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OPTIMIZED SOLAR CHARGE CONTROLLER USING HYBRID MPPT ALGORITHM FOR A THREE PHASE FOUR LEG INVERTER

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ABSTRACT

This paper presents a comprehensive study on advanced maximum power point tracking (MPPT) algorithms integrated with three-phase four leg inverters for photovoltaic (PV) systems along with a new hybrid MPPT algorithm. The research synthesizes findings from two innovative approaches: a variable perturbation adaptive P&O algorithm and a modified incremental conductance (INC) method. These algorithms address limitations of traditional MPPT techniques by enhancing tracking speed, stability, and adaptability under varying irradiance conditions. The integration of MPPT algorithms with three-phase inverters is explored, emphasizing their role in ensuring high power quality, minimizing total harmonic distortion, and maintaining system stability. Additionally, the inclusion of reactive power compensation further optimizes grid-connected operations. Simulation and experimental results validate the effectiveness of the proposed strategies, highlighting their ability to maximize energy capture and improve dynamic and steady-state performance. This study provides a robust framework for developing efficient and reliable PV systems for both standalone and grid-connected applications.

KEYWORDS: *MPPT Algorithm; Inverter; INC algorithm; Photovoltaic system; P&O algorithm; solar energy harvesting; THD; three phase inverter.*

INTRODUCTION

The increasing global demand for renewable energy sources has positioned photovoltaic (PV) systems as a critical technology for sustainable energy generation [3]. With the rapid advancements in solar cell efficiency and power electronics, PV systems have become more cost-effective and widely adopted for both grid-connected and standalone applications [1][10]. However, the performance and reliability of these systems are highly dependent on their ability to extract the maximum available power from PV panels under varying environmental conditions, such as changes in solar irradiance and temperature[2][10]. This capability is achieved through Maximum Power Point Tracking (MPPT) algorithms, which are an integral part of modern PV systems [1].

Traditional MPPT methods, such as perturb and observe (P&O) and incremental conductance (INC), have been extensively studied and implemented due to their simplicity and moderate performance [3]. However, these methods often face challenges, including oscillations around the maximum power point (MPP), slow tracking under dynamic conditions, and limited adaptability to rapid changes in irradiance [1][4]. To overcome these limitations, advanced MPPT algorithms have been developed to enhance tracking accuracy, improve dynamic response, and ensure stability [5][1].

At the same time, three-phase inverters are crucial components of PV systems, responsible for converting the direct current (DC) output from the PV panels into alternating current (AC) suitable for grid integration or standalone operation. Multilevel inverters (MLIs), in particular, have gained prominence due to their ability to reduce total harmonic distortion (THD), improve voltage levels, and minimize electromagnetic interference (EMI) [6][25]. When integrated with robust MPPT algorithms, three-phase inverters can significantly enhance the overall efficiency and power quality of PV systems [24].

This paper investigates two advanced MPPT strategies: the variable perturbation adaptive P&O algorithm and the modified incremental conductance method. The former combines coarse and fine perturbation adjustments to achieve fast tracking and reduced oscillations, while the latter integrates a variable-step approach to prevent DC-link voltage collapse during irradiance disturbances. Additionally, the modified INC method incorporates reactive power compensation, which optimizes grid-connected PV systems by alleviating the burden on the utility grid [23].

Through simulation and experimental studies, this research demonstrates the effectiveness of these algorithms when integrated with three-phase inverters. The findings highlight improvements in energy capture, system stability, and operational efficiency under both dynamic and steady-state conditions [1][22]. This study provides a robust framework for advancing the design and implementation of PV systems, addressing key challenges in renewable energy generation and contributing to the transition toward sustainable energy solutions [21].

MPPT Techniques for PV Systems

Photovoltaic (PV) systems are characterized by nonlinear voltage-current (V-I) and power-voltage (P-V) characteristics, which vary significantly with changes in solar irradiance and temperature. To optimize energy generation, PV systems require maximum power point tracking (MPPT) techniques to operate at their maximum power point (MPP) [1][19]. MPPT algorithms dynamically adjust the system's operating parameters to ensure maximum energy extraction under fluctuating environmental and load conditions [10].

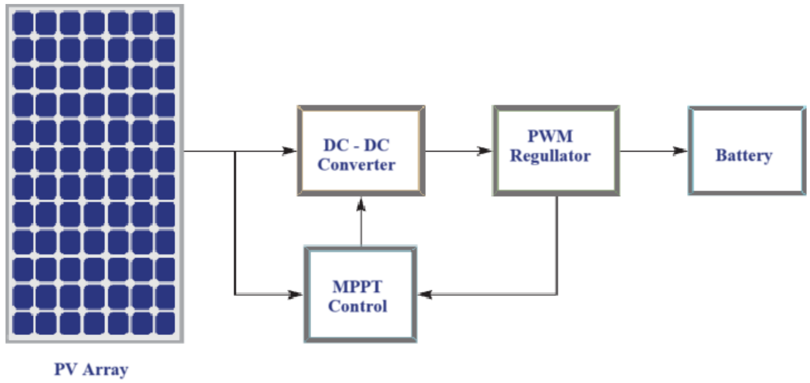

Figure 1: Block Diagram of MPPT Controller

Conventional MPPT methods, such as Perturb and Observe (P&O), Incremental Conductance (INC), and Fractional Open-Circuit Voltage (FOCV) or Short-Circuit Current (FSCC), are widely used in PV systems [18]. Each of these methods has its advantages and limitations: Perturb and Observe (P&O) –This algorithm perturbs the operating voltage or current and observes the resulting change in power. Based on the direction of power variation, it adjusts the operating point to approach the MPP. Although simple to implement, P&O suffers from power oscillations around the MPP in steady-state conditions and has a slow response under rapidly changing irradiance [1][17]. Incremental Conductance (INC) – This method identifies the MPP by comparing the incremental conductance (ΔI/ΔV\Delta I / \Delta VΔI/ΔV) with the instantaneous conductance (I/VI / VI/V). While more accurate than P&O during dynamic changes, INC requires precise measurements and involves higher computational complexity. FOCV/FSCC Methods – These methods estimate the MPP using a fixed proportion of the open-circuit voltage or short-circuit current. They are simple but less accurate, particularly under varying weather conditions, as the fixed ratio assumption introduces errors [10][1].

Advanced MPPT Techniques

Conventional methods often struggle with trade-offs between tracking speed, accuracy, and system stability, particularly under rapid irradiance changes. To overcome these limitations, advanced MPPT techniques have been developed [17][1].Variable Perturbation Adaptive P&O – This method enhances the traditional P&O by introducing variable perturbation sizes through three sub-algorithms: Current Perturbation Algorithm (CPA) – Focuses on current perturbation for faster tracking. Adaptive Control Algorithm (ACA) – Adjusts the operating point dynamically based on irradiance changes [17]. Variable Perturbation Algorithm (VPA) – Minimizes oscillations around the MPP by dynamically reducing perturbation size near the optimal point. The algorithm improves tracking speed and stability while reducing oscillations and computational complexity. Implementation with a boost converter ensures efficient energy transfer and hardware simplicity.

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Modified Incremental Conductance [1] – This method addresses the instability of traditional INC under rapidly changing irradiance by introducing a variable-step approach. It incorporates a closed-loop control mechanism to balance input and output power, maintaining DC-link voltage stability and preventing collapse. The method dynamically resets the reference power of the inverter based on current PV output to respond to step changes in insolation. Its integration with three-phase inverters allows reactive power compensation, enhancing grid-connected system performance [16]. Artificial Intelligence-Based Methods – Techniques such as Neural Networks (NN) and Fuzzy Logic Controllers (FLC) have been explored to handle the nonlinear characteristics of PV systems. These methods are highly adaptable and efficient but require significant computational resources and training data, limiting their scalability in cost-sensitive applications [15][10].

Comparison of Techniques

Method	**Accuracy**	**Complexity**	**Dynamic Response**	**Stability**
Perturb and Observe (P&O)	Moderate	Low	Moderate	Moderate
Incremental Conductance	High	Moderate	High	Moderate
FOCV/FSCC	Low	Low	Fast	Low
Variable Perturbation P&O	High	Moderate	Fast	High
Modified INC	High	High	Fast	Very High
AI-Based Methods	Very High	Very High	Very Fast	Very High

Advancements in MPPT techniques are geared toward hybrid approaches combining the strengths of multiple methods [1][10]. For example, integrating AI-based algorithms with adaptive methods could offer superior adaptability and precision. Additionally, hardware improvements in sensors and processors will further enable real-time implementation of computationally intensive algorithms, making PV systems more efficient and reliable [14].By employing advanced MPPT techniques, PV systems can significantly improve energy capture and stability, paving the way for more sustainable energy solutions.

THREE PHASE FOUR LEG INVERTERS

Types of Three Phase Four Wire system

Inverter configuration to mitigate the unbalance in three phase system must have a neutral line for the flow of neutral current. Four wire inverter topology is for balanced voltages production by controlling the neutral current, even under unbalanced load. The two popular configurations of converter that provide a neutral connection are [2][3],

(a) Split DC link capacitor type.

(b) Four leg inverter topology.

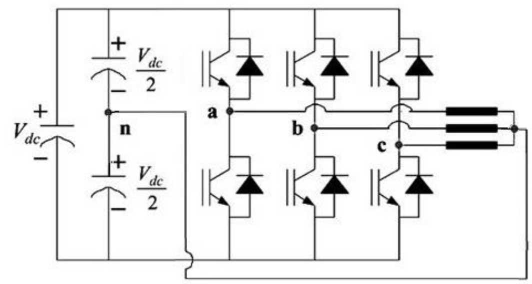


Figure 2. Split DC link capacitor inverter

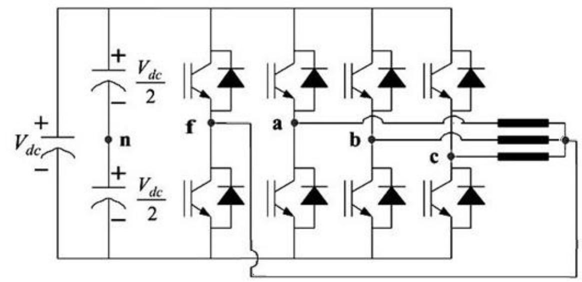


Figure 3. Four leg inverter

Split DC Link capacitor type

This is the conventional and simple approach to handle neutral current by linking it to the centre point of DC link capacitors, so that the neutral current can flow through the capacitors [14][2]. This configuration has only six switches and thereby reduced cost of installation and switching loss. As the neutral point is connected to the centre point of DC link, the compensation current will flow through the upper and lower capacitors, causes variations in DC link voltages [8]. In an algorithm that simultaneously control current harmonics, neutral current and DC voltage variation across capacitors, using 3DSVM is presented. Here two zero vectors that point to the opposite axis are utilized for balancing the voltages across the upper and lower capacitors [13][10]. The drawbacks of this method are (i) high value capacitor requirement for DC link voltage regulation and (ii) poor utilization of DC link voltage.

Four leg inverter topology

This topology is the advanced alternate inverter configuration to handle neutral due to unbalanced load. The drawbacks of split DC link capacitor system can be solved using this configuration by tying neutral link with fourth leg. Neutral link is accessible for current compensation and provides maximum DC link utilization, with other advantages requires small capacitance value, EMI and CMV reduction [12]. Compared to conventional three legged converter controlled by 2D space vector modulation, a four legged converter requires 3DSVM with sixteen switching vectors. The switching vector controllability of this topology is better than split capacitor topology [1].

PROPOSED SYSTEM

Optimized charge controller using Hybrid MPPT Algorithm for a Three-Phase Inverter

The proposed system integrates advanced maximum power point tracking (MPPT) algorithms with a three-phase inverter to optimize the performance of photovoltaic (PV) systems under varying environmental conditions [1][10]. By combining the strengths of the Variable Perturbation Adaptive P&O Algorithm and the Modified Incremental Conductance (INC) Algorithm [1], the system achieves efficient energy harvesting, improved stability, and enhanced power quality.

Additionally, the incorporation of reactive power compensation ensures compatibility with grid-connected applications, providing a comprehensive and versatile solution for renewable energy generation [1][10].

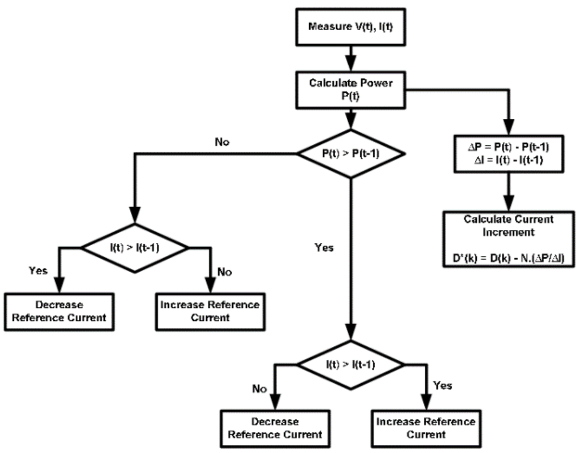


Figure 4. Variable Perturbation Adaptive P&O Algorithm

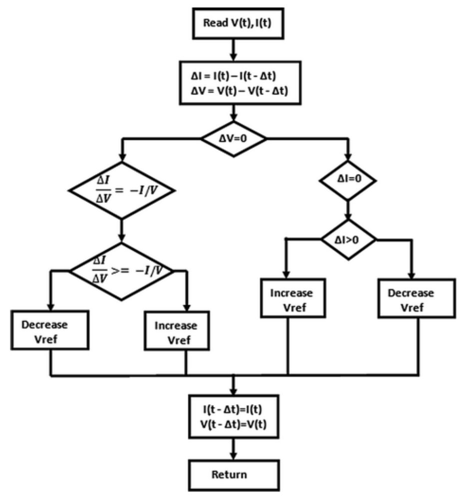


Figure 5. Modified Incremental Conductance (INC) Algorithm

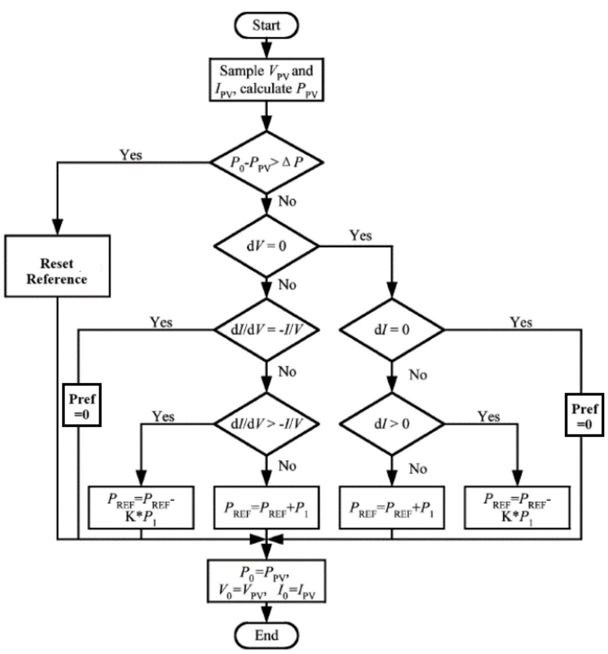
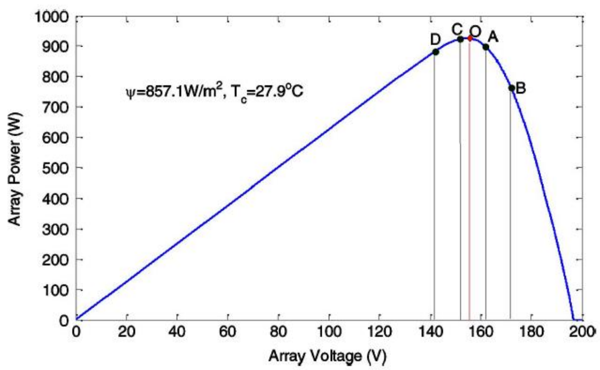
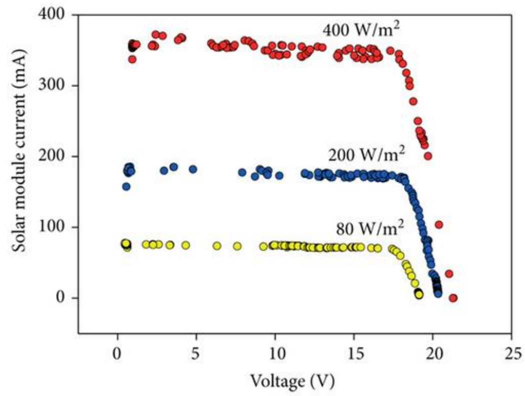


Figure 6. Proposed Hybrid MPPT Algorithm

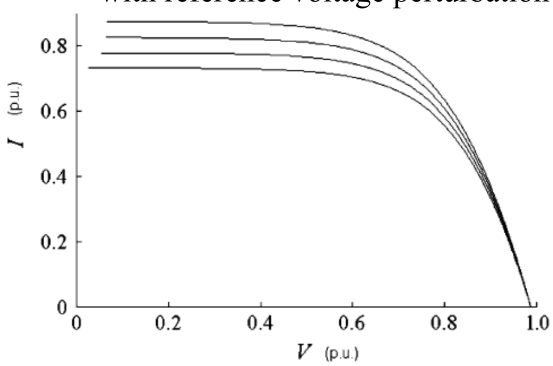
RESULT AND DISCUSSION



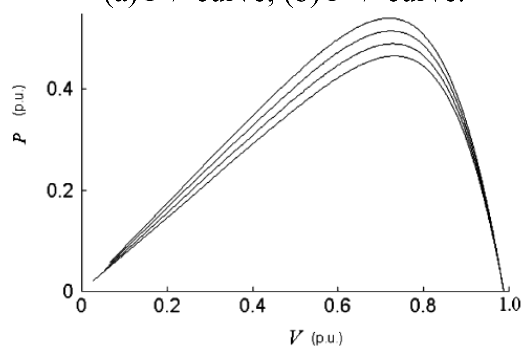
(a) Behaviour of Hybrid MPPT algorithm with reference voltage perturbation



(b) Power test result of the solar module: (a) *I-V* curve; (b) *P-V* curve.



(c) Simulated V-I Characteristics of PV panels with Hybrid MPPT



(d) Simulated P-V Characteristics of PV panels with Hybrid MPPT

Figure 7. Simulation Results

The validity of mathematical analysis and the feasibility of the proposed algorithm are verified by time domain simulation studies in the MATLAB/SIMULINK environment for a three-level four-leg inverter. The inverter's load is an inductive load (R=50Ω, L=20mH), the input voltage of the inverter is set to vdc = 20 kV, the switching frequency is fs = 5 kHz. Fig. 7 shows the three-level operation of the experimental PV pumping system employing hybrid MPPT algorithm with reference voltage perturbation when the system was started and run at 857.1-W/m solar irradiance and 27.9 C cell temperature with a low perturbation frequency of 1 Hz and a high step size of 10 V. System operation can be better explained with reference to the array power–voltage curve at the same irradiance and cell temperature levels

CONCLUSION

The proposed hybrid MPPT-based PV system integrates advanced tracking algorithms with three-phase four leg inverter control to deliver optimized energy harvesting, enhanced stability, and high power quality. The combination of the Variable Perturbation Adaptive P&O and Modified INC algorithms ensures superior performance under both steady-state and dynamic conditions. By incorporating reactive power compensation, the system provides a robust and efficient solution for renewable energy applications, supporting both standalone and grid-connected operations. Future enhancements may explore the integration of artificial intelligence for further optimization and scalability.

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