circuit current) to open circuit voltage.

4 Results and Discussions

The simulation of two MPPT algorithms in study were carried out in Matlab Simulink. The MPP tracked by both algorithms in study under different test cases of constant irradiance conditions and rapid changed irradiance conditions are shown in Tables 1 and 2 respectively. It can be seen clearly from the results that both algorithms were able to perform MPP tracking up to 99% efficiency. However, for the case under 200 W/m^2 irradiance condition, both the algorithms were not perform well as in high irradiance condition. This is because under low irradiance tracking condition, the output current from the PV module was very low. This caused the system to experience significant variation in the current when the large changes of searching duty cycle during the tracking process, which in term also caused severe oscillation in system voltage. Due to this, it increases the tracking difficulty of the algorithms.

Table 1 Simulation results of PSO and BSA tracking under constant irradiance condition

Irradiance (W/m^2)	Output power (W)			Efficiency (%)	
	Theoretical	PSO	BSA	PSO	BSA
1000	735.0	734.8	734.8	99.97	99.97
800	582.6	582.5	581.4	99.98	99.79
600	430.3	430.0	429.2	99.93	99.74
400	280.3	278.0	278.4	99.18	99.32
200	134.5	125.7	127.1	93.46	94.50

Table 2 MPP tracked by PSO and BSA under rapid changed irradiance condition

Irradiance changes (W/m^2)	Output power (W)			Output power (W)		
	(before irradiance changes)			(after irradiance changes)		
	Theoretical	PSO	BSA	Theoretical	PSO	BSA
800–1000	582.6	579.5	582.4	735.0	734.9	734.6
600–1000	430.3	430.4	429.2	735.0	734.7	734.9
1000–800	735.0	734.8	734.8	582.6	582.5	581.9
1000–500	735.0	734.8	734.8	355.3	355.1	354.7

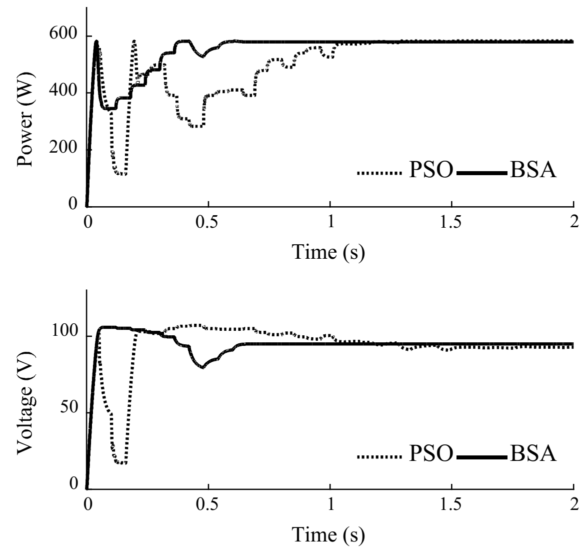

Fig. 3 Tracking performance of PSO and BSA under constant irradiance at 800 W/m^2

From the study, it can also realized that the tracking speed of the both algorithms varies with the tracking condition. Unlike conventional hill climbing MPPT methods, the soft computing methods perform random searched from the search space and the outcome from the search will directly affect the tracking speed and efficiency. However, in this study it can be found that the BSA was able to perform faster tracking than PSO under most situation. As can be seen from the results shown in Fig. 3, under 800 W/m^2 irradiance condition, the time taken for the BSA to reach MPP was approximately 0.56 s while the time taken for PSO to reach MPP was 1.05 s. However, it can be seen that under 800 and 600 W/m^2 irradiance condition, BSA shows slightly lower efficiency than PSO. This is because whenever the change of system power is within the predetermined steady state oscillation threshold (th_{osc}), the algorithm will assume the MPP has been achieved and the search process was terminated.

One of the key components for a MPPT algorithm is to react promptly and effectively towards the sudden change in system power. Such condition is very common especially in tropical country where cloud often covers the sun and cause the sudden drop in irradiance level. The ability of the MPPT algorithm to cater this situation effectively is extremely important to ensure that the PV system can always operate at its optimal operating point to extract maximum power. In this study, both MPPT algorithms were examined under rapid increasing (positive rapid changing) and rapid decreasing (negative step changing) irradiance environment to examine the tracking ability. As can be seen from the results in Table 2, it can be observed in this study that both algorithms were able to cater the rapid change irradiance condition effectively.

From the results shown in Table 2, both algorithms were able to alter the operating point of the PV system in order to ensure that the system was still operate at its MPP

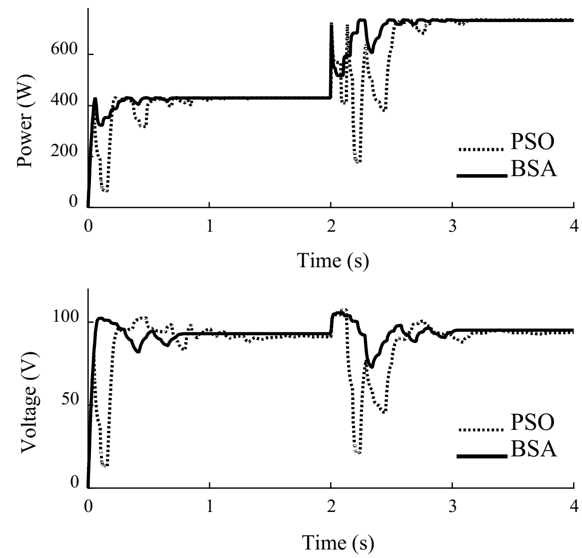

Fig. 4 Tracking performance of PSO and BSA under rapid change irradiance condition from 600 to 1000 W/m^2

after the change of irradiance. Besides that, the prompt response of the algorithms during the change of irradiance was also crucial to ensure that the system power loss was minimized. As observed in Fig. 4, it was found that both algorithms were able to response immediately at the instance of irradiance changing. However, it can also be seen that the BSA was able to converge towards the MPP faster than PSO. This is due to the relative simpler of the nature of the algorithm where it only requires the change of search boundaries with the comparison of the tracked power with its achieved MPP.

5 Conclusion

In this study, the performance of both binary search algorithm and particle swarm optimization MPPT method were implemented and evaluated successfully in Matlab Simulink. From the study, BSA has shown the capability to adapt to the rapid change of irradiance effectively together with PSO. In addition, with the less tuning parameters and fast convergence of BSA, it also brought to the potential of the implementation of the algorithm in PV system.

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