Enhancing Solar PV Energy Generation: Investigating a Versatile DS Control Method for Single-Stage Systems Integrated with Three-Phase Grid

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Abstract: This study examines how photovoltaic (PV) systems operate when exposed to various levels of radiation and non-linear loads. The hybrid approach, which combines the Perturb and Observe algorithm with the Cuckoo Search Algorithm, was used to analyze two systems, System 1 and System 2. In Case 1, both systems displayed consistent voltage outputs and low total harmonic distortion (THD%) with a continuous irradiation input of 1000W/m2. Compared to System 1, System 2 displayed greater performance and a lower THD%. In Case 2, both systems displayed stability and changing THD% levels with an irradiation input that ranged from 500W/m2 to 1000W/m2. These insights help us comprehend how PV systems behave and function in various operational environments

Keywords: Biodiesel, photovoltaic systems, irradiation levels, non-linear loads, Perturb and Observe algorithm, Cuckoo Search Algorithm,

I. INTRODUCTION

Solar photovoltaic (PV) systems have emerged as a very promising option for producing power in response to the growing global demand for environmentally acceptable and sustainable energy sources. These technologies directly transform the sun's plentiful energy into useful electrical energy. In order to reduce greenhouse gas emissions and support the switch to clean, renewable energy sources, solar PV technology is essential. The idea behind solar photovoltaic (PV) systems is to use the photovoltaic effect, which includes turning sunlight directly into electricity. The solar panel, sometimes referred to as a photovoltaic module, is the brain of a solar PV system. These panels are made up of several linked solar cells made of silicon or another semiconductor material. These cells produce an electric current when sunlight strikes them, igniting the semiconductor material's electrons. The basis of solar PV technology is the direct conversion of sunlight into power. Solar PV systems are relevant in many sectors due to their adaptability. Since they enable homes to produce their own electricity and lessen their dependency on traditional grid-based power sources, they are commonly used in residential settings. Solar PV systems can be integrated into building structures or installed on rooftops in commercial and industrial settings to provide businesses with clean, affordable power. Additionally, utility-scale solar PV projects like solar parks and big solar farms provide a substantial contribution to the creation of renewable energy for the grid.

As a result of improvements in solar PV technology, which have boosted efficiency and lowered costs, these systems are now more widely used and deployed. The efficiency of solar cells in converting sunlight into energy has increased thanks to advancements in panel design, components, and manufacturing techniques. The overall output of solar PV systems will increase as more sunshine can be transformed into useful power. Solar PV systems have also become more dependable and robust thanks to improvements in installation techniques and system components, enabling longer lifespans and better performance. Government incentives, supportive laws, falling prices, and rising environmental consciousness are a few of the elements that are propelling the global expansion of solar PV systems. In order to meet their goals for renewable energy and cut carbon emissions, countries all over the world are aggressively supporting the installation of solar PV systems. As a result, solar PV has developed into one of the renewable energy technologies with the quickest rate of growth, and it is now playing a critical part in the shift to a more sustainable and clean energy future.

Advanced control strategies are necessary to optimize the performance and integration of solar PV systems with the current power grid.This study's goal is to create and assess a distributed sparse (DS) multipurpose control strategy for a single-stage solar PV energy generating system (SPEGS) connected to a three-phase grid. The SPEGS's performance, dependability, and adaptability are to be improved by the suggested control strategy, enabling efficient power generation and smooth grid integration.

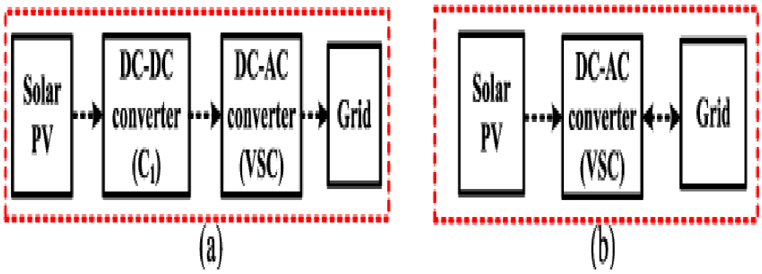

Figure 1 Single-Stage Solar PV Energy Generation System

In conventional PV systems, power output is typically maximized based on the level of instantaneous solar irradiation. These methods, however, might not fully utilize the system's capacity and neglect the needs of the grid and dynamic operational situations. These constraints are addressed by the multipurpose DS control approach in this study by offering improved functionality and adaptability. To enable effective and coordinated functioning of the SPEGS components, the distributed sparse control technique makes use of cutting-edge algorithms and communications technologies. The system can attain better response times, fault detection, and mitigation capabilities by adopting distributed control techniques. The sparse control system also optimizes resource use, allowing for effective voltage regulation and management of power flow.

II. RELATED WORK

Gebrehiwot et al. (2019) [1] has out a thorough investigation of the cost-benefit analysis and optimization of hybrid power systems for off-grid rural electrification in Ethiopia. Their research looked at the viability of combining diesel generators with renewable energy sources like solar and wind to offer dependable and sustainable access to electricity in rural locations. The study evaluated the technical and financial performance of several system configurations, taking into account elements including energy output, system dependability, and cost-effectiveness.

Murugaperumal et al. (2020) [2] Through load forecasting and various operation techniques, the best design of hybrid renewable energy systems for rural electrification was examined. The goal of their research was to create effective methods for creating hybrid systems that mix solar, wind, and other renewable energy sources. The study aims to improve the performance and cost-effectiveness of rural electrification systems by taking into account load forecasting techniques and assessing various operating strategies.

Dadkhah and Niroomand (2021)[3] presented a thorough analysis, classification, and comparison of optimization techniques for photovoltaic (PV) systems' maximum power point tracking (MPPT) parameters. The study investigated various MPPT algorithms and optimization methods to enhance the productivity and effectiveness of PV systems. The goal of the research was to provide direction for choosing and implementing the best MPPT strategies for PV systems by evaluating the advantages and disadvantages of various approaches.

Nkambule et al. (2021) [4] conducted a study on the thorough assessment of MPPT algorithms for PV systems using machine learning under various weather situations. The study's main objective was to evaluate how well machine learning-based MPPT algorithms captured the maximum power output from PV systems under various weather scenarios. The study sought to determine the most efficient machine learning algorithms for MPPT applications by taking into account elements including accuracy, robustness, and environmental change-adaptability.

Liu et al. (2019) [5] examined the supercapacitor energy storage unit (SCESU) and permanent magnet synchronous generator (PMSG)-based wind turbine generation system's high voltage ride-through control approach. The research concentrated on creating a control approach to improve the grid performance and stability of wind turbine systems based on PMSG during high voltage events. The study's integration of SCESU sought to increase wind turbines' ability to ride past obstacles and guarantee continuous power generation.

Giri et al. (2020) [6] performed analysis on voltage source converter (VSC) control for off-grid distributed power generating systems to improve power quality. In order to improve power quality metrics such voltage stability, harmonics reduction, and reactive power compensation, the study set out to design control algorithms for VSCs. The project aims to improve the overall performance and reliability of off-grid distributed power production systems by adopting advanced control techniques.

Xue (2015) [7] studied the idea of a comprehensive energy network or energy internet, which seeks to combine and optimize numerous energy infrastructures and resources. The study examined the advantages and disadvantages of developing a networked energy system that enables effective energy production, delivery, and use. The concept's ramifications for the energy industry's future were examined, along with how it can improve sustainability and dependability.

Wang et al. (2015) [8] used three-phase uncontrolled rectification chargers to investigate harmonic amplification in electric vehicle charging stations. The study's main objective was to evaluate the effects of harmonic distortions produced by charging systems on the grid's power quality. Through calculations and analysis, the study sought to shed light on the phenomenon of harmonic amplification and its consequences on the electrical grid, emphasizing the necessity of taking harmonics into account while designing and operating charging stations.

Kumar (2017) [9] gave a review of the issues, norms, and fixes related to power quality. The research reviewed the pertinent standards and recommendations for power quality management and attempted to give an overview of common power quality problems, such as voltage sags, harmonics, and voltage flicker. To ensure the dependable and effective operation of electrical systems, the study emphasized the importance of resolving power quality issues. It also looked at the various technologies and solutions available for power quality enhancement.

Tiwari and Tomar (2014)[10] completed a thorough literature assessment on Distribution Static Compensator (DSTATCOM)-based power quality improvement. The study concentrated on using the proprietary power device DSTATCOM to mitigate problems with voltage sag, swell, flicker, and harmonics. The report reviewed earlier studies and research, emphasized DSTATCOM's efficiency in enhancing power quality, and covered its operational and control procedures.

Khadse and Shriwastava (2016) [11] examined how a Distribution Static Compensator (DSTATCOM) based on a Voltage Source Converter (VSC) could improve voltage stability and power quality. The goal of the study was to use VSC-based DSTATCOM to increase voltage stability and reduce power quality issues in distribution systems. The study focused on the DSTATCOM's role in improving voltage stability and overall power quality in electrical networks while examining its operating characteristics and control methodologies.

Kumar and Babu (2015) [12] presented a study on the application of a three-leg Voltage Source Converter (VSC)-based Distribution Static Compensator (DSTATCOM) and a Zig-Zag transformer for a microgrid powered by diesel generators. The research centered on reducing voltage fluctuations, harmonics, and reactive power concerns in order to improve the power quality and stability of the microgrid. To increase the overall performance and dependability of the microgrid, the study suggested using the Zig-Zag transformer and three-leg VSC-based DSTATCOM as a control and compensation solution.

Dovgun et al. (2020) [13] For three-phase, four-wire low voltage networks, a distributed power quality conditioning system was designed. The study sought to address low voltage network power quality problems such as harmonics, imbalance, and voltage swings. The study suggested a decentralized method for real-time monitoring, analysis, and compensation of power quality issues using intelligent electronic devices and algorithms. The research centered on deploying distributed power conditioning systems to enhance the quality and stability of the power supply in low voltage networks.

III. METHODOLOGY

In this study, the performance of a solar photovoltaic (PV) energy generation system under two different circumstances was examined and analyzed. The software MATLAB, which offers a stable foundation for modeling and simulating complicated systems, was used for the implementation.

The Perturb and Observe (P&O) algorithm is the method that is most frequently employed to control the converter. The P&O algorithm continuously modifies the PV system's operating point while monitoring changes in output distortion reduction. The algorithm decides whether to raise or lower the operational point to get closer based on this observation. To decrease the harmonics produced by the nonlinear load, P&O and the Cuckoo Algorithm were used in this research project.

For solar photovoltaic (PV) systems, P&O (Perturb and Observe) is frequently utilized to regulate the converter parameters. It is made to continually modify the PV array's operating point in order to minimize distortions and fluctuations under a variety of environmental conditions in order to maximize the power output of a PV system.

The Cuckoo Search technique is an optimization technique that draws inspiration from nature and is based on the actions of cuckoo birds. In 2009, Xin-She Yang and Suash Deb made the suggestion. The algorithm mimics cuckoos' reproductive activity and their parasitic brood parasitism to solve optimization challenges.

A. Case 1 – Analysis of the energy system with constant irradiation input (1000W/m2)

Two alternative systems were subjected to an experiment with an irradiation level of 1000 W/m2 to evaluate how well they performed in real-world scenarios. System 1's converter system's voltage and current output were optimized using the Perturb and Observe technique. System 2 used the Cuckoo Search method in conjunction with the Perturb and Observe method. Additionally, the effect of a non-linear load on the system's performance and compliance was assessed, and variables like voltage, current, harmonic distortion, and the characteristics of the load line were examined.

B. Case 2 – Analysis of the energy system with variable irradiation input (500 -1000W/m2)

A larger range of irradiation values, from 0.5 W/m2 to 1000 W/m2, were examined in Case 2 of the research to examine the performance of two separate systems in various environmental settings. Perturb and Observe algorithm was used in system 1 to improve the converter system process, while a hybrid strategy combining Perturb and Observe algorithm and Cuckoo Search Algorithm was used in system 2 to improve the converter system process. By combining the advantages of the two methods, this hybridization intended to improve the system's capability to precisely track the maximum power point. To analyze different parameters and assess the system's performance, simulations were run. The study aims to investigate the system's flexibility and effectiveness under various irradiation levels and to offer suggestions for improving solar PV systems.

IV RESULT ANALYSIS

In two separate scenarios, the performance of the controller system utilized in solar photovoltaic (PV) energy generation systems was the focus of this study project. In Case 1, a solar PV system is subjected to an experiment with an irradiation level of 1000 W/m2 to evaluate its performance under actual circumstances. The converter system's voltage and current output is optimized using the Perturb and Observe algorithm and hybrid algorithm. The performance of both the systems using the Perturb and Observe algorithm and the Hybrid method is examined in Case 2, which covers a wider range of irradiation levels from 0.5 W/m2 to 1000 W/m2. A hybrid strategy is used by fusing the Perturb and Observe algorithm with the Cuckoo Search Algorithm to improve the converter system process. The performance of the system, including voltage, current, harmonic distortion, and load line characteristics, will be thoroughly examined throughout this chapter. The system's behavior and conformance with desired specifications and standards will be clarified through these discussions. The information gleaned from both examples will help advance our knowledge of and ability to use solar PV energy generation systems for a more environmentally friendly and long-lasting future.

A. Case 1: Analysis of the energy system with constant irradiation input (1000W/m2)

- **Solar Energy System having P&O Controlled converter system with PI regulators (System 1)**

To simulate the realistic solar energy incident on the PV panels in Case 1, a precise irradiation value of 1000 W/m2 was used. The goal was to assess the system's performance and behavior under actual operational circumstances. The PV system's power output was optimized using the Perturb and Observe (P&O) algorithm as the control method. The P&O method is frequently used to modify the PV array's operating point based on changes in current and voltage brought on by shifting environmental circumstances.

A non-linear load was added to the system to investigate its response to non-linear loads. Electrical signals from non-linear loads may become distorted and harmonic, which could have an impact on the system's effectiveness. The purpose of including a non-linear load was to assess its impact on various facets of the system's operation. Voltage, current, harmonic distortion, and the characteristics of the load line were measured and examined. These variables are crucial in evaluating the system's performance and figuring out whether it complies with the desired requirements and standards.

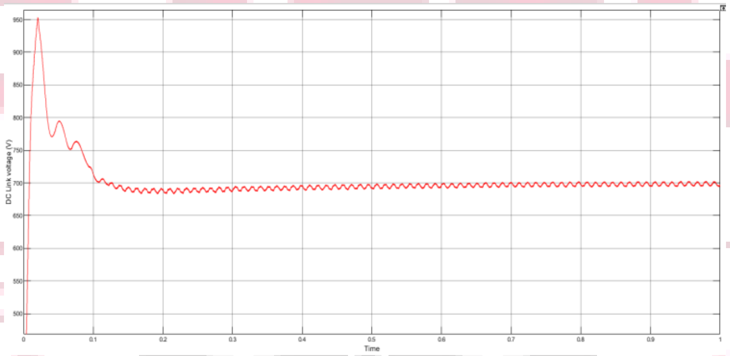

Figure 2 DC link Voltage output from the system in system 1 for case 1

In Case 1 of this work, the system output was DC link voltage. The graph shows how the DC link voltage varies over time; after 0.5 seconds, the system voltage stabilizes at 700 V.

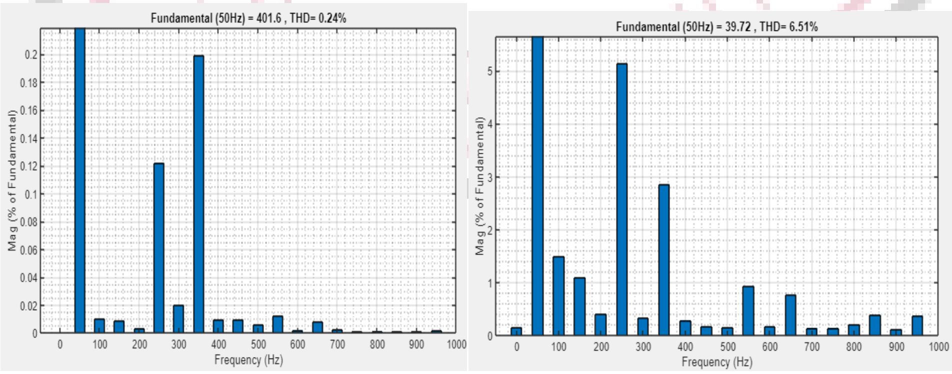

Figure 3 THD% Evaluation of Voltage and Current Output at Non-Linear Load Terminal in system 1 for Case 1

0.24% was measured as the Total Harmonic Distortion (THD%) in Case 1's voltage output at the non-linear load terminal.The current output has a 6.51% measured Total Harmonic Distortion (THD%).

- **Solar energy system with Hybrid Control Approach for Converter Control for Quality Enhancement (System 2)**

In order to evaluate the system's behavior and performance under realistic circumstances, the irradiation value for Case 1 of System 2 is set at 1000 W/m2. The converter control method uses the Perturb and Observe (P&O) algorithm and the Cuckoo Search Algorithm to maximize power production.

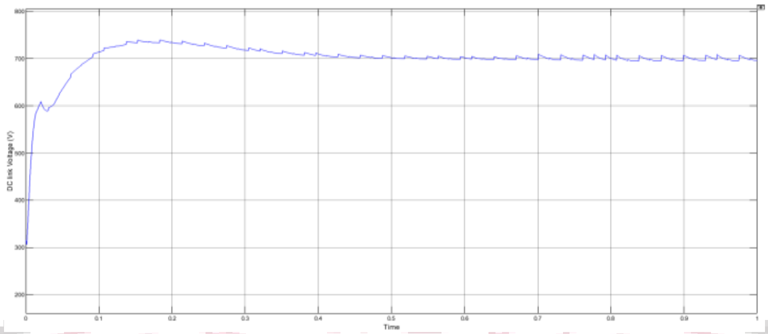

Figure 4 DC link Voltage output from the system in system 2 for case 1

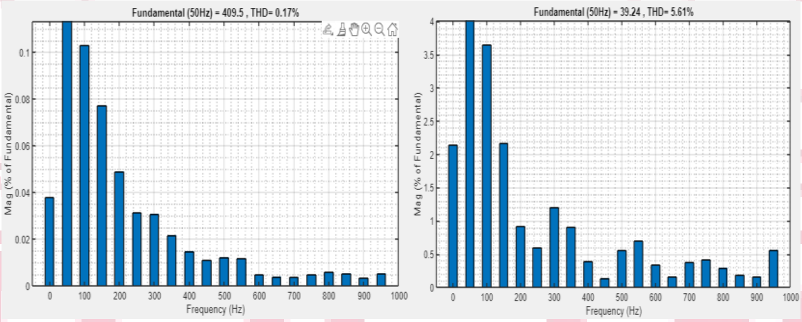

Figure 5 THD% Evaluation of Voltage&Current Output at Non-Linear Load Terminal in system 2 for Case 1

Total Harmonic Distortion (THD%) of 0.17% was detected in the voltage output at the non-linear load terminal in Case 1.Total Harmonic Distortion (THD%) was measured at 5.61% in System 2's current output at the non-linear load terminal for Case 1.

B. Case 2: Analysis of the energy system with variable irradiation input (500 -1000W/m2) (System 1 and System 2)

0.5 W/m2 to 1000 W/m2 of varying irradiance values were chosen for Case 2 of System 1 in order to evaluate the system's behavior and performance under various environmental circumstances.

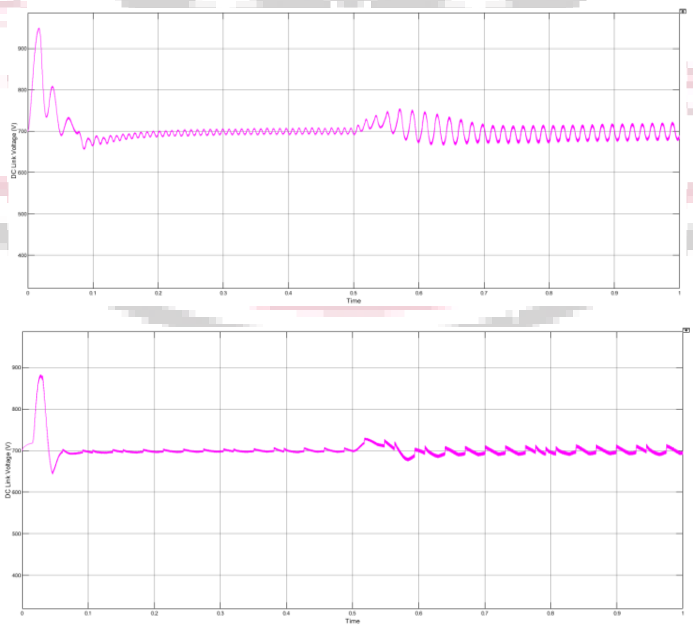

Figure 6 DC link Voltage output from the system in system 1 and system 2 for case 2

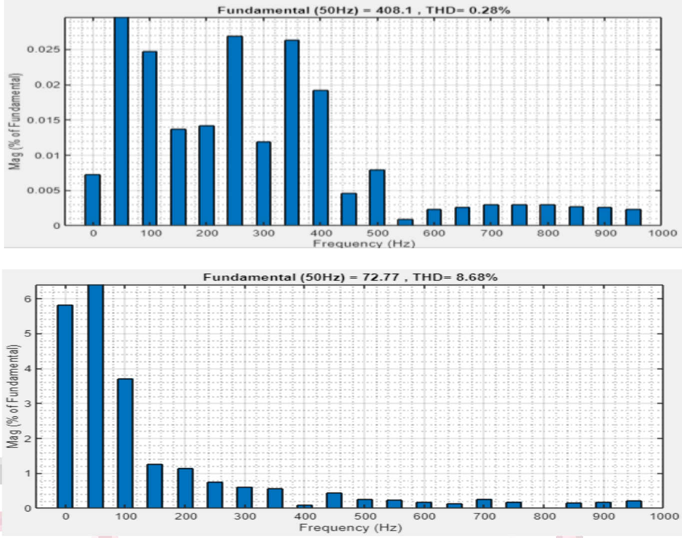

Figure 7 THD% Evaluation of Voltage and Current Output at Non-Linear Load Terminal in system 2 for Case 2

Total Harmonic Distortion (THD%) of 0.28% was detected in Case 1's voltage output at the non-linear load terminal.Total Harmonic Distortion (THD%) of 8.68% was observed in the current output at the non-linear load terminal in System 2 for Case 2

V .CONCLUSION

In Case 1, two systems were assessed with an input of constant illumination of 1000W/m2. While System 2 used a hybrid strategy combining the Cuckoo Search Algorithm with the technique of perturb and Observe algorithm, System 1 used the Perturb and Observe algorithm. System 1 demonstrated voltage stability of 700V and a THD% of 0.24% in the voltage output, highlighting the impact of a non-linear load. System 2 reduced THD% with a voltage output of 0.17%. In Case 2, both systems maintained stability at 700V with varied irradiation input, however System 1 displayed higher THD% compared to Case 1, and System 2 demonstrated improved performance with lower THD%. These results shed light on how the system behaves and performs in various scenarios.

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