SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Performance Analysis of Deterministic Particle Swarm Optimization MPPT for a Standalone Photovoltaic System

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ARTICLE INFO

Article history:
Received 17 August 2023
Received in revised form 15 January 2024
Accepted 15 June 2024
Available online 25 July 2024

Keywords:
Photovoltaic; Maximum power point tracking; Deterministic particle swarm optimization

ABSTRACT

This paper presents a study of Deterministic Particle Swarm Optimization (DPSO) in maximum power point tracking. DPSO is applied to a standalone PV system with a boost converter. This method is implemented primary to solve the problem in conventional techniques such as Perturb and Observe (P&O) and Incremental Conductance (IC) in failure to detect optimum point under certain condition, fixed step-size and high steady-state oscillation. Deterministic method is applied to conventional Particle Swarm Optimization (PSO) and takes advantage over guiding the behaviour of the particles through experience. The velocity of the particle is predicted and evaluated until the optimum point is achieved. A standalone photovoltaic (PV) system is constructed with MATLAB Simulink and DPSO is deployed and tested by simulation. The effectiveness of DPSO is evaluated under uniform condition at standard test condition (STC), medium and low irradiance. The results show that the DPSO successfully converge at optimum point with low steady-state oscillation, and it has high efficiency.

1. Introduction

Moving toward green technology and net zero carbon emissions has made this call imperative not only for governments but also from the industries. Producing a reliable and sustainable energy is the major concern in this context. Out of all the renewable energy sources such as wind, biomass, bioenergy and geothermal, photovoltaic (PV) is seen as one of the most potential candidates [6,23,25,26]. Solar energy has advantages due to its availability, environmentally friendly, low maintenance cost and low operational cost [7,23,24]. However, the main challenge of solar energy is due to its dependency on environmental conditions [11]. The intensity of the solar radiation changes with environment and temperature. Thus, it has a major effect on the energy harvested [17,18]. As the solution to the aforementioned problem, a maximum power point tracking controller is embedded to the PV system [16,17,22].

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https://doi.org/10.37934/araset.49.1.108116

Various maximum power point tracking (MPPT) techniques are proposed by researchers to tackle the issues. Conventional techniques such as Perturb and Observe (P&O) and Incremental Conductance (IC) come with great merits in simplicity and widely used in applications [17,18]. However, these techniques suffer from low efficiency and high steady-state oscillation [6,8,20,24]. Moreover, these algorithms also fail to work under partial shading and caused massive losses to the PV system [4,24]. Hence, due to the above restrictions have challenge the researchers moving towards more robust control techniques for photovoltaic system.

Soft computing, artificial intelligence and bio-inspired are among the proposed techniques to alleviate the problems in conventional MPPT controllers [14,23]. Soft computing technique come with great merit in solving complex problem and has high accuracy in distinguishing the MPP [18,22]. However, the main challenge in this technique is in determining the control parameters such as initial state, size of particles, searching space and control parameters [4,13]. Inappropriate selection of these parameters cause failure to detect the real optimum and cause massive losses to the PV system [13,24]. For example, PSO has tendency to misguide the particles to inaccurate optimum point if selection of the initial parameters is assigned too far away from the searching area [6,7,12]. This only can be solved by increasing the number of particles in the search area and increasing the number of populations [4,5]. However, the only feasible solution is by increasing the number of particles in which it will prolong the convergence speed [10,15]. The trade-off between these two factors needed to be considered wisely. Otherwise, it might not practical in MPPT as long time period might not able to accommodate with the rapid changes of environment [9,10].

Many years of research have been done to analysis and solve the nonlinear equations which involve in real life model applications [1-3]. Applications of soft computing, artificial intelligence and bio-inspired techniques clearly have advantages in solving these nonlinear equations especially involving MPPT research. According to the previous studies [19,21], these techniques have a great capability in tracking the MPP in uniform irradiance conditions. However, in partial shading conditions, the multiple MPP occurs and most algorithms such as P&O, IC including PSO have tendencies to fail tracking the best MPP due to many factors such as restrictions, unsuitable parameters and trapping in local MPP instead of searching global MPP. Thus, an innovative algorithm like DPSO is required to solve these problems and efficiently tracking MPP in any conditions.

This paper proposed a study on the performance of Deterministic Particle Swarm Optimization (DPSO) in improving the performance of conventional MPPT techniques. The main key in this paper is on the determination of the velocity is done based on the previous history. The purpose of this paper is for verification for DPSO in MPPT application. The technique has few advantages in term of initial position of particles and the next decision of the particle movement is decided based on the previous history. Significantly, reduce the tendency of immature convergence. The remaining sections of the paper are arranged as follows. Section 2 presented on the methodology, while Section 3 describes on the results. Finally, section 4 discusses on the conclusion.

2. Methodology

A standalone photovoltaic system as shown in Figure 1 is constructed under MATLAB Simulink. The specifications of the PV module are as shown in Table 1. Boost converter with following specifications: switching frequency, f_{sw} = 20 kHz, inductor L= 270 uH and capacitors C_{in} = C_{out} = 220 uF are used in the simulation. PV voltage and PV current are fed into voltage and current sensors as the main inputs to the MPPT controller. The output from the controller which in duty cycle is fed to MOSFET at the optimum power, P_{mpp}.

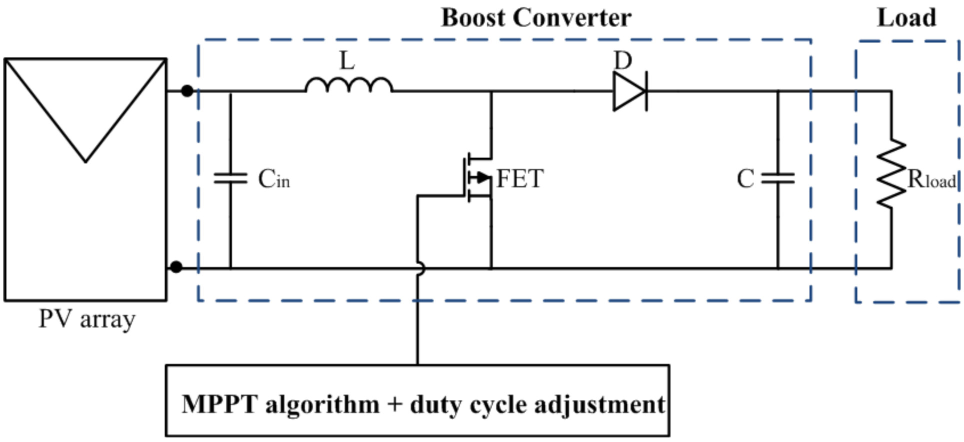


Fig. 1. A standalone photovoltaic system with boost converter

Table 1
PV module specifications

Parameter	Value at 1000 W/m^2 at 25 ^{o}C
P_{max}	50W
V_{oc}	22.2V
I_{MPP}	2.7A
V_{MPP}	18.2V
I_{SC}	3A
I_{SC} % Temp	0.06
V_{OC} % Temp	-0.34

The flow chart for the DPSO is as shown in Figure 2. Firstly, all the parameters for the MPPT algorithm such as voltage, current, power, particles number and DPSO parameters are initialized. The boundaries are set in between D_{min} and D_{max}. The boundaries are set between 0.1 until 0.75 as it is limited by the boost converter. The duty cycle, D_i at respective power is stored, in which i is the number of particles. Next the power at respective duty cycle is calculated and stored at the assigned array. If during first initialization, the particle reached the optimum, thus it will guide all the particles moved to the respective optimum point. The process continues until all the particles reached the same optimum point. However, if during first initialization the particles did not reach the convergence, the process continues until the optimum point is reached. The movement of the particle is guiding as in Eq. (1).

$$D_i(k+1) = D_i(k) + V_i(k+1) \tag{1}$$

Eq. (2) is for updating velocity.

$$v_i(k+1) = wv_i(k+1) + \{G_{best} + P_{besti} - 2x_i(k)\} \tag{2}$$

Best particle in only update if new best particle, $P_{best(new)}$ is more than $P_{best(old)}$ to achieve maximum optimization. However, if no new power is detected then no updated on the power. The power will hold the previous power, $P_{best(old)}$. Then, best particle is compared with the global best particle, G_{best}. The global best particle, G_{best} is only updated if new global best particle, $G_{best(new)}$ is found. All the process continues until all the particle reached convergence towards maximum optimization.

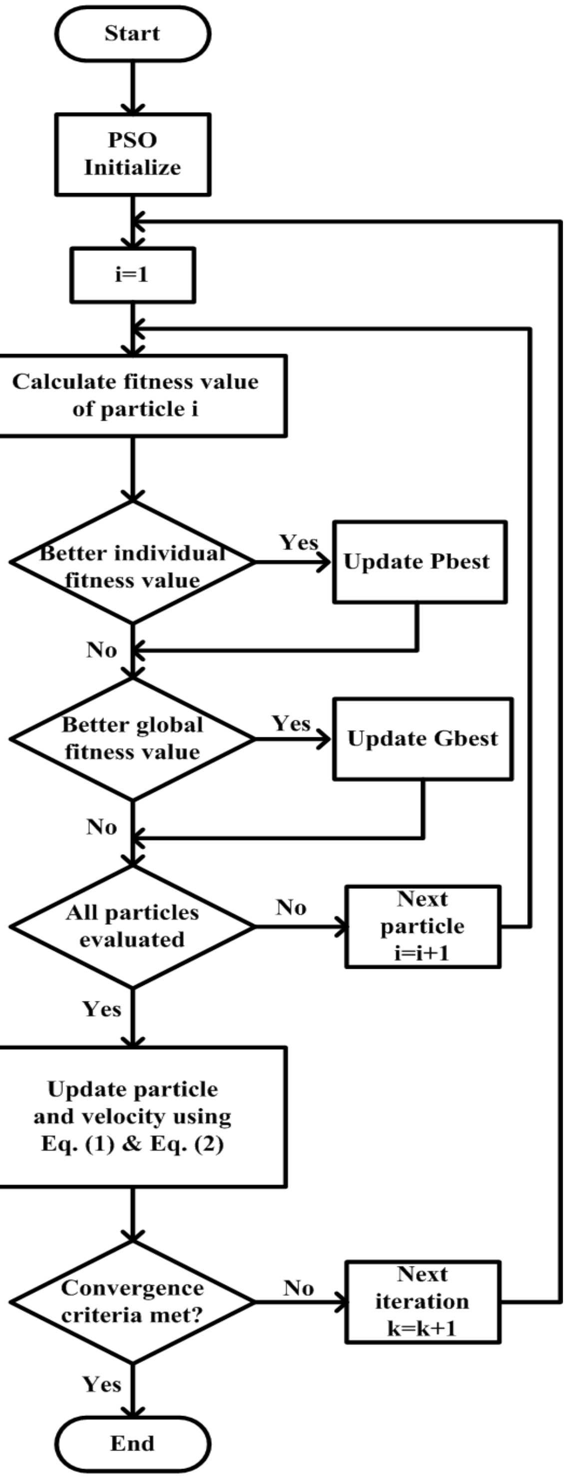
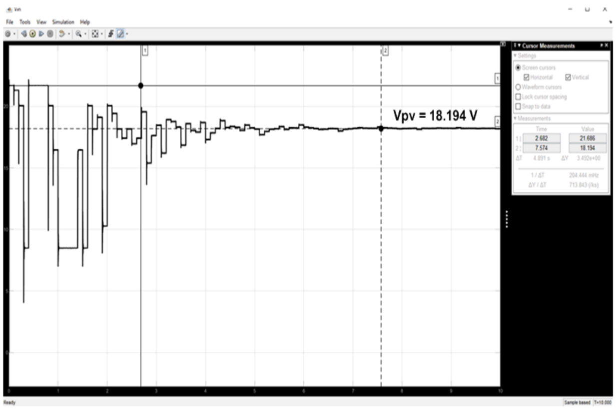


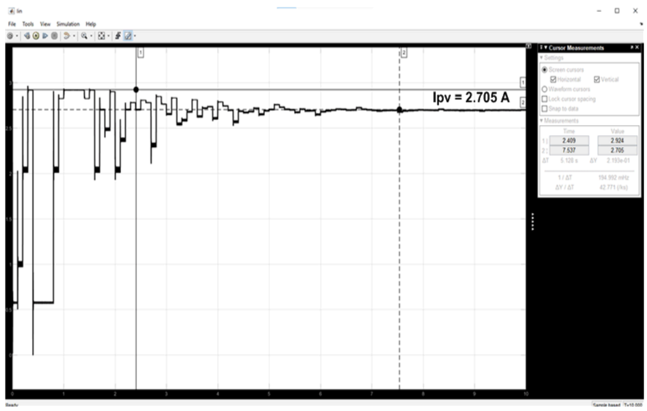
Fig. 2. Flowchart of Deterministic Particle Swarm Optimization (DPSO)

3. Results

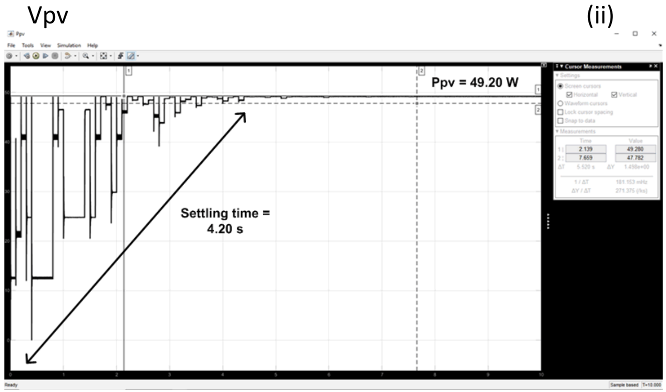
The effectiveness of DPSO is tested under uniform irradiance at 1000 W/m^2(STC), medium irradiance at 600 W/m^2 and low irradiance at 200 W/m^2 at 25 ^{0}C. The PV current and PV voltage is investigated under STC, medium and low irradiance. Figure 3 (a), (b) and (c) show the PV voltage, PV current and PV power for DPSO under 1000 W/m^2, 600 W/m^2 and 200 W/m^2. Based on the result, the tracked PV power by DPSO is 49.20 W with tracking speed of 4.20 s under 1000 W/m^2. Based on the waveform obtained, there is no steady-state oscillation observed. The simulation results show the tracking efficiency of 98.56 %. Under 600 W/m^2 the tracked output PV power is 29.84 W and settling time of 5.02 s with 99.47 % of tracking efficiency. Meanwhile, under 200 W/m^2 the optimum power tracked by DPSO is 9.39 W with settling time of 0.25 s with tracking efficiency of 93.90 %.



(i) Vpv

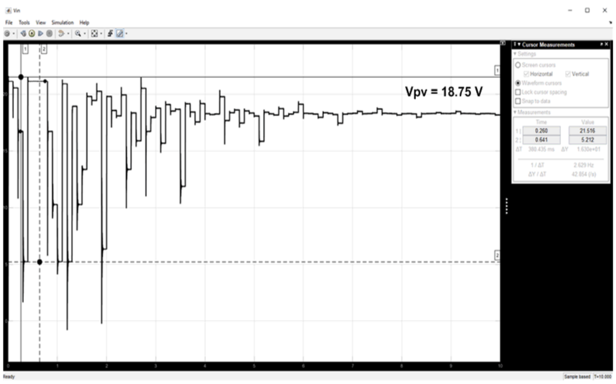


(ii) Ipv

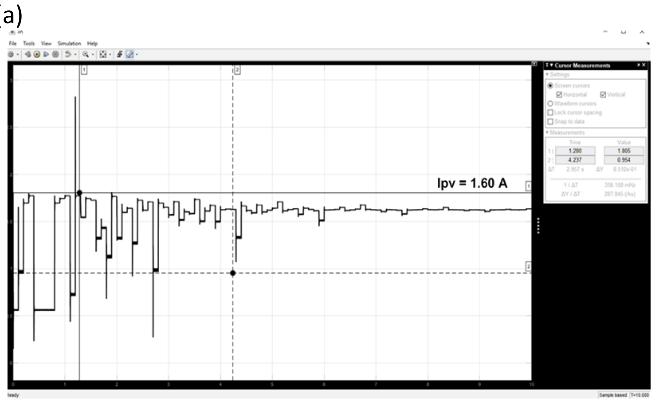


(iii) Ppv

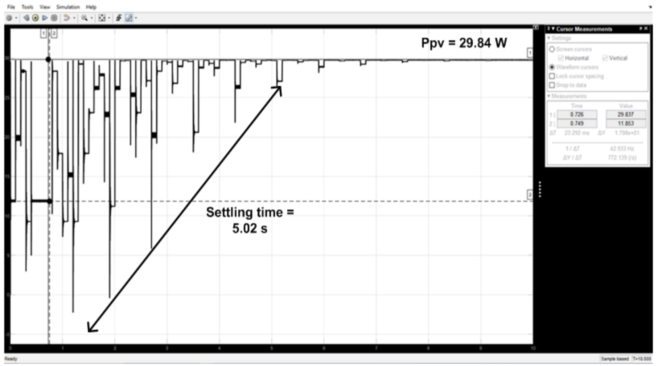
(a)



(i) Vpv

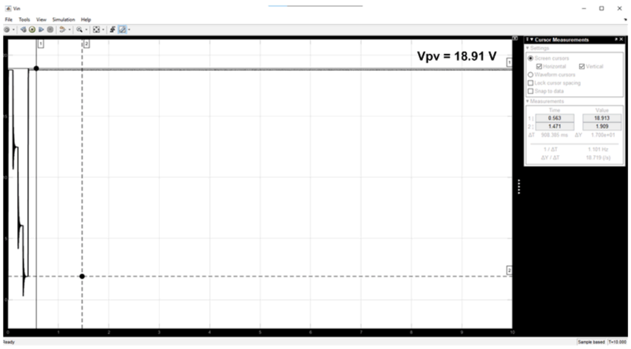


(ii) Ipv

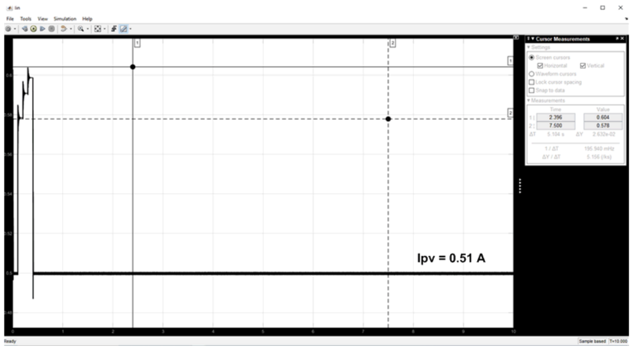


(iii) Ppv

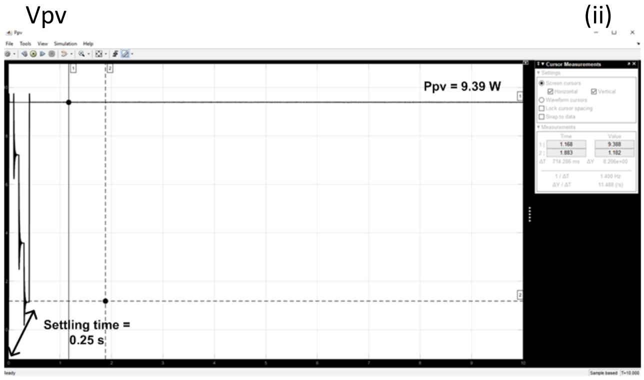
(b)



(i) Vpv



(ii) Ipv

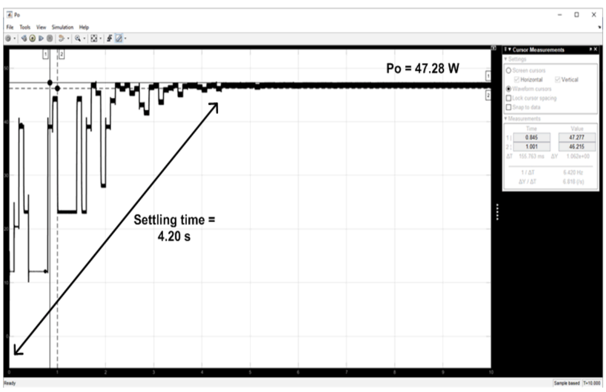


(iii) Ppv

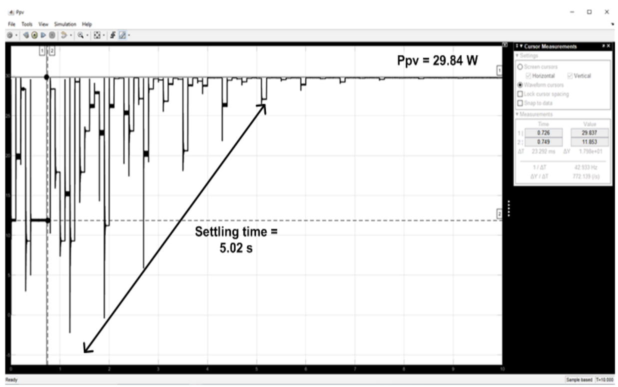
(c)

Fig. 3. MPPT DPSO tracking under (a) 1000 W/m^2 (b) 600 W/m^2 and (c) 200 W/m^2 irradiance

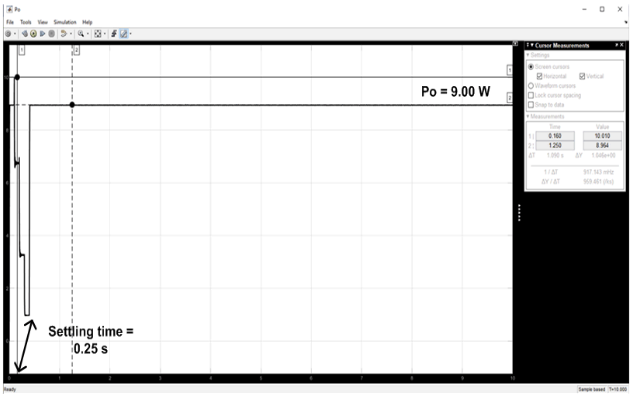
Figure 4 shows simulations result at the output of the boost converter. Based on the simulation results, the output power at the load is 47.28 W under 1000 W/m^2 irradiance. There is no steady-state oscillation observed once the optimum point is tracked by the DPSO. The tracking time is at 4.20 s. The efficiency at the output converter is at 94.56 %. The output power at the load under 600 W/m^2 is 29.84 W with settling time of 5.02 s and efficiency is at 99.47 %. Meanwhile for irradiance under 200 W/m^2, the output power at load is 9.00 W with settling time of 0.25 s and efficiency at 90.00 %. Based on the results obtained from simulation results, there is no steady-state oscillations observed after all the particles reached the convergence due to no velocity difference once all the particles reached the optimum point.



(i)



(ii)



(iii)

Fig. 4. Output power at load under (i) 1000 W/m^2 (b) 600 W/m^2 and (c) 200 W/m^2 irradiance

4. Conclusions

A Deterministic Particle Swarm Optimization is presented in this paper. Deterministic approach is embedded to conventional PSO to enhance the searching criteria. This method is done to solve the issue of steady-state oscillation and low tracking efficiency. The ability to hold the previous memory helps to expediate the search process. The efficiency of the DPSO in a standalone pv system is investigated under STC, medium and low irradiance. It is observed that efficiency of the tracking is improved, and almost zero steady-state oscillation is observed. This is due to the characteristics of DPSO in which once all the particles reached the convergence, there is no longer perturbation, leads to zero steady-state oscillation. Furthermore, by adding another state of checking in the technique, another checking process is done by comparing it with the previous history. The previous memory is hold until no other best point is found. The effectiveness of the DPSO is verified MATLAB Simulink. The simulation results show excellent performance of DPSO in term of tracking speed in the range of 0.25s until 4.50 s, almost zero steady-state oscillations and average overall tracking efficiency of 93.90 % to 99.47 %.

Acknowledgement
This research was funded by a grant from Ministry of Higher Education of Malaysia FRGS/1/2022/TK08/UNIMAP/02/47.

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