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Maximum Power Point Tracking Algorithm for Solar System Using MATLAB

Jaid Mujawar[1], Manojkumar Patil[2], Prof. P. S. Magdum[3]

Student, Dept. of Electrical Engineering, D.K.T.E Society's Textile and Engineering Institute, Ichalkaranji, Maharashtra, India[1]

Student, Dept. of Electrical Engineering, D.K.T.E Society's Textile and Engineering Institute, Ichalkaranji, Maharashtra, India[2]

Asst. Prof., Dept. of Electrical Engineering, D.K.T.E Society's Textile and Engineering Institute, Ichalkaranji, Maharashtra, India[3]

Abstract: In the current energy scenario, solar photovoltaic (PV) systems have emerged as a key solution to sustainable power generation. However, the efficiency of these systems is highly influenced by environmental factors such as solar irradiance and temperature. This paper presents a detailed MATLAB/Simulink-based simulation of a Maximum Power Point Tracking (MPPT) system using the Perturb and Observe (P&O) algorithm integrated with a buck converter. The PV array parameters were modeled considering variable irradiance levels from 1000 W/m² to 500 W/m² and a constant temperature of 25°C. The buck converter was designed to step down the voltage from the maximum power point value of 30.7V to a desired load voltage of 15V, with switching frequency set to 10 kHz and a maximum power output of 250 W. Inductor (L), capacitor (C), and load resistance (R) values were calculated using MATLAB code to optimize converter performance. The proposed system effectively tracks the maximum power point in varying environmental conditions and enhances the overall efficiency of the PV system. The results validate the accuracy and stability of the P&O algorithm, making this approach suitable for practical deployment in residential, industrial, and off-grid solar applications.

Keywords: MPPT, Perturb and Observe, Buck Converter, MATLAB Simulation, Solar PV System, Renewable Energy, Maximum Power Point, Irradiance Variation, Power Electronics, Photovoltaic Efficiency.

I.INTRODUCTION

The growing demand for clean and renewable sources of energy has positioned solar photovoltaic (PV) systems as a vital solution to meet the global energy crisis. Solar energy, being abundant, eco-friendly, and sustainable, offers significant potential for addressing the increasing energy demands, especially in developing countries. However, one of the major challenges associated with PV systems is their relatively low efficiency, which is influenced by constantly changing atmospheric conditions such as solar irradiance and temperature. As a result, the actual output from a PV system rarely matches its theoretical maximum. To overcome this inefficiency, it is essential to implement Maximum Power Point Tracking (MPPT) techniques that allow the system to operate at its optimal power output point under all conditions.

MPPT algorithms continuously track the power-voltage characteristics of the PV array and adjust the operating point to extract the maximum power available. Among the various MPPT algorithms developed, the Perturb and Observe (P&O) method is one of the most widely used due to its simplicity, low cost, and ease of implementation. This method periodically perturbs the operating voltage and observes the resulting changes in output power to determine the direction in which the maximum power lies.

This research focuses on simulating a solar PV system integrated with an MPPT controller using the P&O algorithm and a buck converter, designed and implemented in MATLAB/Simulink. The buck converter plays a crucial role in adjusting the PV output to match the desired load requirements while maintaining high conversion efficiency. The system is modeled based on practical parameters such as open-circuit voltage, short-circuit current, and voltage/current at the maximum power point. The simulation includes the calculation of appropriate inductor, capacitor, and resistor values for the converter to ensure stable performance. The model is then tested under varying irradiance conditions to evaluate the efficiency and effectiveness of the MPPT strategy.

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II.LITERATURE REVIEW

2.1 Maximum Power Point Tracking Techniques

Maximum Power Point Tracking (MPPT) is vital to ensure that solar PV systems operate at their highest efficiency under varying conditions. Among various MPPT techniques, the Perturb and Observe (P&O) method is widely adopted due to its simplicity and ease of implementation. Esram and Chapman (2007) reviewed MPPT algorithms and concluded that while advanced methods like fuzzy logic and neural networks offer higher accuracy, P&O remains practical for real-time systems because of its low computational requirement.

2.2 Modeling of PV Array in MATLAB

Accurate modeling of the PV array is critical for simulating and validating MPPT performance. Patel and Agarwal (2008) showcased a MATLAB-based model considering temperature and irradiance variations to reflect real environmental conditions. In this project, the PV module is modeled with a maximum power output of 250W, and simulations are conducted with irradiance values ranging from 1000 W/m² to 500 W/m² at a constant temperature of 25°C.

2.3 Role of Buck Converter

The buck converter plays a central role in adjusting the PV output voltage to meet load requirements while tracking maximum power. Rashid (2014) explained that efficient design of converters requires appropriate selection of inductance, capacitance, and switching frequency. In this simulation, a buck converter is designed for 30.7V input and 15V output with a 10 kHz switching frequency. MATLAB is used to calculate the values of L = 4.598e-04 H, C = 1.3900e-05 F, and R = 0.8993 Ω for stable operation.

2.4 Simulation-Based MPPT Control

Simulation platforms like MATLAB/Simulink are highly effective for testing MPPT algorithms. Elgendy et al. (2012) demonstrated the success of simulation in predicting real-world behavior of MPPT-controlled PV systems. This study uses Simulink to integrate the PV model, buck converter, and P&O control algorithm, providing a comprehensive virtual environment to evaluate system response and verify tracking performance before any physical implementation

III.METHODOLOGY

The methodology followed in this project can be categorized into sequential phases that ensure clarity of objective, accurate modeling, and validation of results through simulation. Each phase is implemented systematically in MATLAB/Simulink to closely represent real world behavior. Problem Definition and Data Collection: Initial parameters such as maximum power, Voc, Isc, Vmpp, Impp, irradiation range, and temperature were identified. This allowed proper modeling of the PV array and ensured that simulation conditions reflected realistic values. Modeling of PV Array: The solar panel was simulated using MATLAB's built-in Simscape components, incorporating its nonlinear characteristics influenced by irradiance and temperature. Design of Buck Converter: A DC-DC buck converter was designed based on the required output voltage and known input (Vmpp). Using design equations and MATLAB coding, accurate values of inductance (L), capacitance ©, and resistance ® were calculated to operate the converter in continuous conduction mode.

The converter's switching frequency was set to 10 kHz. Implementation of MPPT using P&O Algorithm: A control logic block using the Perturb and Observe method was developed to dynamically adjust the duty cycle based on the feedback of voltage and power. This ensured the system tracked and maintained operation at the Maximum Power Point. System Integration and Simulation: All modules – PV, MPPT, buck converter, and load – were integrated and simulated. Varying irradiation was applied, and the system response was observed to verify if the duty cycle was properly adjusted and maximum power was delivered to the load. Result Analysis: Output parameters such as voltage, current, power, and duty cycle were plotted and studied. The effectiveness of the MPPT algorithm and the converter was validated through the observed stable output at the load despite input fluctuations.

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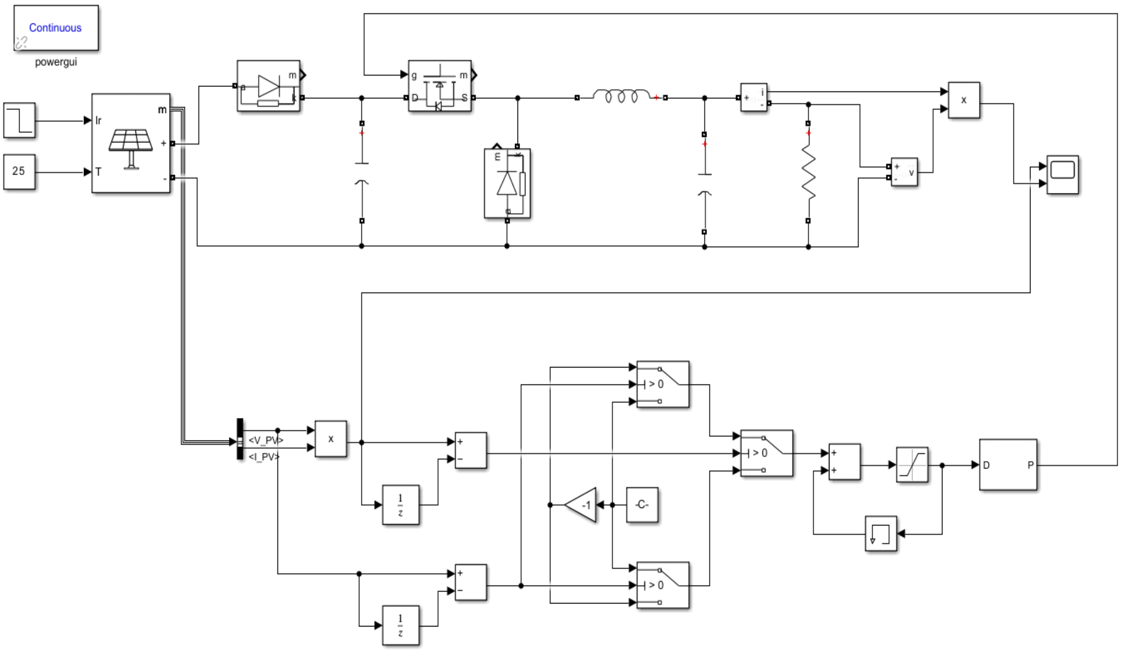
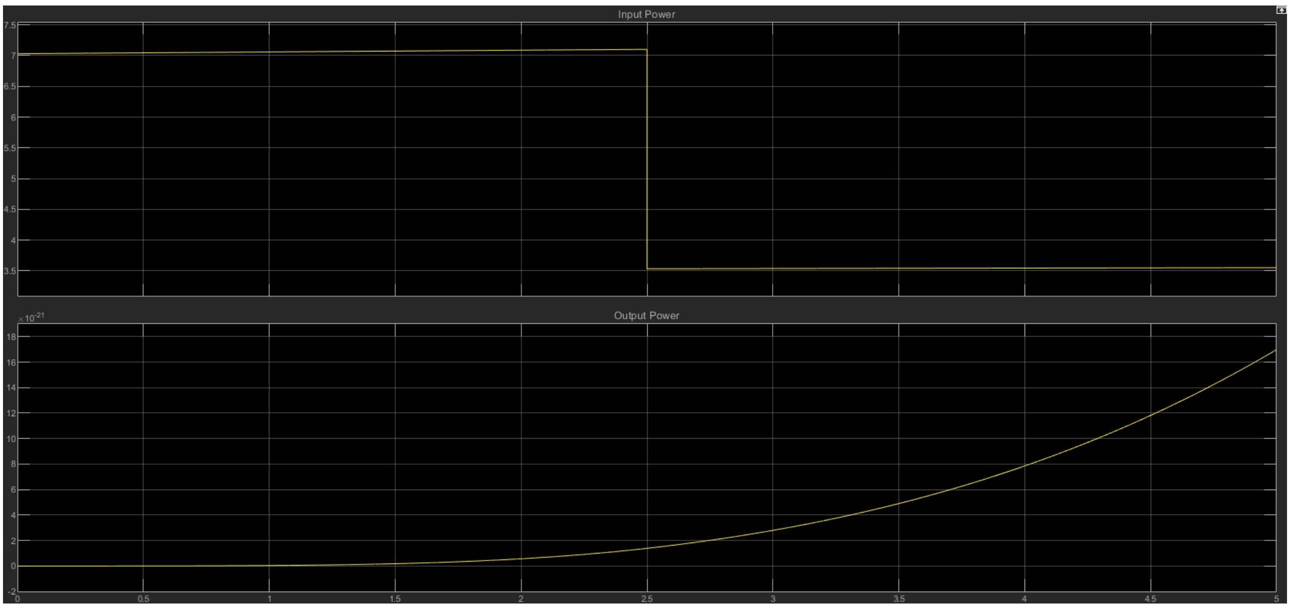
IV.SIMULATION MODEL



V.RESULTS



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VI.CONSTRUCTION AND WORKING

The proposed MPPT system is designed around a modular block structure that includes a photovoltaic (PV) array, a buck converter, a Perturb and Observe (P&O) control algorithm, and a variable load. The PV array serves as the primary power-generating source and is influenced by two main input variables: solar irradiance and temperature. In this model, irradiance is varied from 1000 W/m² to 500 W/m², while the temperature is kept constant at 25°C to simulate realistic environmental changes. The output of the PV panel, which fluctuates based on irradiance, is fed into a buck converter that steps down the voltage from the panel to a constant output of 15V required by the load.

The Perturb and Observe algorithm forms the core control logic of the system. It works by perturbing (adjusting) the operating voltage and observing the resulting change in power. Based on whether the power increases or decreases, the algorithm decides whether to increase or decrease the duty cycle of the PWM signal controlling the buck converter. This continuous feedback loop ensures that the system dynamically tracks the Maximum Power Point (MPP), maximizing energy extraction from the PV panel. The values of the inductor (L = 459.8 µH), capacitor (C = 13.9 µF), and load resistance (R = 0.8993 Ω) were carefully calculated using MATLAB code to ensure efficient power transfer and system stability. The methodology combines mathematical modeling, simulation validation, and iterative tuning to create a responsive, accurate, and energy efficient MPPT system under varying solar conditions.

This study successfully demonstrates the significant impact of nonlinear load variation on power factor and harmonic distortion in electrical systems. Through MATLAB/Simulink simulation, it was observed that as the inductance in a diode bridge-rectifier based R-L load increases, the Total Harmonic Distortion (THD) rises, leading to a noticeable decline in power factor. The FFT analysis confirmed the presence of dominant low-order harmonics, while scope-based waveform observation revealed increased phase displacement and distortion with higher inductance. These findings highlight the critical role of harmonic analysis in power system design and the need for harmonic mitigation techniques in industrial applications. The simulation model proved to be an effective and flexible tool for evaluating power quality issues, enabling engineers to predict system behavior under varying load conditions and take corrective actions to maintain efficiency and stability.

VII.ADVANTAGES

1. Efficient Power Extraction - Continuously tracks the Maximum Power Point to utilize the full potential of the solar panel.
2. Dynamic Response to Environmental Changes - Adjusts duty cycle in real time based on changes in irradiance and temperature.
3. Reduced Power Losses - Buck converter ensures minimal energy loss during voltage conversion.
4. Optimized Load Performance - Maintains a stable output voltage (15V), ideal for sensitive electronic loads.
5. Cost-Effective Design - Uses a simple and reliable P&O algorithm without the need for expensive hardware.
6. Accurate Simulation-Based Calculations - Inductor, capacitor, and resistor values are precisely computed using MATLAB code.
7. Modular and Scalable System - The system can be adapted for larger PV setups or integrated into hybrid energy systems
8. Improved Reliability - Simulation testing helps identify optimal operating parameters before real-world implementation

VIII.APPLICATIONS

- Solar Home Systems
- Off-grid Rural Grid
- Battery Charging System
- Photovoltaic Generation

IX.CONCLUSION

The MATLAB Simulink simulation of the five-level multilevel inverter successfully demonstrated the effective conversion of a DC input into a stepped AC output waveform using a cascaded H-bridge topology. The use of key components such as MOSFETs, DC voltage sources, and pulse generator blocks enabled precise switching control and efficient power conversion.

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The multilevel structure of the inverter not only provided improved power quality by producing output waveforms closer to a pure sine wave but also contributed to reduced total harmonic distortion and lower switching losses compared to conventional two-level inverters. This simulation highlights the advantages of using multilevel inverter technology in terms of enhanced performance, better voltage control, and increased compatibility with industrial and sensitive electronic applications.

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