

PAPER 119 – MAXIMUM POWER TRACKING OF PHOTOVOLTAIC UNDER PARTIAL SHADING WITH SPRING SEARCH ALGORITHM INTEGRATED WITH PERTURB AND OBSERVE

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ABSTRACT

Solar power generation is perfectly suited for clean energy and meeting the increasing energy demands owing to its abundance and easy maintenance. However, it has low efficiency as maximum power is not extracted from the photo-voltaic panel due to solar irradiance obstruction causing partial shading condition. This condition creates multiple power peaks of which the maximum power peak is selected for maximum power utilization. To achieve this, a tracker based on spring search algorithm integrated with perturb and observe algorithm (SSA-PO), and operationally tied with DC-DC boost converter was developed for maximum power point tracking of the photovoltaic system at constant solar irradiance and during partial shading conditions. This generated a tracking efficiency of 97.8% at PSC1, 96.3% at PSC2 and 96.9% at PSC3, therefore, yielding an improvement of 0.15% and 2.29% during constant and partial shading conditions, and tracking time was 6.8% and 2.5% improvement when compared with the result of artificial bee colony algorithm with perturb and observe (ABC-PO).

KEYWORDS: Boost converter, MPPT, Partial shading, Photovoltaic, Tracking efficiency.

1 INTRODUCTION

The demand for energy world-wide is rapidly increasing, the International Energy Agency (IEA) predicted the world energy consumption will increase by 44% from 2006-2030 (A. K. Pandey et al., 2016). The conventional way of power generation that uses fossil fuel still provide the larger part of energy demand and has the challenges of carbon emission, installation cost and is being depleted (Başoğlu, 2022),(Li et al., 2018), thus, the need for renewable energy. Solar photovoltaic (PV) is widely applied in standalone and on-grid application as a result of its easy maintenance, low cost of installation, absence of noise, and free from pollution(Dileep & Singh, 2017).

In PV system sunlight is converted into direct current without any green-house gas emission which is widely advocated by governments (Ali & Mohamed, 2022). The current-voltage (I-V) curve of PV depends on temperature and irradiance. Under constant temperature and increase in irradiance, the PV current increases in direct proportion with negligible effect on PV voltage (Ahmad et al., 2019). The efficiency of the solar power generation needs to be improved, thus, several MPPT methods are developed to extract maximum power from the PV system (Dileep & Singh, 2017),(Rezk & Eltamaly, 2015). Conventional MPPT methods include, Incremental conductance technique (Mao et al., 2020)(Putri et al., 2015), Perturb and Observe techniques (Mo et al., 2022) etc. Perturb and observe method is the simplest method among the various methods. Conventional MPPT methods are effective under uniform irradiance conditions but are ineffective under changing atmospheric conditions and partial shading condition (PSC) (Liu et al., 2008),(A. Pandey et al., 2008). Thus, under PSC, to track the MPP, the conventional methods should be integrated with soft computing algorithms for better efficiency.

Photovoltaic arrays are connected in series or parallel so as to obtain required amount of voltage and current, and there is possibility of partial shading condition as a result of shadow of buildings, trees, moving clouds etc. The panels will receive a varying solar irradiation, which will give rise to partial shading condition (Ram et al., 2017). Under PSC the power vs voltage curve produces multiple peaks with only one peak which represent the true MPP, known as Global MPP (GMPP) and local MPP (LMPP). The conventional methods can only track the LMPP and are unable to track the GMPP due to system non-linearity. This will lead to power loss and low efficiency of the system. To improve the efficiency a soft computing method is fused with the P&O technique or other conventional methods (Zainuri et al., 2014).

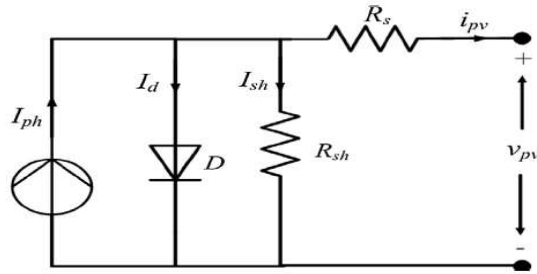
The aim of this research is to develop a PV array MPPT model under partial shading with boost converter by developing a spring search algorithm integrated with perturb and observe (SSA-PO) and apply on PV system configured with boost converter, and evaluating its performance based on tracking efficiency and time.

2 THEORETICAL ANALYSIS

In this section the theoretical background to the study is going to be discussed.

2.1 Photovoltaic Cell Model

In solar cell modelling, single diode and double diode model methods are used, also organic cell modelling apart from the silicon cell model is being developed over the years (Mazhari, 2006) and is the basic energy conversion unit of the PV system (Tayeb et al., 2022). However, the double diode method is complex (Ram et al., 2017). To predict the energy generation of photovoltaic cell, the single diode circuit model is used as represented in Figure



1.

Fig 1: Circuit Diagram of PV Cell Model

The characteristic equation of the one diode model could be obtained from Kirchhoff's current law using:

$$I_{pv} = I_{ph} - I_d - I_{sh} \quad (1)$$

Where, I_{ph} is Photons current, I_d is Diode current, I_{pv} is Photovoltaic current and I_{sh} is shunt resistor current

The characteristic equation in (1) is also expressed using:

$$I_{pv} = N_p \left\{ I_{ph} - I_o \left[\exp \left(\frac{q(V_{pv} + I_{pv}R_s)}{N_s A k T} \right) - 1 \right] \right\} - \frac{V_{pv} + I_{pv}R_s}{R_p} \quad (2)$$

Where, I_o is saturation current, N_p is number of parallel cell, N_s is number of series cell, q is electron charge, A is ideality factor, k is Boltzmann constant and T is cell temperature.

The saturation current which is dependent on temperature variation and the photon current are expressed using (Dileep & Singh, 2017):

$$I_o = I_{rs} \left(\frac{T}{T_{ref}} \right)^3 \exp \left[\frac{qE_g}{Ak} \left(\frac{1}{T_{ref}} - \frac{1}{T} \right) \right] \quad (3)$$

$$I_{ph} = (I_{sc} + (T - T_{ref}) K_i) \frac{G}{1000} \quad (4)$$

Where, G is irradiance, E_g is band gap energy, I_{rs} is reverse saturation current, K_i is short circuit current temperature coefficient and T_{ref} is the reference temperature.

Modules are also connected in series and parallel to meet power demand. A standard panel has 36 or 72 number of cell arrangement (Tey et al., 2018).

2.2 PV Array with Partial Shading

The solar array performance is often affected by partial shading as solar irradiance is obstructed from fully reaching the panels, which drastically reduce the output power. Figure 2, shows the diagram of PV array under partial shading. The array is receiving a varying solar irradiance, which will create multiple local maximum power point and global maximum power point (Pal & Mukherjee, 2020).

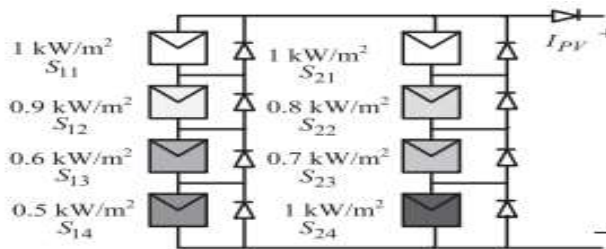


Figure 2: PV Array with partial shading

2.3 Spring Search Algorithm (SSA)

The principle behind this optimization technique is based on Hooke's law. Equation (5) is the expression of Hooke's law (spring force).

$$F_s = -KY \quad (5)$$

Where, F_s is spring force, K is a constant and Y is the strain or compression of the spring.

3.0 MATERIAL AND METHODS

The objectives of this research were realized through the implementation of spring search algorithm with boost converter using MATLAB/Simulink.

3.1 Objective Function and Constraints

The problem presented in this research is non-linear, as such, in this research the maximum power point of the PV array is to be optimized. Therefore, the power is the objective function that the algorithm is required to optimize while voltage and current are the decision variables, this is expressed using:

$$P_m = \sum_{z=1}^n V_{mz} I_{mz} \quad (6)$$

Where, n is the number of the solar panels, V_{mz} is maximum voltage of solar panel numbered z , I_{mz} is the maximum current of solar panel numbered z .

3.2 P_v Array Specification

The parameters of a single PV module at standard temperature of 25°C and insolation of 1000W/m² is shown in table 1. In this work, the PV array is made up of 2 modules connected in series (Pilakkat & Kanthalakshmi, 2019). To generate the required P-V and I-V curve, three shading conditions PSC1, PSC2, PSC3 are presented, which are:

- i. When the PV array has pattern 1000W/m² and 1000W/m² (PSC 1)
- ii. When the PV array has a shading pattern of 1000W/m² and 500 W/m² (PSC2)
- iii. When the PV array has a shading pattern 300W/m² and 800W/m² (PSC3)

Table 1: PV Module Specification of Vikram Eldora-37

<i>Parameter</i>	<i>Value</i>
Maximum power (P_{max})	37W
Voltage at MPP (V_{mpp})	17V
Current at MPP (I_{mpp})	2.25A
Open circuit voltage (V_{oc})	21.8V
Short circuit current (I_{sc})	2.8A
Module efficiency	10.10%
Short circuit current temperature coefficient	0.04%/°C

3.3 Development of SSA-PO Algorithm for PV MPPT Model under PSC with Boost Converter

The implementation of PV MPPT model under partial shading condition using SSA-PO is described using the flow chart in Figure 3.

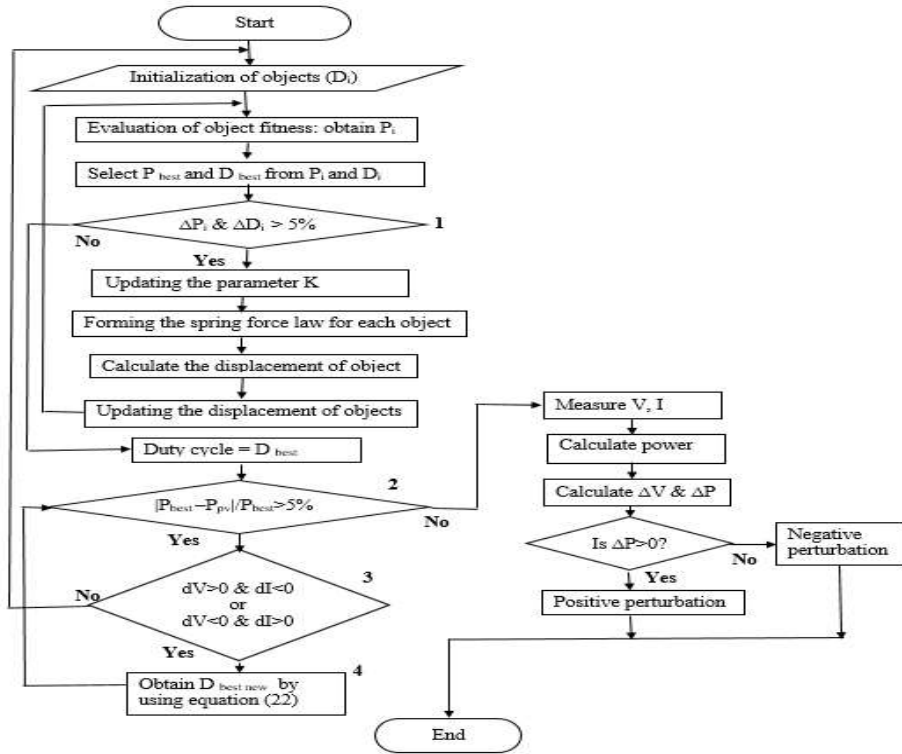


Figure 3: Flow-chart of SSA-PO Algorithm

Figure 4, shows the developed Simulink model of the proposed SSA-PO algorithm connected to the switching device of the boost converter, which has wide acceptance in PV power system as it has good efficiency (Fathabadi, 2016). The algorithm generates the duty cycle that controls the converter, as such, maximum power tracked by the algorithm is supplied to the resistive load at the output terminal of the converter.

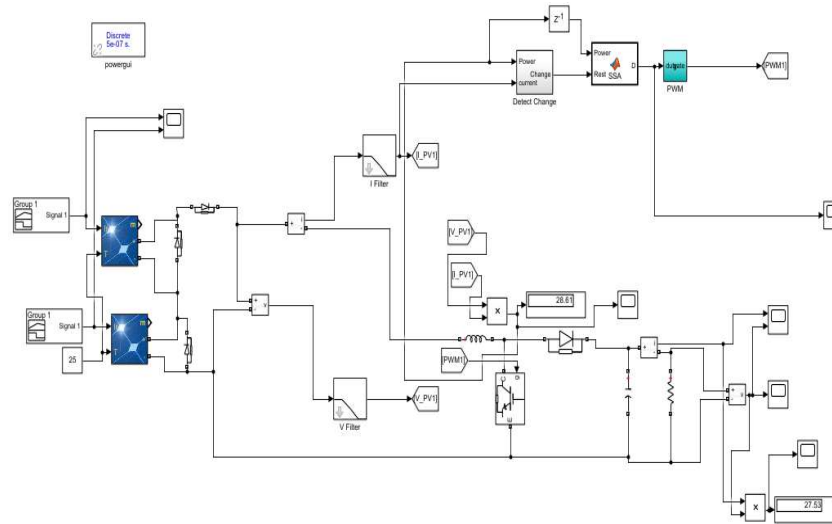


Figure 4: Developed Simulation Model of SSA-PO with Boost converter

4.0 RESULT AND DISCUSSION

In this section, the implementation was carried out in MATLAB/SIMULINK and the result compared with ABC-PO algorithm with boost converter, using efficiency and tracking time as performance metrics.

4.1 Result obtained with ABC-PO Method

Table 2 shows the result obtained with ABC-PO method. The power (P) is tracked at 69.06W at time (T) 0.16 seconds as compared to 70.72W of the photovoltaic power of the system at constant irradiance (1000W/m² and 1000W/m²) from 3.2. Therefore, with ABC-PO method, the efficiency is found to be 97.65% with a tracking error of 2.3% at constant solar irradiance. At time 1 second, the photovoltaic power of the system dropped to 30.63W due to irradiance change from 1000W/m² to 500W/m². The ABC-PO tracked the power (P) to be 29.7W at time (T) 1.04 second with tracking efficiency of 96.9% and tracking error of 3.03%.

At partial shading conditions of PSC2 (1000W/m² and 500W/m²) and PSC3 (800W/m² and 300W/m²) as shown in 3.2. From table 2, the ABC-PO tracked the power to be 16.13W at time 0.09s. However, at time 1 second the irradiance changed and the power output increases due to increase in solar irradiance on the PV array. The ABC-PO tracked the power to be 21.76W at time 1.056 second.

4.2 Result obtained with SSA-PO Method

In this section the developed technique is used to track the GMPP from the solar array at constant and partial shading condition. From table 2, it shows the power tracked when the solar array is under PSC1 and PSC2 as shown in 3.2. When the PV array has irradiances of 1000W/m² and 1000W/m², the SSA-PO tracked the power to be 73.55W at time 0.149 second as compared to the 75.19W of the photovoltaic system at constant irradiance. The tracking efficiency was found to be 97.8% with tracking error of 2.18% at constant solar irradiance.

Furthermore, at time 1 second the irradiance changed from 1000W/m² to 500W/m² hence the power dropped. The SSA-PO tracked the GMPP and the power was found at 27.5W at time 1.075 seconds compared to 28.55W of the photovoltaic system during partial shading condition. This reduction in power output was due to the reduction in solar irradiance received by the solar array. The tracking efficiency was 96.3% with tracking error of 3.6%.

At partial shading conditions PSC2 (1000W/m² and 500W/m²) and PSC3 (800W/m² and 300W/m²) as shown in 3.2. From Table 2, the SSA-PO tracked the power to be 19.95W at time 0.1s. However, at time 1 second the irradiance changed and the power output increased due to increase in solar irradiance on the PV array. The SSA-PO tracked the power to be 27.51W at time 1.029 second, which indicated power increase due to solar irradiance increase.

Table 2: Results obtained from developed method and ABC-PO method at partial shading condition PSC1, PSC2 and PSC3.

<i>Parameter Description</i>	<i>ABC-PO (PSC1, PSC2, PSC3)</i>	<i>Developed method (PSC1, PSC2, PSC3)</i>	<i>% Improvement (PSC1, PSC2, PSC3)</i>
<i>Tracking Time (sec)</i>	0.16, 1.04, 1.056	0.149, 1.075, 1.029	6.8, 3.3, 2.5
<i>Open-circuit Voltage (V)</i>	36.24, 23.69, 20.05	37.23, 22.83, 22.8	0.99, 0.86, 2.75
<i>Short-circuit Current (A)</i>	1.907, 1.2, 1.09	1.96, 1.204, 1.207	2.78, 0.33, 10.7
<i>Maximum Power point (W)</i>	69.06, 29.7, 21.76	73.55, 27.5, 27.51	6.5, 7.4, 26.4
<i>Relative Error (%)</i>	2.3, 3.03, 2.32	2.18, 3.6, 0.01	0.12, 0.57, 2.31
<i>Tracing Efficiency (%)</i>	97.65, 96.9, 94	97.8, 96.3, 96.29	0.15, 0.6, 2.29

5. CONCLUSION

This research presents the development of maximum power tracking method of a PV system under and varying solar irradiance with SSA-PO method. In this work, a DC-DC boost converter was modelled and employed between the PV array and the load. A spring search algorithm integrated with Perturb and observe (SSA-PO) MPPT was developed to determine the duty-cycle of the boost converter for maximum power tracking under partial and constant irradiance. Finally, the developed method result was compared with the performance of ABC-PO using tracking efficiency and time as performance metrics.

The developed work obtained 0.15% and 2.29% improvement in tracking efficiency compared with ABC-PO respectively under constant and partial shading condition. Also, the developed method obtained 6.8% and 2.5% improvement in tracking time under constant and partial shading condition compare with ABC-PO method.

The developed work employed boost converter to enable maximum power tracking, I recommend further work should employ Zeta converter with the developed technique.

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