Performance Comparison of Various Maximum Power Point Tracking Techniques for Solar PV Systems

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Abstract* – The increasing demand for electrical energy, driven by rapid technological growth, population rise, and high fuel prices has accelerated investments in renewable energy, particularly solar power. However, solar PV systems suffer from efficiency since losses due to variations in solar irradiation and temperature resulting in nonlinear electrical characteristics. To enhance efficiency of solar PV systems various Maximum Power Point Tracking (MPPT) techniques are employed by researchers to optimize power extraction from PV systems. This work investigates the tracking performance of various MPPT algorithms that includes Perturb and Observe (P&O), Incremental Conductance, Cuckoo Search Optimization and Fuzzy Logic Controller. The MATLAB/Simulink simulations are utilized to evaluate and compare these techniques in managing the duty cycle of a DC-DC boost converter for maximum power extraction of solar PV systems.

Keywords – ***Solar PV system, Maximum Power Point Tracking, Perturb and Observe, Incremental Conductance, Cuckoo Search Optimization.***

1. INTRODUCTION

Renewable energy, or "green energy," utilizes naturally replenished resources like sunlight, wind, water, and geothermal heat, offering a sustainable alternative to fossil fuels and contributing to a cleaner, more secure energy future. Solar energy is significant as a clean, renewable, and sustainable energy source, crucial for reducing our reliance on fossil fuels, mitigating climate change, and fostering sustainable development. The global energy landscape is undergoing a transformative shift toward renewable energy sources to meet the ever-increasing demand for electricity. This shift is driven by rapid technological advancements, population growth, and rising fuel costs associated with conventional energy production. Among renewable energy sources, solar photovoltaic (PV) systems have emerged as a promising and sustainable solution due to their ability to harness abundant solar energy. However, the efficiency of solar PV systems is significantly influenced by environmental factors such as solar irradiation intensity and temperature variations, leading to nonlinear electrical characteristics and reduced energy conversion efficiency.

To overcome these challenges, researchers have developed various Maximum Power Point Tracking (MPPT) techniques to maximize the energy extracted from solar panels under the Maximum Power Point (MPP) under varying environmental conditions and to determine the most suitable MPPT technique for enhancing the efficiency of solar PV systems varying atmospheric conditions. MPPT technology ensures optimal power utilization by dynamically adjusting the operating point of the PV system. Several MPPT algorithms have been proposed and studied, including conventional methods such as Perturb and Observe (P&O) and Incremental Conductance (IC), as well as advanced techniques like Cuckoo Search Optimization and Fuzzy Logic Control (FLC). These algorithms play a crucial role in improving the efficiency of PV systems by optimizing the duty cycle of DC-DC boost converters, which regulate the power flow from the PV module to the load.

This paper focuses on analysing and comparing the performance of different MPPT techniques using MATLAB/Simulink simulations. The objective is to evaluate the effectiveness of each method in MPPT.

2. SYSTEM DESCRIPTION

2.1 Characteristics of Solar PV Panel- Solar photovoltaic (PV) panels, also known as solar panels, are devices that convert sunlight directly into electricity using the photovoltaic effect, a phenomenon where certain materials generate an electric current when exposed to light. Solar PV panels are made up of photovoltaic (PV) cells, which are semiconductor materials that, when exposed to sunlight, release electrons, creating an electric current. When sunlight hits a PV cell, the light energy is absorbed by the semiconductor material, causing electrons to become energized and move, generating an electrical current. Solar panels are often arranged in groups called arrays or systems, which also include an inverter to convert the direct current (DC) electricity produced by the panels into alternating current (AC) electricity, which is the type of electricity used in homes and businesses. Solar PV panels, also known as photovoltaic panels, convert sunlight into electricity through the photovoltaic effect, and their key characteristics include efficiency, durability, portability, and cost-effectiveness, with applications ranging from residential to large-scale power generation.

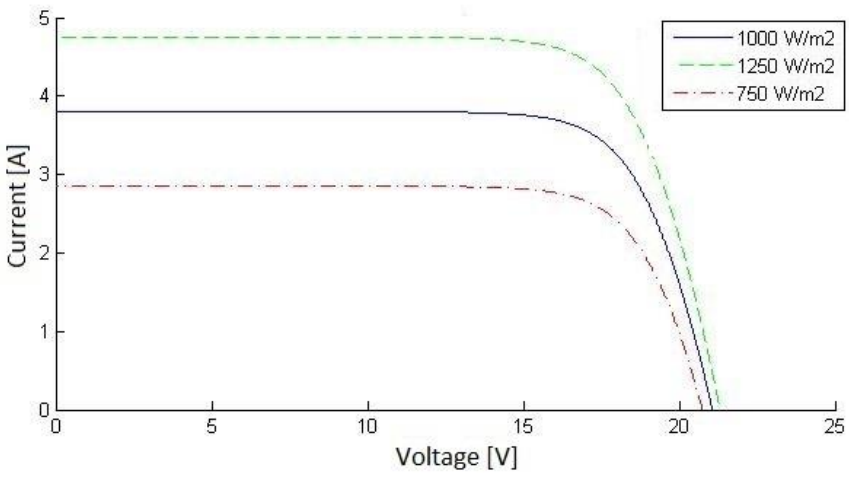

Fig. 1: I-V Characteristics of Solar PV Panel.

2.2 Boost Converter- The boost converter is designed to step up a fluctuating solar panel voltage to a higher constant DC voltage. It uses voltage feedback to keep the output voltage constant. The formula for a boost converter's output voltage (V_o) in relation to the input voltage (V_i) is:

$$Vo=Vi/(1-D)$$

In this formula, D is the duty cycle, which the value between 0 and 100%.

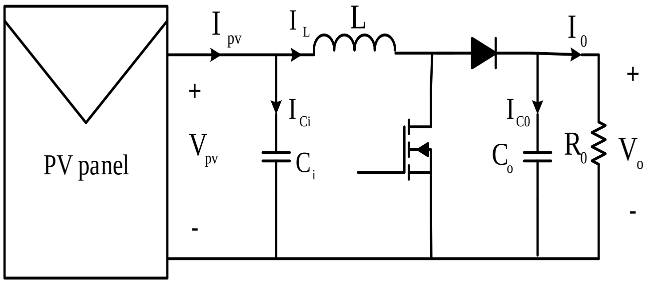

Fig. 2: Boost Converter with PV panel as input source

2.3 Perturb and Observe Algorithm- The Perturb and Observe (P&O) algorithm, a common MPPT method, works by perturbing the operating voltage of a photovoltaic (PV) system and observing the resulting power output, adjusting the voltage based on whether power increased or decreased.

Table 1: P&O algorithm functioning

ΔPpv	**ΔVpv**	**D**
<0	<0	Decrease
<0	>0	Increase
>0	<0	Increase
>0	>0	Decrease

2.4 Incremental Conductance (IC) Algorithm- For photovoltaic systems, using the relationship between instantaneous and incremental conductance to efficiently track the maximum power point under various conditions. The incremental conductance method leverages the principle that at the MPP, the slope of the power-voltage (P-V) curve is zero (dP/dV = 0).

Table 2: IC algorithm functioning

$\Delta V_{pv} = 0$		$\Delta V_{pv} \neq 0$	
ΔI_{pv}	D	$\Delta I_{pv} / \Delta V_{pv}$	D
=0	No change	$= - (I_{pv}/V_{pv})$	No change
>0	Decrease	$> - (I_{pv}/V_{pv})$	Decrease
<0	Increase	$< - (I_{pv}/V_{pv})$	Increase

2.5 Cuckoo Search Optimization- The Cuckoo Search algorithm is a recently developed meta-heuristic optimization algorithm, which is used for solving optimization problems. This is a nature-inspired meta-heuristic algorithm, which is based on the brood parasitism of some cuckoo species.

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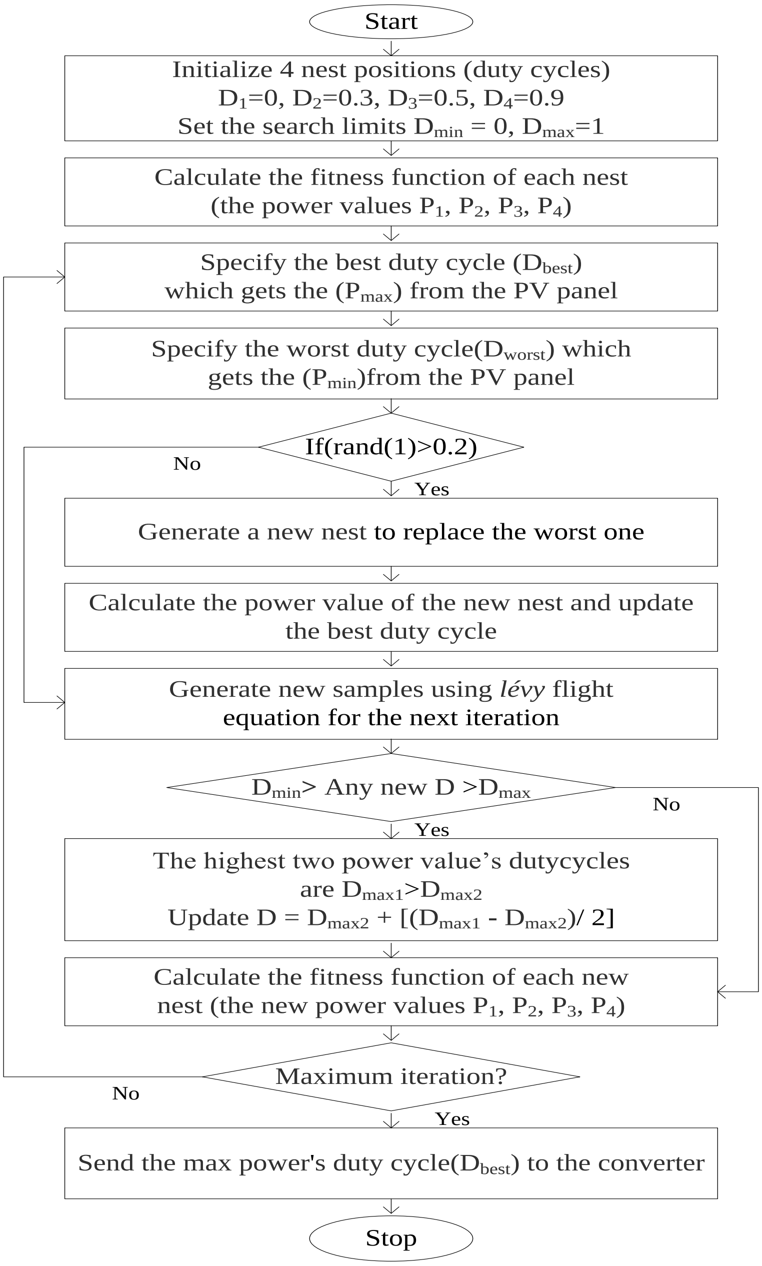

Fig. 3: Flowchart of Cuckoo Search Optimization.

3. METHODOLOGY

3.1 Maximum Power Point Tracking- MPPT is an algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called maximum power point (or peak power voltage). Maximum Power Point Tracking is a technology used in solar power systems to maximize the efficiency of PV panels. MPPT systems adjust the operating point of the solar panels to ensure they operate at their maximum power output, even with changing sunlight intensity and temperature conditions.

A typical simulation diagram for an MPPT system in a photovoltaic (PV) application includes a PV array, a DC/DC converter, and an MPPT controller. The PV array provides the DC power, the

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DC/DC converter adjusts the voltage and current to match the load, and the MPPT controller optimizes the voltage and current settings to maximize power extraction.

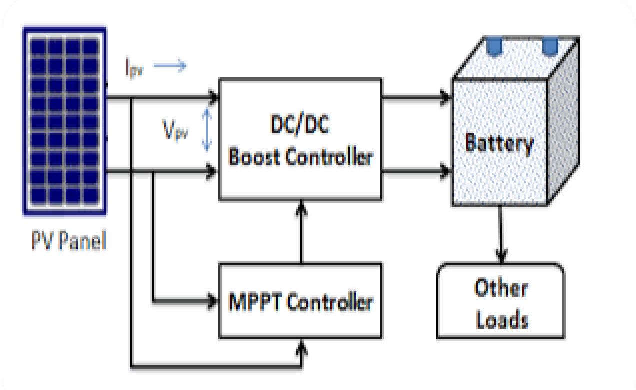

Fig. 4: Block Diagram of Maximum Power Point Tracking

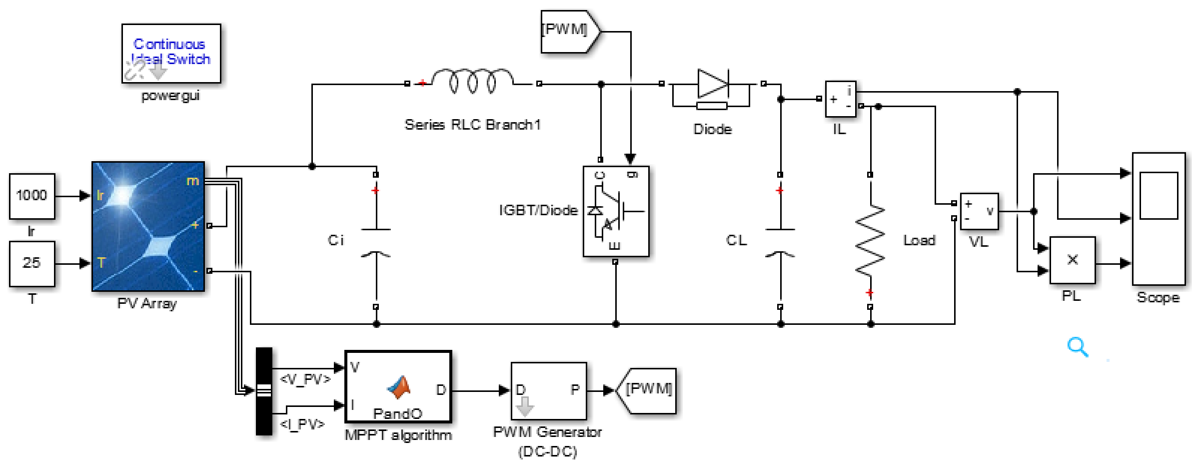

Fig. 5: Simulation Diagram of MPPT in MATLAB-Simulink environment.

4. SIMULATION RESULTS AND DISCUSSIONS

The simulation has been carried in Matlab/Simulink environment at 1000w/m² solar radiation and 25 °C temperature. The simulation parameters used in this study are,

- Maximum Power, P = 444.86 W
  - Number of series connected solar PV panels = 5
  - Number of parallel connected solar PV panels = 1349
- Open circuit voltage, V_{oc} = 90.5 V
- Short circuit current, I_{sc} = 6.21 A
- Voltage at maximum power point, V_{mp} = 76.6 V
- Current at maximum power point, I_{mp} = 5.8 A

4.1 P&O Algorithm

The simulation results i.e voltage, current and power responses of MPPT with P&O algorithm has been shown in fig. 6. From the results it is observed that P&O algorithm exhibits continuous oscillations in steady state which is the major drawback of P&O algorithm.

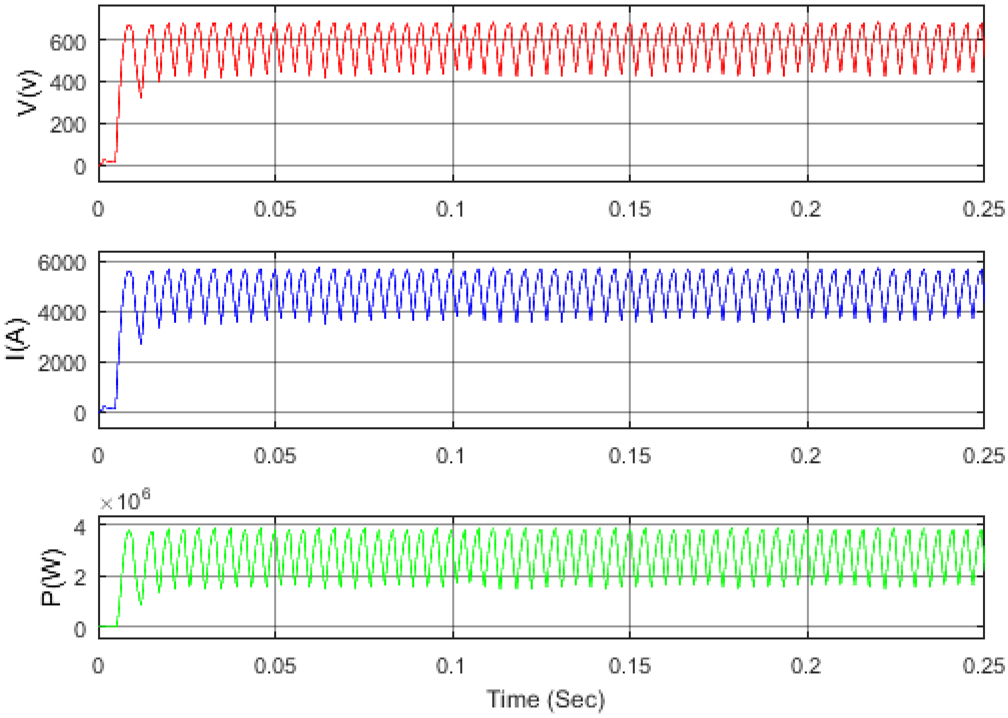

Fig. 6: Voltage, current and power MPPT responses with P&O Algorithm.

4.2 IC Algorithm

The simulation results i.e voltage, current and power responses of MPPT with IC algorithm is shown in Fig. 7. From these results it observed that IC algorithm also exhibits continuous oscillations just like P&O algorithm with a decrement in magnitude of oscillation.

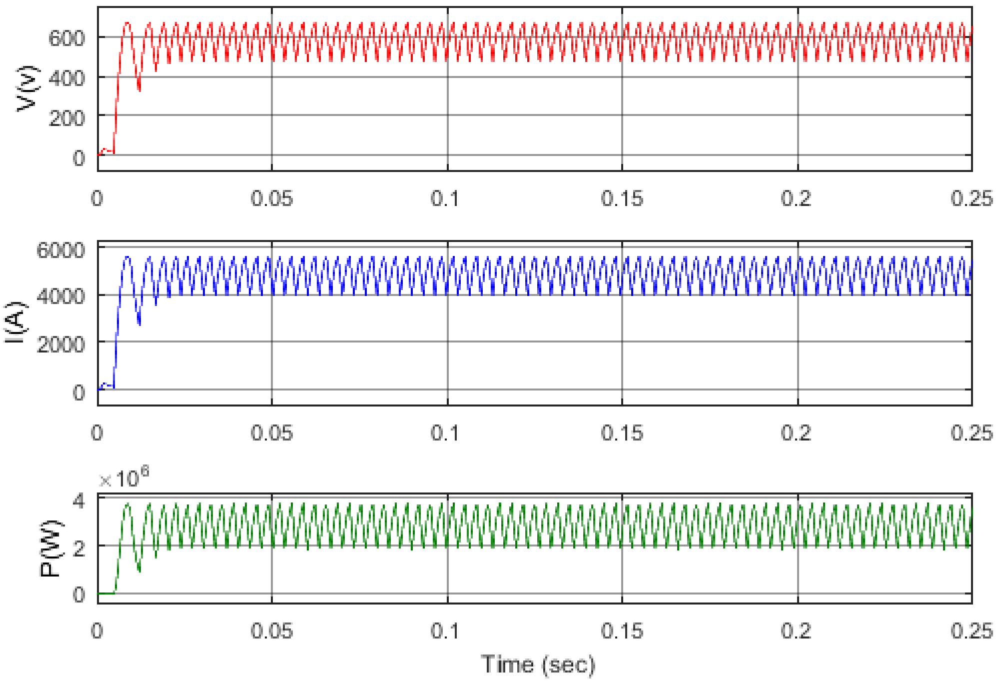

Fig. 7: Voltage, current and power MPPT responses with IC Algorithm.

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4.3 CS Algorithm

The simulation results i.e voltage, current and power responses of MPPT with CS algorithm is shown in below Fig. 8. From these results it observed that the CS algorithm exhibits oscillations in transient state which are gradually decreasing and finally settled in steady state without any oscillations.

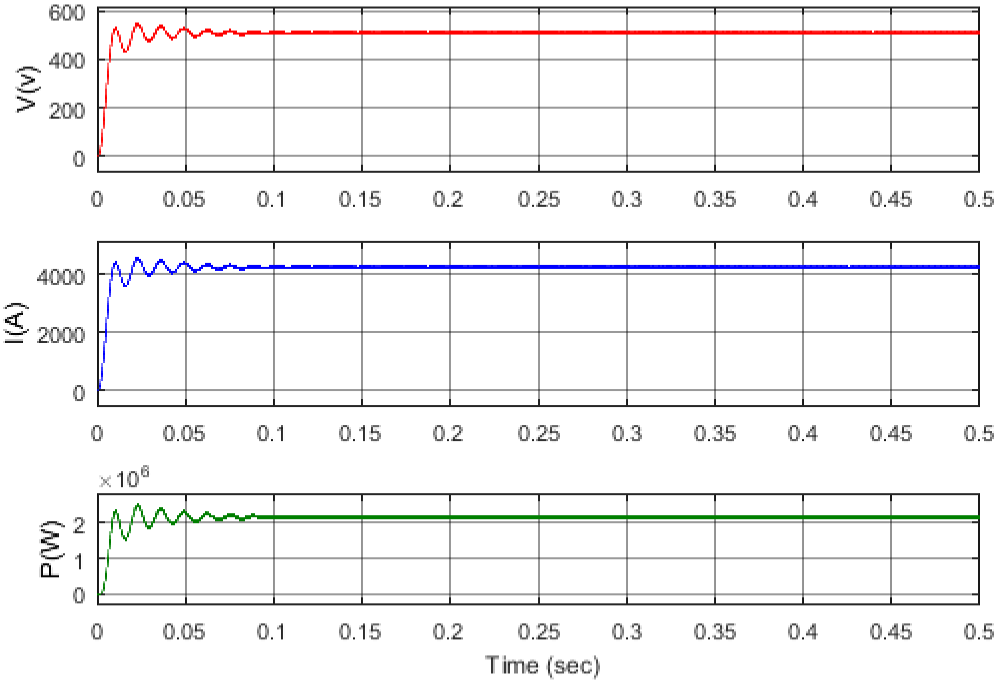

Fig. 8: Voltage, current and power MPPT responses with CS Algorithm

4.4 Comparative Analysis

The MPP tracking performance of P&O, IC and CS methods for the considered PV system has been compared graphically in Fig.8. It is observed that P&O algorithm exhibited oscillations with larger magnitude compared to the IC algorithm in steady state conditions. The CS algorithm tracks MPP of the solar PV system with minor oscillations in transient state.

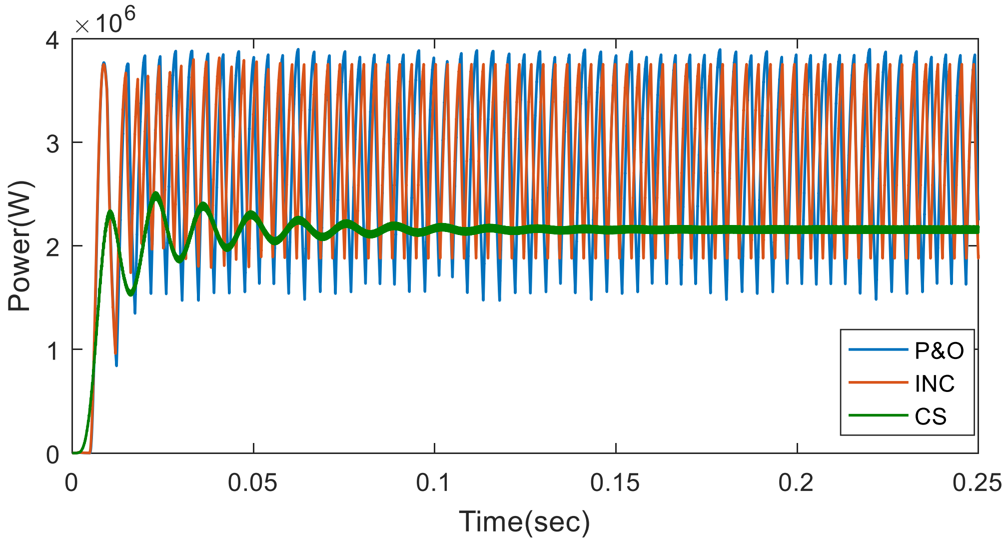

Fig. 8: MPPT power response comparison with P&O, IC and CS Algorithms.

5. CONCLUSION

In this paper, the Maximum Power Point Tracking performance of conventional Perturb & Observe and Incremental Conductance algorithms are compared with the optimization based Cuckoo Search algorithm for a Solar PV system at a solar radiation of 1000 w/m^2 and 25 ºC in the Matlab/Simulink environment. From the simulation results it is evident that the P&O algorithm exhibits more oscillations compared to the IC algorithm in steady state conditions. The CS algorithm tracks the solar PV system's MPP with slight fluctuations in the transient state.

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