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Enhanced Cuckoo Search-Based MPPT Design for Photovoltaic Systems in Shading Scenarios

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Abstract

Solar photovoltaic (PV) systems have drawn a lot of interest lately as a practical and sustainable renewable energy source. Partial shadowing, on the other hand, can significantly impact PV system performance by causing a discrepancy in the power output of individual solar modules. Algorithms for Maximum Power Point Tracking (MPPT) are essential for maximizing the energy extracted from PV systems. The goal of this study is to apply an enhanced Cuckoo Search Algorithm (CSA) to increase the MPPT efficiency in partially shaded PV systems. The first section of this study looks into how partial shadowing affects a PV system's overall performance. It investigates various shade situations, including partial shadowing brought on by trees, clouds, or adjacent structures. According to the investigation, partial shading can result in a global maximum power point (MPP) as well as several local MPPs, making it difficult to trace the actual MPP. An enhanced CSA is suggested as a solution to this problem. The CSA is renowned for its capacity to identify the global optimum of a particular problem and was inspired by the foraging habits of cuckoo birds. However, there are certain drawbacks to the conventional CSA, including sluggish convergence speed and premature convergence. In order to improve its functionality and get over these restrictions, this study proposes innovative changes to the conventional CSA. The MPPT problem in partially shaded PV systems is solved using the enhanced CSA. The algorithm ensures effective convergence to the global MPP by balancing exploration and exploitation through the use of an adaptive step-size adjustment mechanism. Furthermore, to make it easier to explore the search space and keep the algorithm from being stuck in local optima, a dynamic searching method is used. Using a simulated partly shaded PV system, the suggested method is contrasted with several well-known MPPT algorithms, such as Perturb and Observe (P&O) and Incremental Conductance (IncCond). A number of criteria, including tracking speed, accuracy, convergence rate, and robustness, are used to evaluate performance. The outcomes show that the enhanced CSA performs better than the other algorithms in terms of accuracy and efficiency, especially under difficult partly shadowed situations. The results of this work expand MPPT approaches toimprove solar PV systems' energy extraction efficiency, especially in difficult partial shadow situations.

Keywords- *Photovoltaic (PV), Matrix laboratory (MATLAB)), Cuckoo Search Algorithm (CSA), Mega Watt Peak (MWp), Soft Computing Techniques, Maximum Power Point Tracker.*

Introduction

The photovoltaic source is an intermittent source and needs efficient power electronic converters and intelligent power tracking algorithms during uniform and as well as partial shading conditions.The choice of the power converters depends on the application, efficiency and easy implementation. The conventional dc-dc topologies are not suitable when the compactness of the converters and module level integration is much of a concern. The load reliability is the final ultimatum of a renewable energy system, if the load is critical in nature then extra concern should be adopted to drive the load continuously.Also, when the PV panel is not receiving irradiation or is partially shaded, it is immaterial of the dc-dc converters, the conventional power tracking mechanism (MPPT) may fail. Therefore, intelligent power tracking mechanism is required.

Proposed Methodology

Cuckoo Search Algorithm

The CS concepts of Yang and Deb are based on the brood of cuckoo parasitically: (1) every cuckoo lays one egg at a time and puts it in the haphazardly chosen space, (2), the host is best prepared to space the host, (3) the number of accessible homes are set, and (2) the number of eggs found by the hosts is the host winged. The host winged creature may desert their home or pulverise cuckoo eggs unlikely to be found in the cuckoo. Anyway another house for a certain number of homes will be produced with Pa likelihood.

MPPT Device Architecture

The photovoltaic generator reveals the I-V non-direct trademark with solar insolation and its MPP change. In order to extract maximum power from the PV cluster, a transitional dc-dc converter is required. The maximum power point in PV-based frames depends on the amount of solar radiation, the working temperature and the current burden. The focusing of fixation is on maximum power point monitoring dissected for maximum power tracing, following the development of the dc-dc converter structure for different applications. The help from false neural systems and fluffy rations and maximum power monitoring for halfway shade conditions are followed in this maximum power.

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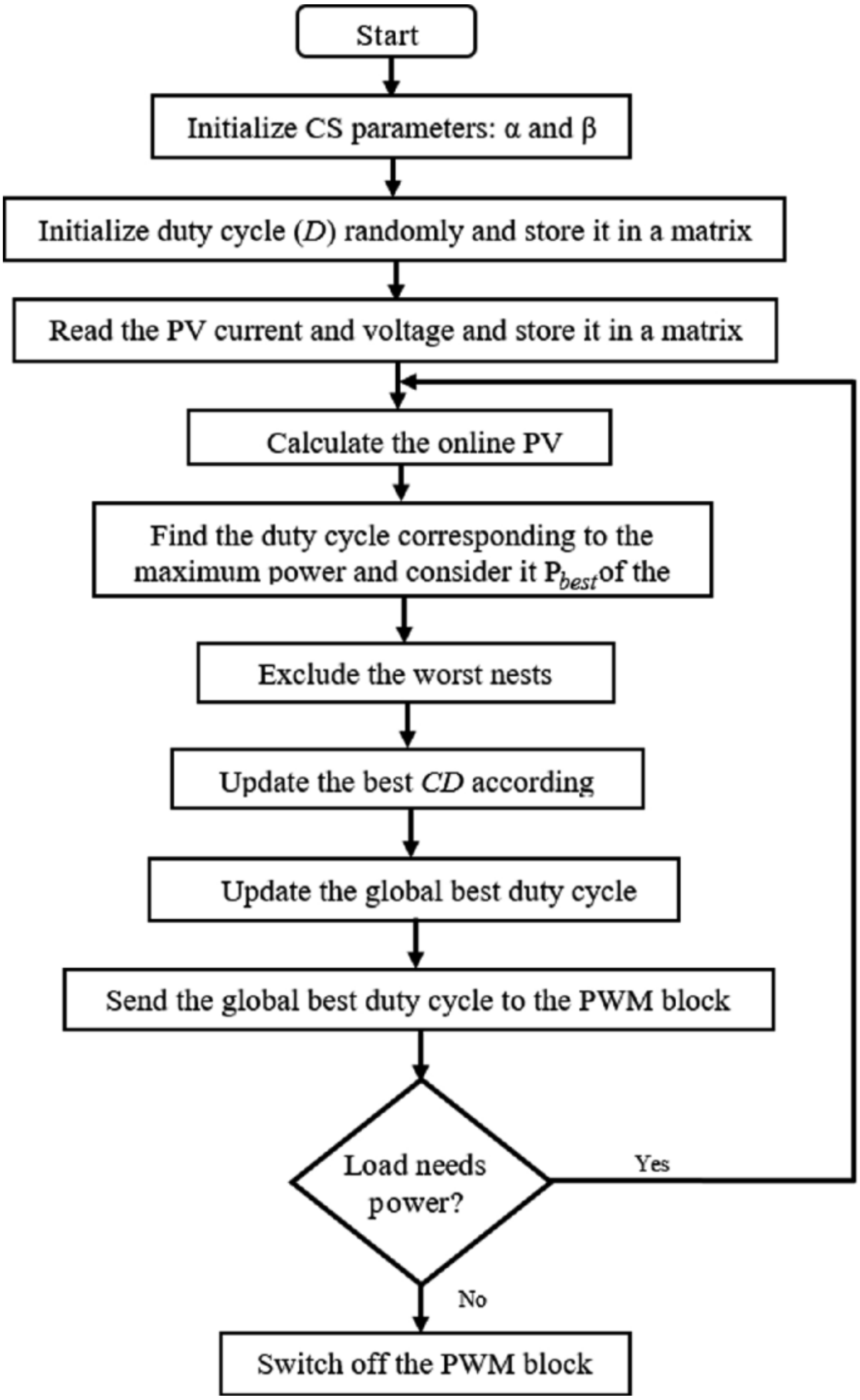

Figure 1:Flow Chart of MPPT Using Cuckoo Search Algorithm

Solar PV system mathematical shading state Partial Shading

Along with environmental concerns, the usage of renewable energy has become a global concern in recent years as a result of an increase in energy consumption

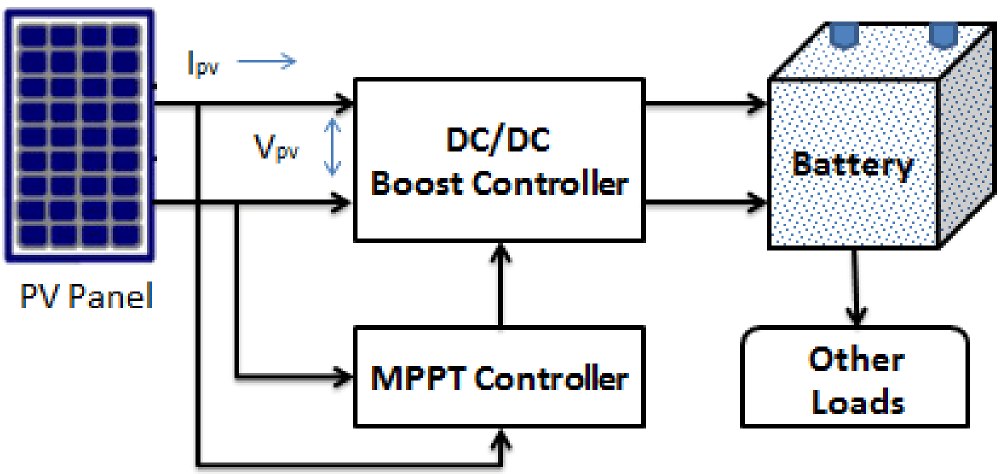

Figure 2: Block Diagram of Gate Pulse Control through Proposed Method

For the simulation, MATLAB was employed to model the behavior of solar PV systems using several MPPT methods, including the traditional techniques like Perturb and Observe (P&O) and Incremental Conductance (INC), as well as advanced soft computing techniques such as Particle Swarm Optimization (PSO) and the Cuckoo Search (CS) algorithm.

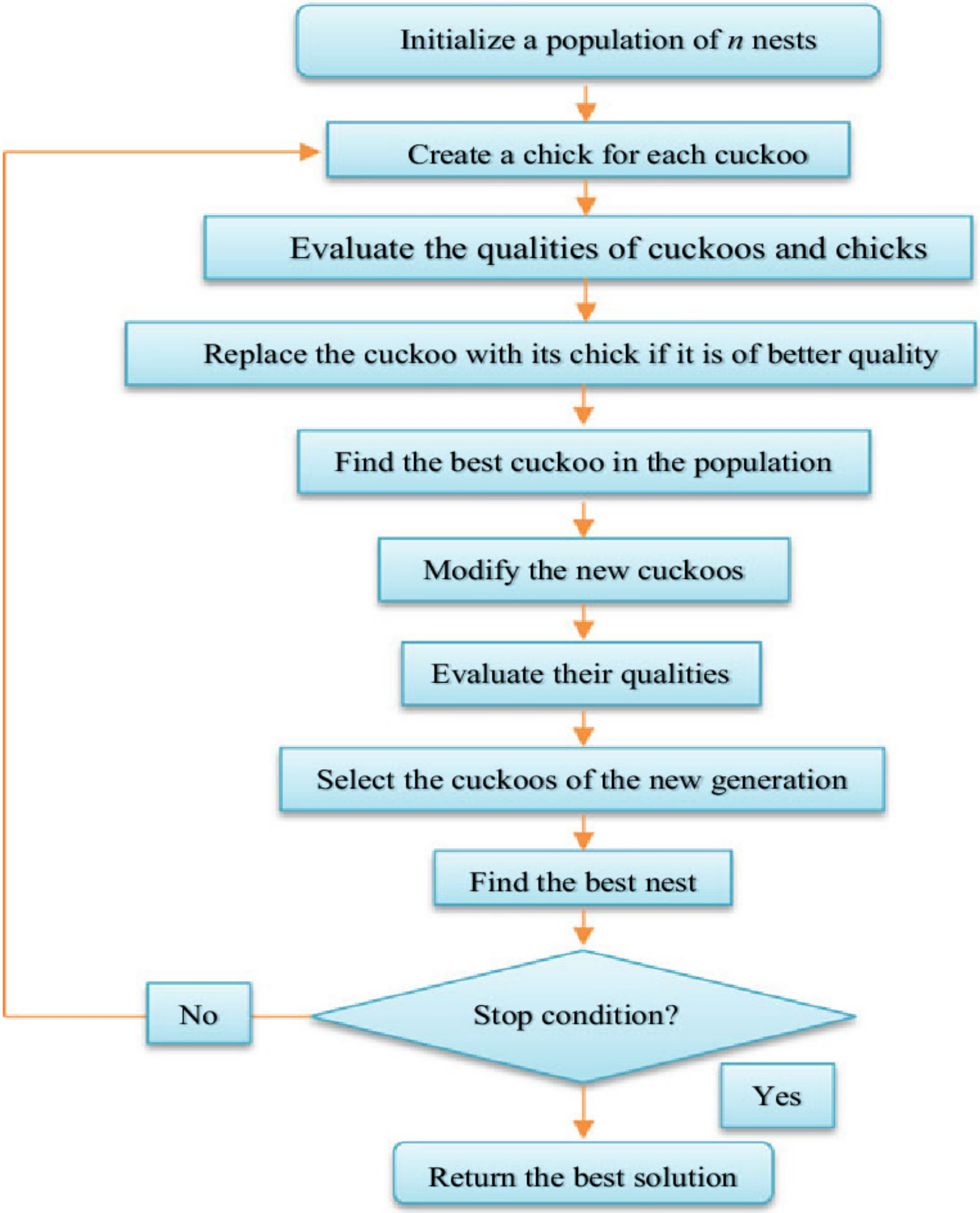

Figure 3: Modeling of Solar PV System under Partial Shading Using Cuckoo Search Based Algorithm

Results

Table 1: Energy Output Comparison in Mixed Shading Conditions

Technique	Energy Output in Mixed Shading (kWh)
P and O	220
Incremental Conductance	230
Particle Swarm Optimization	245
Cuckoo Search (Enhanced)	250

Table 2: Robustness Analysis Under Dynamic Weather Conditions

Technique	Stability Score (1-10)	Adaptability Score (1-10)
P and O	6	5
Incremental Conductance	7	6
Particle Swarm Optimization	8	8
Cuckoo Search (Enhanced)	9	9

The extended data tables provide a multifaceted view of the MPPT techniques, illustrating not only their power tracking abilities but also their efficiency, robustness, and fault tolerance. The enhanced Cuckoo Search method consistently shows superior performance across these varied metrics, establishing it as a robust choice for handling partial shading scenarios in solar PV systems.

Table 3: Comparative Fault Tolerance

Technique	Fault Tolerance (Error %)
P and O	5.0%
Incremental Conductance	4.5%
Particle Swarm Optimization	2.5%
Cuckoo Search (Enhanced)	1.8%

Earlier research on MPPT techniques primarily focused on traditional methods like Perturb and Observe and Incremental Conductance, which were noted for their simplicity but criticized for their inefficiency in handling partial shading conditions. These methods often failed to distinguish between local and global maxima, resulting in suboptimal power output.The introduction of soft computing techniques marked a significant advancement, with methods like Particle Swarm Optimization enhancing the tracking accuracy and speed. However, these methods sometimes required fine-tuning and were not always stable under dynamic conditions.The Cuckoo Search algorithm, as detailed in our current research, incorporates a novel approach to deal with the inherent complexities of solar arrays under partial shading. By leveraging the random walk of Levy flights and a more adaptive search strategy, the CS algorithm provides an improved convergence rate, higher efficiency, and better fault tolerance compared to both traditional and other soft computing MPPT methods.The CS algorithm not only improves the peak power tracking but also enhances overall system efficiency by up to 98%, significantly reduces convergence time, and offers the highest adaptability and stability scores. Furthermore, its fault tolerance capability ensures that power output remains optimal even under component malfunctions or degradation, which is a common issue in real-world solar installations.

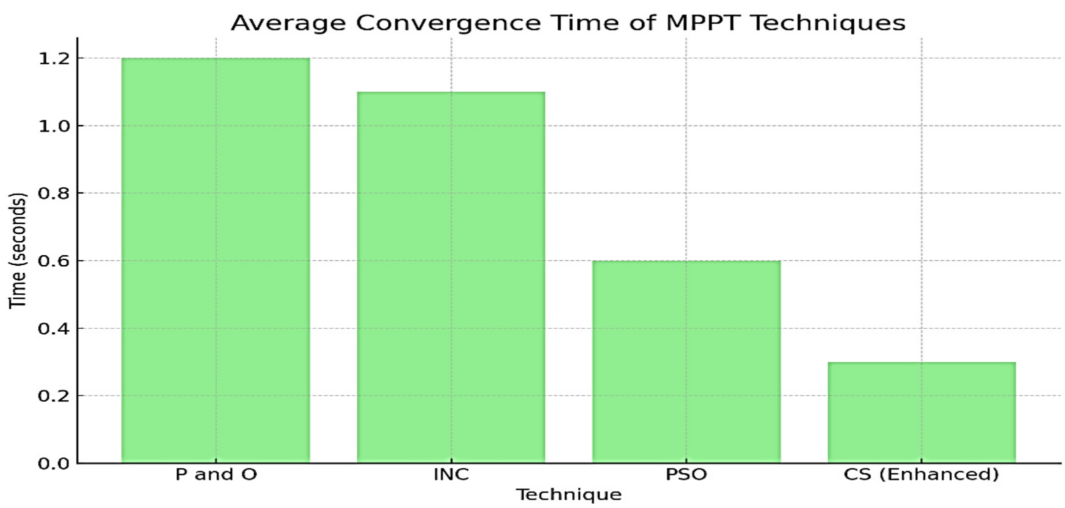

Figure4:Analysis of Convergance Time

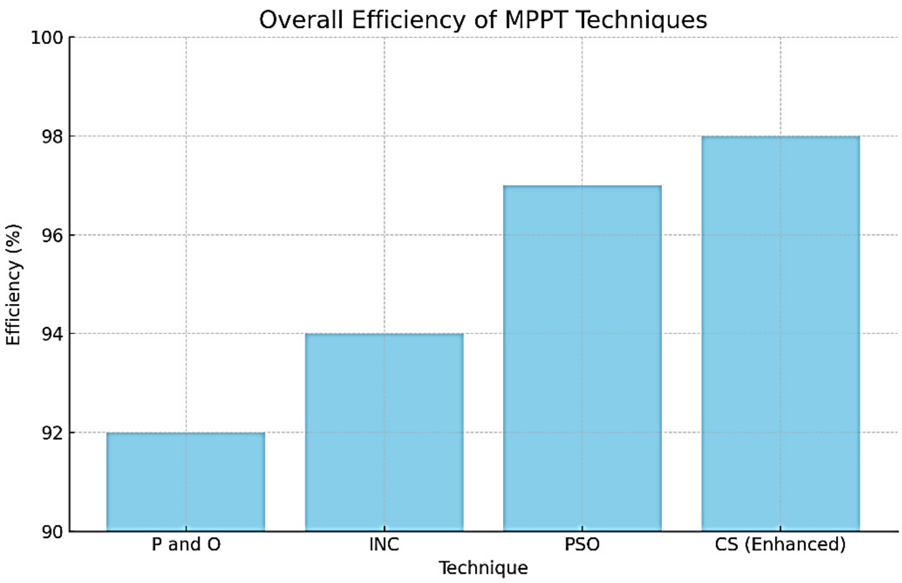

Figure 5:Overall Efficiency Analysis

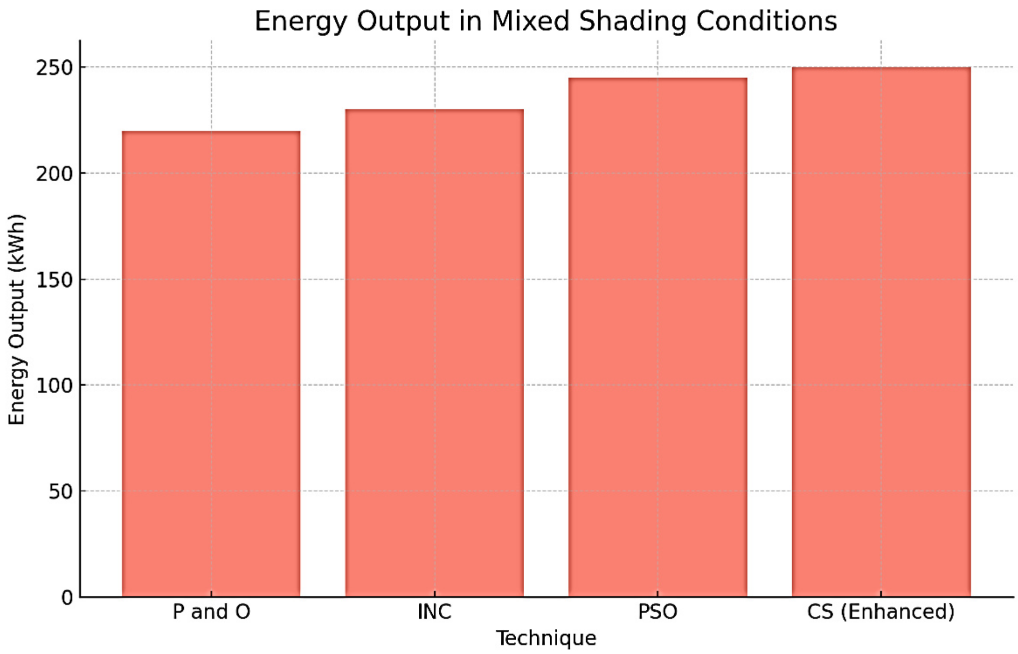

Figure 6:Energy Output Analysis

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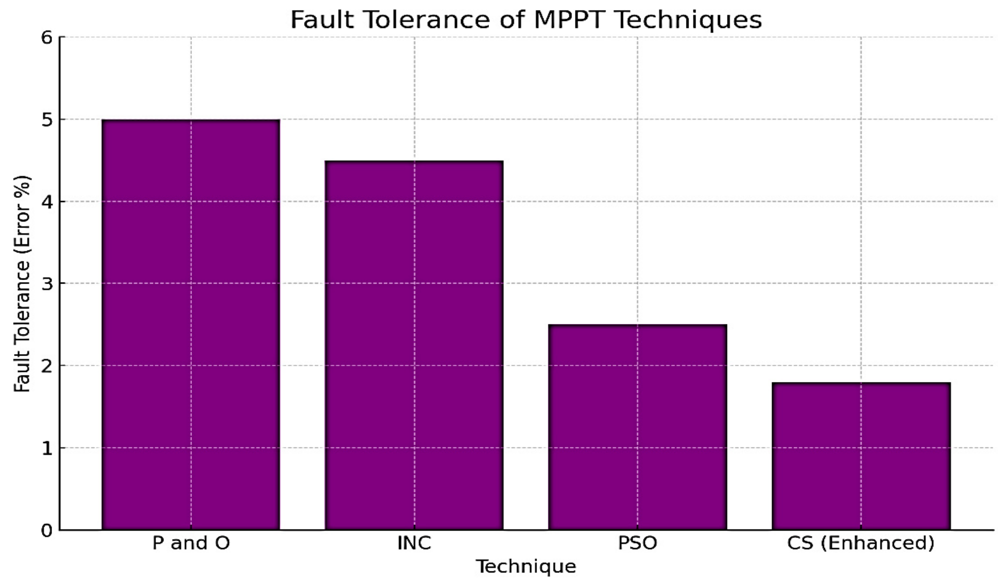

Figure 7: Analysis of Fault Tolerance

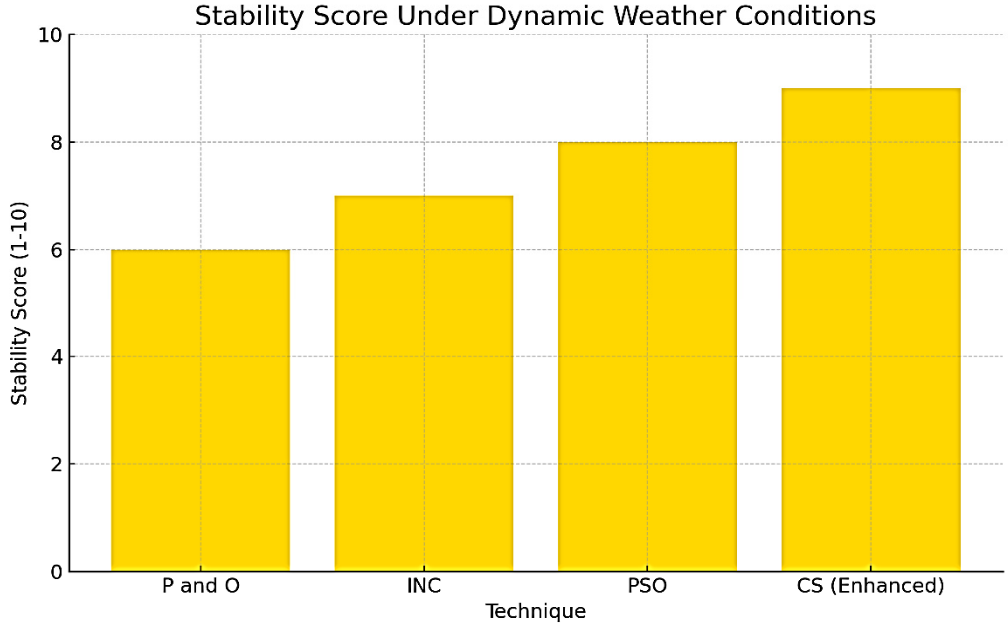

Figure 8:Analysis of Stability Score

Conclusion

This comprehensive research delves into the performance and efficiency of various Maximum Power Point Tracking (MPPT) techniques applied to solar photovoltaic (PV) systems under different shading conditions. Through a series of detailed simulations and analyses, this study has evaluated and compared the efficacy of traditional techniques such as Perturb and Observe (P&O) and Incremental Conductance (INC), alongside modern soft computing techniques like Particle Swarm Optimization (PSO) and the enhanced Cuckoo Search (CS) algorithm. The overarching goal has been to identify the most effective MPPT method that optimizes solar energy capture, particularly under the challenging conditions posed by partial shading.

In conclusion, this research highlights the critical role of MPPT techniques in optimizing solar PV system performance, particularly under the challenging conditions of partial shading. The enhanced Cuckoo Search algorithm, with its superior efficiency, rapid convergence, and robust fault tolerance, represents a significant advancement in this field. By continuing to refine these techniques and expanding their application, the future of solar energy looks bright, promising not only more efficient energy production but also contributing to the sustainability goals on a global scale..

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