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Global maximum power tracking of PV system under partial shading

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Abstract

The increased usage of electrical energy in the recent times leads to a greater demand. It invites large development in the production of electrical energy from renewable energy sources. It involves more evolving technologies. Out of all energy extraction from solar would be abundant. Photovoltaic (PV) are one such components helps in deriving large amounts of energy, this has become more easiest method due to its economic liabilities and the world has aimed its interest in developing the PV technology, which gives clean energy. This paper objective is to implement various Maximum Power Point Tracking (MPPT) algorithms, mainly Cuckoo Search Algorithm, fuzzy logic control (FLC) and conventional perturb and observe (P&O), incremental conductance (INC) on solar PV systems. These controlled MPPT algorithms helps in driving DC-DC boost converter, which helps to obtain maximum output from the PV Panels/cells/modules/Arrays. The obtained results are compared with each other under several operating conditions. The operating conditions include change in irradiance, change in temperature dynamically, and partial shading on PV panels. The implemented MPPT algorithms require only the PV array voltage and current to control DC-DC converter, which makes them economically feasible and attractive. From the results, it can be observed that Cuckoo search algorithm gives better results under partial shading situations.

Keywords: PV array, MPPT, Cuckoo Search Algorithm, partial shading

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1. Introduction

Out of all available non-conventional energy sources, solar energy is the one which can be considered due to its abundant availability. Solar panels are the basic components to draw the energy from sun. The principle involved in deriving electrical energy from solar modules is the photovoltaic effect. The primary and main advantage of the photovoltaic module is, it is easily available source and holds no moving parts, there by producing no noise leading to low maintenance costs. Though there are many advantages in production of electricity from PV modules/Arrays, the efficiency drops due to electrical and optical losses. These losses are very complicated to handle and these losses may occur due to partial shading conditions.

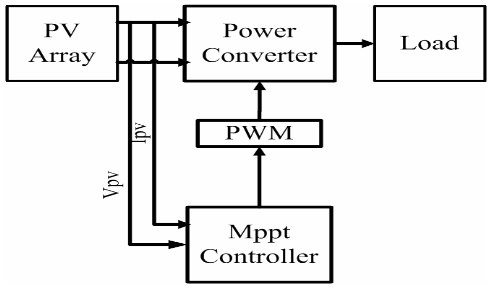

Figure 1. Schematic diagram of MPPT Controller with PV system

From a PV system, maximum power extraction depends on three factors. One is by selection of PV arrays, the second one is reconfiguration of the PV arrays and the third one is with the help of MPPT techniques (Rajani and Ramesh, 2021; Ramesh et al, 2021). MPP tracker is required for getting global MPP. Figure 1 gives the schematic diagram of MPPT Controller with PV system.

Various types of MPPT techniques performance has been verified in this paper. The remaining part of the paper is organized as Part 2 gives the idea about PV system, Part 3 explains partial shading conditions, Part 4 briefs the most commonly used and effective MPPT algorithms including Cuckoo search algorithm. Part 5 discusses the simulation results and Part 6 concludes the paper.

2. PV System

A solar cell, often known as a photovoltaic cell, is the initial component of a solar panel. Each photovoltaic (PV) unit is made of multiple interconnected PV cells in series, parallel or combination of both. Series connected PV modules give maximum voltage and a parallel connection are used to get maximum current. Photovoltaic array is a linked collection of photovoltaic modules (Pakkiraiah et al, 2016; Sarayu Vunnam et al, 2021). The schematic view of solar cell is shown in Figure 2.

PV cells are essentially semiconductor diodes with a p-n junction which is exposed to light. It creates electricity when it is illuminated by sunlight. Dealing with the nonlinear properties of PV array is a key problem when employing PV power production systems. Since the diode is a non-linear circuit element with inherent impedance that defines the optimal operating point, a solar panel's i-v characteristics are non-linear (Clerici et al, 2015). The maximum power from a solar panel can be extracted when it is operated at global maximum voltage. The MPP is the name given to this voltage.

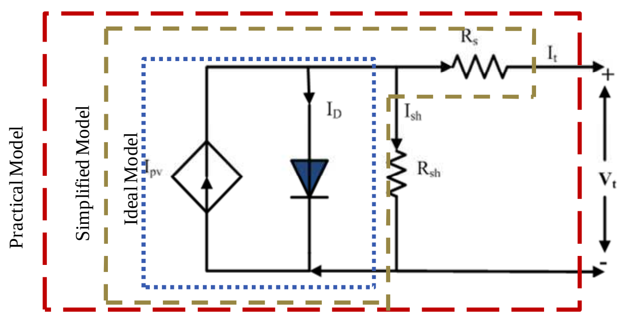

Figure 2. Schematic view of solar cell

PV properties are influenced by irradiance and temperature (Clerici et al, 2015). Because of passing clouds, neighboring houses, or plants, the PV array receives variable amounts of irradiance (Pakkiraiah et al, 2016). There exists several PV models, few of them are multi-diode model, two-diode model, single-diode model, empirical PV models (Anubha et al, 2005). Here, single diode model is considered in all three situations of ideal, simplified and practical modes. The corresponding modeling equations are given.

The following (1) is a mathematical description of the I-V properties of a realistic PV cell model.

$$I_{t,cell} = I_{PV,cell} - I_r \left[\exp\left(\frac{V_{t,cell} + R_S I_{t,cell}}{V_{T,cell} a} \right) - 1 \right] - \frac{V_{t,cell} + R_S I_{t,cell}}{R_{sh}} \quad (1)$$

(2) is a mathematical model for describing the I-V characteristics of a realistic PV module with ns cells linked in series.

$$I = I_{PV} - I_r \left[\exp\left(\frac{V + R_S I}{V_T a} \right) - 1 \right] - \frac{V + R_S I}{R_{SH}} = I_{PV} - I_r \left[\exp\left(\frac{q(V + R_S I)}{n_s kTa} \right) - 1 \right] - \frac{V + R_S I}{R_{SH}} \quad (2)$$

(3) is a mathematical model for describing the I-V curves of a PV array.

$$I_0 = I_{PV} N_P - I_r N_P \left[\exp\left(\frac{q\left(V_0 + R_S \left(\frac{N_S}{N_P} \right) I_0 \right)}{n_s kTa} \right) - 1 \right] - \frac{V_0 + R_S \left(\frac{N_S}{N_P} \right) I_0}{R_{SH} \left(\frac{N_S}{N_P} \right)} \tag{3}$$

Where I_{PV} is cell current produced by solar irradiance [A], I_r diode reverse leakage current [A], I_t the PV cell's terminal current [A], V_t cell, and $V_{T,cell}$ = kT/q are the PV cell's terminal and thermal voltages, respectively, where k is Boltzmann's constant, T is the cell operating temperature**.** R_{sh} is the shunt resistance and R_s is the series resistance. The number of series connected modules are represented by N_s and the number of parallel connected modules are represented by N_p .Terminal voltage is V_0 and terminal current is I_0.

The characteristics of PV system under different irradiance and temperatures are given in figure 3 and figure 4.

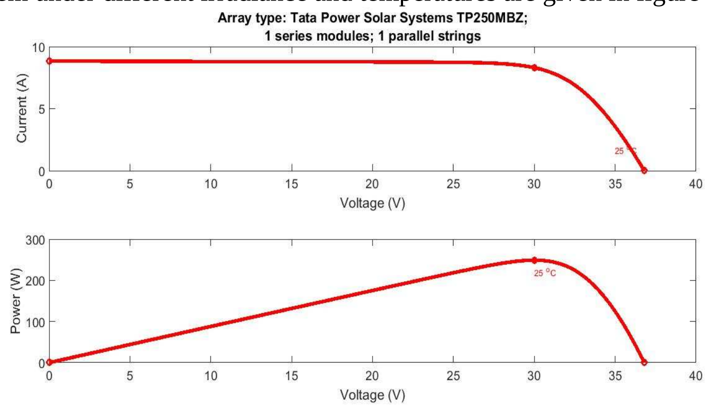

Figure 3. P–V curve of system at 1000(W/m^2) irradiance, 25^{o}C

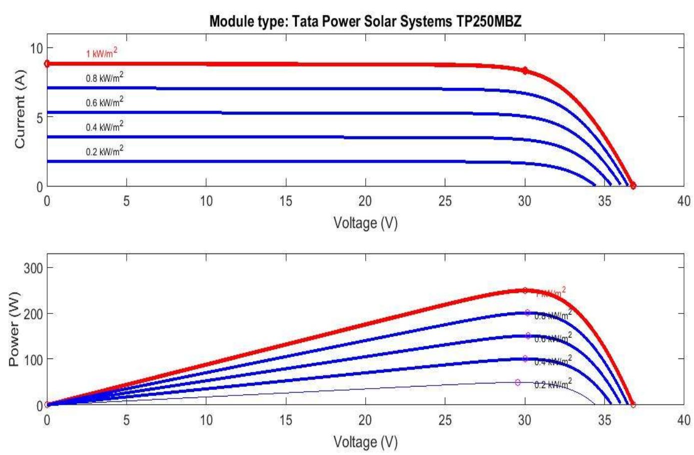

Figure 4. P–V curve of system at different irradiance, temperature conditions

The specifications of the PV system used for the simulation are given in Table 1, Table 2 gives the output power deviations of PV module at various irradiations at 25^o C and the output power variations of PV array under various irradiations at 25^o C are shown in Table 3.

Table 1. Tata Power Solar Systems TP250MBZ PV Module Specifications

Specification	Value
Maximum Power (W)	249
Voltage at MPP VMPP (V)	30
Short-circuit current Isc (A)	8.83
Open circuit voltage Voc (V)	36.8
Current at MPP IMPP (A)	8.3
Cells per module (Ncell)	60
Series-connected modules per string	1
Parallel strings	1

Table 2. Power output of PV Module at different irradiations & 25°c temperature

Irradiation (W/m^2)	PV Module Output (W)
1000	249
800	200.275
600	150.55
400	100.13
200	49.15

Table 3. Specifications of PV Array at different irradiations & 25°c temperature

Irradiation (W/m^2)	PV Module Output (W)
1000	996
800	801.1
600	602.2
400	400.12
200	196.6

3. Partial Shading Conditions

Due to the shadows of stationary or moving objects like trees, buildings, and other structures, partial shading occurs in PV arrays. The irradiance of the PV system changes with respect to these factors. Because of various irradiances on series modules, the same current should pass through all series modules, causing certain modules to act as a burden on non-shaded modules. In order to shield these modules from the hot-spot phenomena, the current of the shaded modules may create a negative drop voltage, which increases. PSC produces numerous peaks in the P–V characteristics of a PV array (Ali Omar Baba et al, 2020). The temperature of the shaded module Due to a phenomenon known as hot-spot, this high temperature or rise in temperature may harm shaded PV systems. As a result, a parallel diode needed to each module to avoid the shaded modules when their voltage reverses. The one with the most power is known as the global peak (GP), while the others are known as local peaks (LP). Figures 5, 6, and 7 provide different case studies of PV curves for various irradiance settings on PV modules.

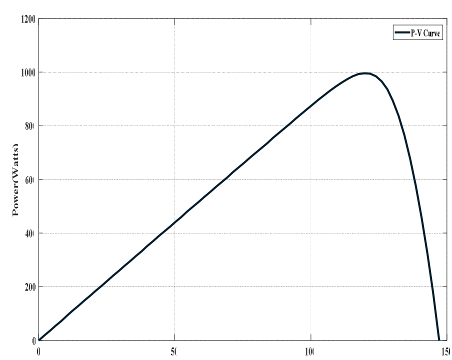

Figure 5. Case study-1: P-V curve for [1000 1000 1000 1000] W/m^2 irradiance

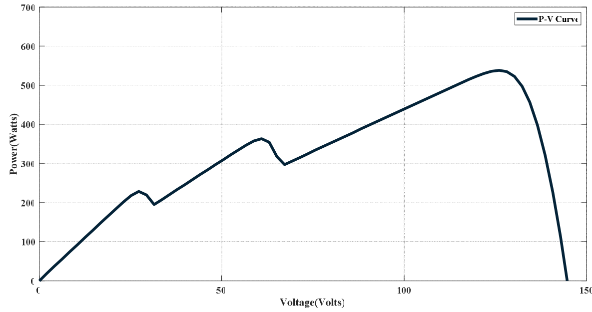

Figure 6. Case study-2: P-V curve for [1000 700 500 500] W/m^2 irradiance

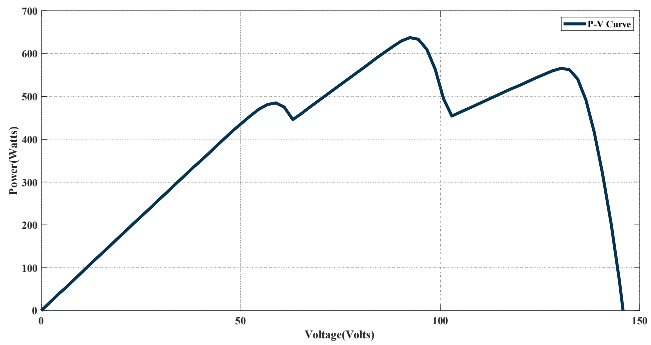

Figure 7. Case study-3: P-V curve for [500 1000 800 1000] W/m^2 irradiance

4. MPPT using Cuckoo search algorithm

To optimize the power generated by the solar panel and improve its output efficiency, it must be run at its optimal power point. In addition, existing solar panels have a relatively poor efficiency **(Morales, 2010)**. The efficiency lowers even more, when there is imbalance between input and output. The sun irradiation affects the maximum power point. PV's nonlinear current–voltage (I–V) curves, which give a single MPP on its power–voltage (P–V) curve, offer a significant difficulty in its use (M. E. Ropp et al, 2000). The situation is made more difficult by the fact that these properties are affected by solar insolation and temperature. MPP changes as these factors change over time. Because of a PV source's high initial capital cost and less energy conversion efficiency, it's required to run it at MPP to get the most power out of it. A DC-DC converter is often used along with PV source and its duty cycle is adjusted to meet the MPP. There are many MPPT (maximum Power Point Tracking) algorithms **(Cheikh et al, 2007)**. Out of those numerous methods the famous methods are Perturb and Observe (P&O) (Jacob James **Nedumgatt et al, 2011**; **Moring et al, 2012**), Incremental Conductance (INC) **(Kalashani and Farsadi, 2014)**. Parasitic Capacitance (PC), Hill Climbing (HC), Constant Voltage (CV), Constant Current (CC), etc. Artificial intelligence based MPPT algorithms (Vanti et al, 2021), are Artificial Neural Networks (ANN), Fuzzy logic Controller (FLC) (Eltamaly, 2021), Adaptive Fuzzy logic Controller, etc. Bio inspired based MPPT algorithms are Particle swarm optimization, Modified Particle swarm optimization, Grey Wolf optimization, Cuckoo Search (CS) (Enany, 2017), Artificial bee Colony(ABC), Ant Colony optimization, Cat Swarm optimization, Bat Algorithm (BA), Jaya Algorithm (GA), Firefly Based Algorithm (Titri et al, 2021), Differential Evolution (DE), Genetic Algorithm(GA), etc. In this work, to get MPP under PSC the Cuckoo search algorithm has been used and the results are compared with P&O, IC, fuzzy methods.

Yang and Deb were the first to propose the Cuckoo search algorithm. The CS algorithm is a Meta-heuristic (MH) approach inspired by the re-production habit of cuckoo bird species. Instead of building its own nest, the bird lays its eggs in the nests of other birds (Enany, 2017). It utilizes a strategy to choose a good host nest in which it flies randomly from one nest to the next, looking for the best one - defined as the one with the best probability of eggs hatching successfully (Enany et al, 2012). The cuckoos sometimes drop the eggs of the host bird out of the nest to increase the chances of their eggs hatching successfully. Some species of cuckoos can adapt the shape of their eggs to be similar to those of the host bird, in order to decrease the chance of discovery. If the host bird discovers the cuckoo's trick, it may throw out the cuckoo's eggs or abandon the nest. The CS optimization technique is based on this natural tendency.

Cuckoo birds, in nature, execute a quasi-random flying or movement that resembles Lévy flight. The term "Lévy flight" refers to a movement or flight whose step length follows the Lévy distribution, allowing the CS algorithm to make such a "large jump" among their tiny flights. This "long leap" is an essential characteristic that allows the CS algorithm to avoid LMPP while also reducing the amount of time it takes to achieve GMPP (Enany et al, 2012). The algorithm is shown in the Figure 8.

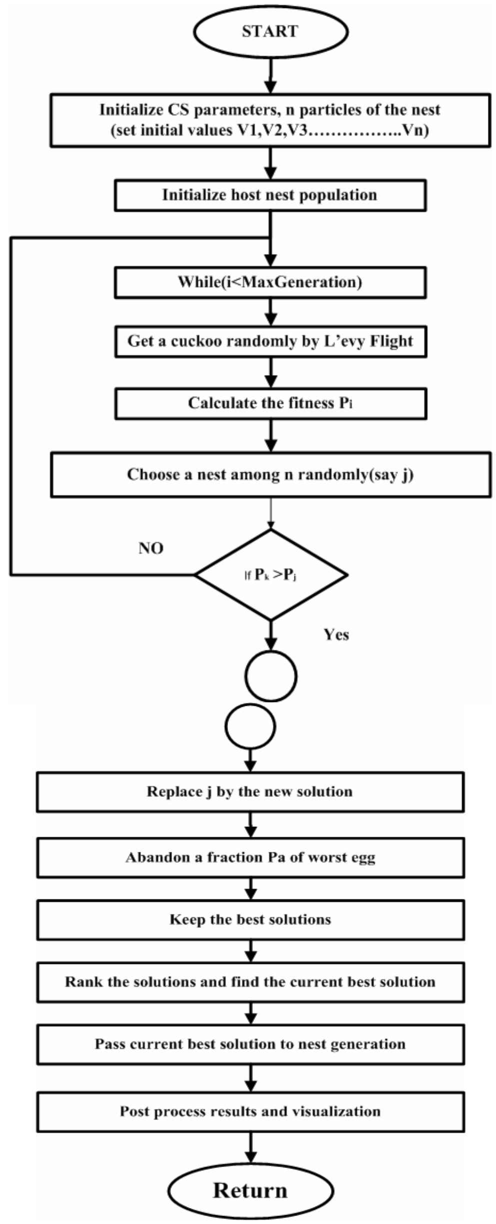

Figure 8. MPPT algorithm with a cuckoo search

Mathematically Lévy flight is given by:

$$X_j^{i+1} = X_j^i + \alpha \otimes \text{Levy} \tag{4}$$

For MPPT it is simplified to:

$$V_j^{i+1} = V_j^i + \alpha \otimes \text{Levy} = V_j^i + s \tag{5}$$

Where S denotes a change in location, and u and v denote normal distributions, K denotes a random step coefficient. Step size entry wise multiplication is equal to 1(α) power law index is 1.5(β), and the integral gamma function is Γ.

$$S \approx K * \left(\frac{u}{|v|^{\frac{1}{\beta}}} \right) * (V_{best} - V_j) \tag{6}$$

$$u \approx N\left(0, \sigma_u^2\right); v \approx N\left(0, \sigma_v^2\right) \tag{7}$$

$$\sigma_u = \left(\frac{\Gamma(1+\beta) * \sin\left(\pi + \frac{\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right) * \beta * \left(2^{\frac{\beta-1}{2}}\right)} \right)^{\frac{1}{\beta}} ; \sigma_{v=1} \tag{8}$$

4. Results and Discussions

In MATLAB/SIMULINK, the MPPT algorithms are simulated and the outcomes are assessed. The specifications of the boost converter components are tabulated in Table 4.

Table 4. Specifications boost converter

Specification	Value
DC Link Capacitor	10μF
Output filter Capacitor	0.23mF
Load resistance	58Ω
Inductance	1.2mH

The simulation result of uniform irradiance of 1000 W/m^2 at 25^{o}C for single panel Tata Power Solar Systems TP250MBZ using Fuzzy logic, Incremental conductance and P & O algorithms are evaluated and their results are shown in Figure 9 and their performance comparisons are shown in Table 5. Figure 10 depicts the dynamic change in irradiance simulation findings. Only the converter output voltage with regard to the simulation time is included in the simulation results.

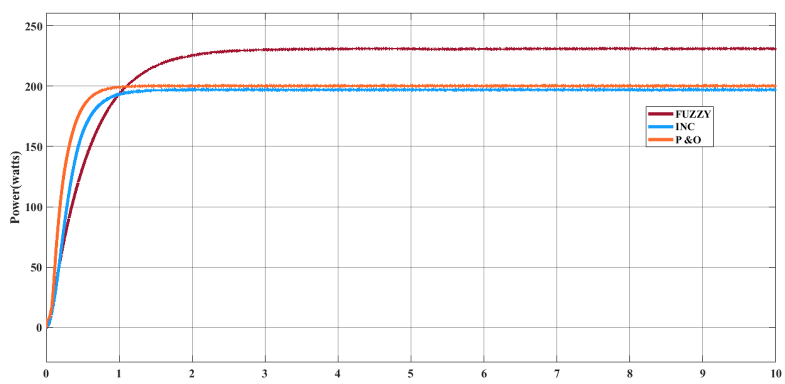

Figure 9. Simulation result of uniform irradiance of 1000 W/m^2 at 25^{o}C

Table 5. Comparisons for 25°C temperature and 1000 W/m^2 irradiance

Algorithm	PV Module Output (W)	Converter output(W)	Efficiency %	Settling time
P&O	249	200	80.32	0.8
INC	249	197	79.11	0.85
Fuzzy logic	249	230	92.36	1.6

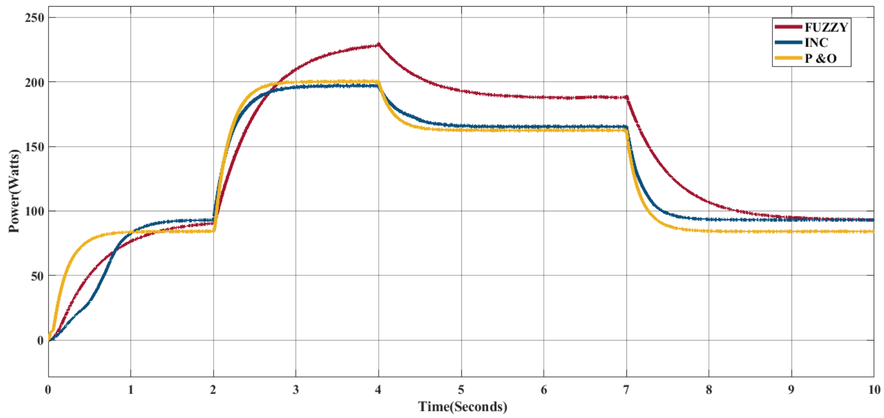

Figure 10. Simulation result of dynamic change in irradiance 25°C

From Table 5, it can be observed that fuzzy logic based MPPT controller has less steady state error compared to P&O and INC. But fuzzy logic based MPPT has 0.8 sec and 0.75 sec more settling time compared to P&O and INC. The output power from single module The PV array has four panels connected in series. The simulation results are carried for the same. As Fuzzy logic involves lot of complicated calculations in evaluating the membership functions. The Fuzzy logic MPPT algorithm is limited to only uniform irradiance and dynamic irradiance change here.

4.1 Case study-1: The Simulation result of uniform irradiance at an array of [1000 1000 1000 1000] W/m^2 at 25°C temperature for Cuckoo search, Incremental conductance and P&O algorithms are shown in Figure 11. Their respective comparisons are given in Table 6.

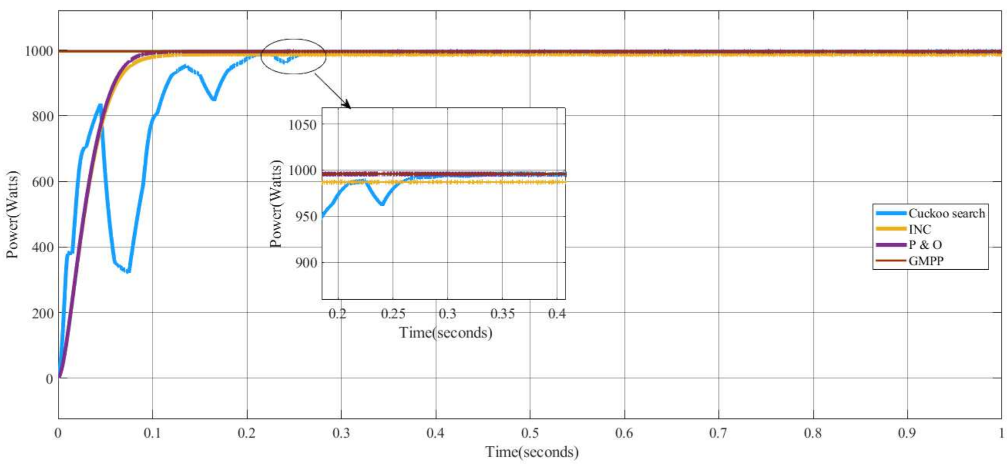

Fig. 11 Simulation result of uniform irradiance: Array of [1000 1000 1000 1000] W/m^2 at 25°C temperature

From Table 6, it can be noted that P&O has 0.29% and 0.9% more efficiency compared to INC and Cuckoo. Cuckoo search has 0.22sec and 0.215sec more settling time compared to P&O and INC. From Fig.9, it has been observed that oscillations are high in Cuckoo search method. Hence, under uniform irradiance condition P&O operating better than Cuckoo search.

Table 6. Comparisons for 25°C temperature and 1000 W/m^2 irradiance

Algorithm	PV Module Output (W)	Converter output(W)	Efficiency %	Settling time
P&O	996	995	99.89	0.08
INC	996	986	98.99	0.085
Cuckoo Search	996	993	99.6	0.3

4.2 Case study-2: Simulation result of partial shading at an array of [1000 700 500 500] W/m^2 at 25°C temperature for Cuckoo search, Incremental conductance and P&O algorithms are shown in Figure 12. Their respective comparisons are given in Table 7.

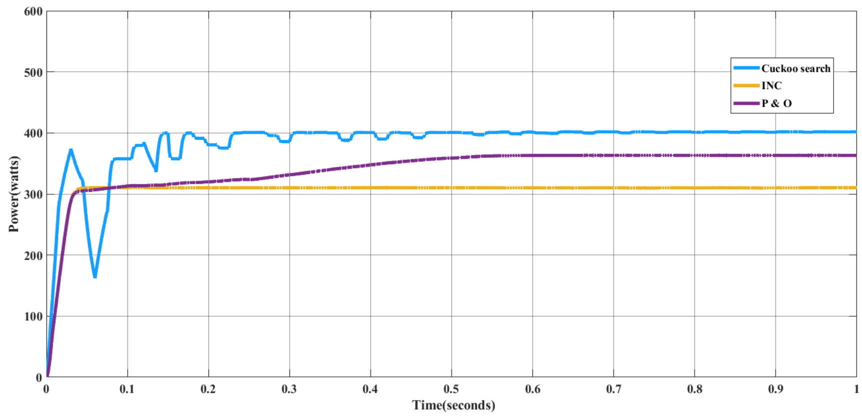

Figure 12. Simulation result of partial shading irradiance: Array [1000 700 500 500] W/m^2 at 25^{o}C temperature

From Table 7, it can be observed that P&O and INC methods fail to track the GMPP. But Cuckoo search successfully tracked the GMPP with efficiency 99.88% and settling time 0.5sec. P&O and INC tracked LMPP with settling time 0.032sec and 0.03sec respectively.

Table 7. Comparisons for partial shading: Array [1000 700 500 500] W/m^2 irradiance at 25^{o}C temperature

Algorithm	**PV Module Output (W)**	**Converter output(W)**	**Efficiency %**	**Settling time**
P&O	537.6	319(LMPP)	59.33	0.032
INC	537.6	310.5(LMPP)	57.77	0.03
Cuckoo Search	537.6	537(GMPP)	99.88	0.5

4.3 Case study-3: Simulation result of partial shading at an array of [500 1000 800 1000] W/m^2 at 25^{o}C temperature for Cuckoo search, Incremental conductance and P&O algorithms are shown in Figure 13. Their respective comparisons are given in Table 8.

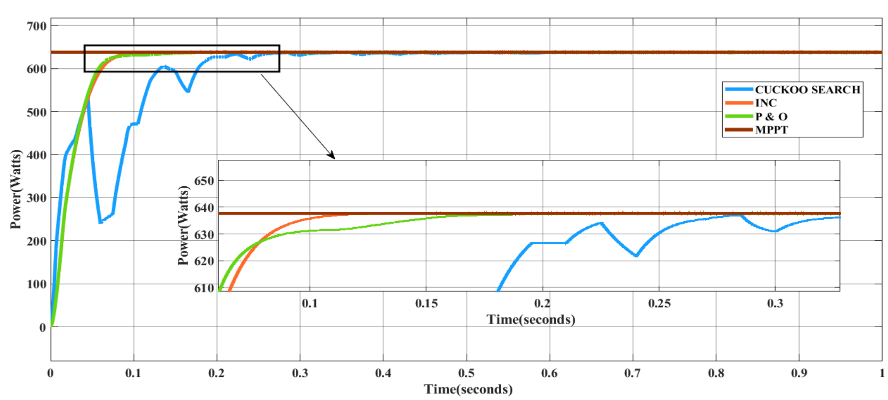

Figure 13. Simulation result of Partial shading: Array [500 1000 800 1000] W/m^2 irradiance at 25^{o}C temperature

From Table 8, it can be observed that P&O and INC methods tracked the GMPP in this partial shading because of initial duty cycle selection. Cuckoo search also tracked the GMPP with efficiency 99.79% and settling time 0.25sec. P&O and INC tracked GMPP with settling time 0.07sec and 0.065sec respectively. P&O and INC methods fail to track the GMPP in some partial shading conditions but Cuckoo search method tracks the GMPP in all shading conditions.

Table 8. Comparisons for partial shading: Array [500 1000 800 1000] W/m^2 irradiance at 25^{o}C temperature

Algorithm	**PV Module Output (W)**	**Converter output(W)**	**Efficiency %**	**Settling time**
P&O	637.8	637.5	99.9	0.07
INC	637.8	637.5	99.9	0.065
Cuckoo Search	637.8	636.5	99.79	0.25

5. Conclusions

In this paper, the analysis of various MPPT algorithms performance on solar PV system under various irradiances has been done. The MPPT algorithms considered are Perturb and Observe, Incremental Conductance, Fuzzy logic and Cuckoo search. From the results, it can be noted that under uniform and dynamic irradiance cases the Fuzzy logic based MPPT method gives greater efficiency than P&O and INC algorithms. But Fuzzy logic includes complexity as the number of membership functions increases. So, Fuzzy logic MPPT method is limited only to uniform irradiance and dynamic irradiance change cases. Under partial shading conditions Cuckoo search algorithm has been considered for the global maximum power tracking. The results are compared using incremental conductance and P & O MPPT algorithms. Cuckoo search algorithm successfully track global maximum power point under all partial shading conditions. Also it could give better performance when used in conjunction with the conventional algorithms.

Nomenclature

i-v	Current Vs Voltage
p-v	Power Vs Voltage
I_{PV}	Photo Current (A)
I_r	Diode reverse current (A)
I_t	Terminal Current (A)
V_t	Terminal Voltage (V)
$V_{t, cell}$	Thermal Voltage (V)
R_s	Series Resistance (ohms)
R_{sh}	Shunt Resistance (ohms)
N_s	Series connected modules
N_p	Parallel connected modules
I_o	PV array terminal Current (A)
V_o	PV array terminal Voltage (V)
V_{oc}	Open circuit voltage (V)
V_{MPP}	Voltage at MPP (V)
I_{MPP}	Current at MPP (A)
I_{sc}	Short-circuit Current (A)
V_s	PV output voltage (V)
T	Time period of complete cycle (t)
T_{off}	Off time period (t)
T_{ON}	ON time period (t)
V_L	Inductor Voltage (V)
V_C	Voltage across capacitor (V)

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