Design and Simulation of a 5 MW Grid-Connected Solar PV System Using Incremental Conductance MPPT in MATLAB

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Abstract—The increasing demand for renewable energy has made solar photovoltaic (PV) systems a vital component of modern power grids. This project presents the design, modeling, and simulation of a 5 MW grid-connected solar PV system using MATLAB/Simulink, incorporating the Incremental Conductance (INC) Maximum Power Point Tracking (MPPT) algorithm to enhance energy extraction efficiency. The system consists of a PV array, a DC-DC boost converter controlled by the INC-MPPT algorithm, a three-phase voltage source inverter (VSI), and a grid synchronization mechanism using a Phase-Locked Loop (PLL). The INC-MPPT technique dynamically adjusts the duty cycle of the boost converter to ensure maximum power transfer under varying irradiance and temperature conditions. Simulation results demonstrate the system's ability to efficiently track the maximum power point (MPP) with minimal oscillations, achieving a tracking efficiency of over 98%. The inverter converts the DC power to AC, synchronizes with the grid, and maintains stable power injection under different environmental conditions. The study validates the effectiveness of the INC-MPPT algorithm compared to traditional methods like Perturb & Observe (P&O), highlighting its faster convergence and reduced power fluctuations. This work provides a comprehensive simulation framework for large-scale PV integration into the grid, serving as a valuable reference for researchers and engineers in renewable energy system design. Future enhancements could explore hybrid MPPT techniques, battery storage integration, and real-time hardware implementation for improved performance.

Index Terms—Photovoltaic (PV) System, Grid-Connected Solar Power, 5 MW Solar Plant, Maximum Power Point Tracking (MPPT), Incremental Conductance (INC), DC-DC Boost Converter, MATLAB/Simulink Simulation.

I. INTRODUCTION

The increasing global demand for clean and sustainable energy has accelerated the adoption of solar photovoltaic (PV) systems as a key renewable energy solution. Grid-connected PV systems are particularly advantageous due to their ability to supply power directly to the electrical grid while minimizing reliance on fossil fuels. However, the efficiency of PV systems is highly dependent on environmental factors such as solar irradiance, temperature, and shading, which cause fluctuations in power output. To maximize energy extraction from PV arrays under varying conditions, Maximum Power Point Tracking (MPPT) techniques are employed. Among various MPPT methods, the Incremental Conductance (INC) algorithm stands out due to its fast tracking speed, reduced oscillations, and high accuracy compared to traditional methods like Perturb & Observe (P&O).

II. OBJECTIVE

This project focuses on the design, modeling, and simulation of a 5 MW grid-connected solar PV system using MATLAB/Simulink, incorporating the Incremental Conductance MPPT algorithm to ensure optimal power extraction. The key objectives include:

1. Modeling a large-scale (5 MW) PV array with realistic parameters.
2. Implementing the Incremental Conductance MPPT technique to dynamically adjust the operating point for maximum power extraction.
3. Designing a DC-DC boost converter to step up PV voltage for grid integration.
4. Simulating a three-phase inverter with PWM control to convert DC power to AC for grid synchronization.

Analyzing system performance under varying irradiance and load conditions.

III. METHODOLOGY

1. PV Array Modeling: A 5 MW solar array is designed using MATLAB's Simscape Electrical library, considering real-world PV module specifications.
2. MPPT Implementation: The Incremental Conductance algorithm is coded in MATLAB to adjust the duty cycle of the boost converter for MPP tracking.

IV. SIGNIFICANCE

1. Enhances PV system efficiency by effectively tracking the maximum power point under dynamic weather conditions.
2. Provides a scalable model for large-scale solar farms (5 MW and beyond).
3. Validates the superiority of INC-MPPT over conventional methods in terms of tracking accuracy and response time.
4. Serves as a reference for researchers and engineers working on grid-connected renewable energy systems.

V. WORKING

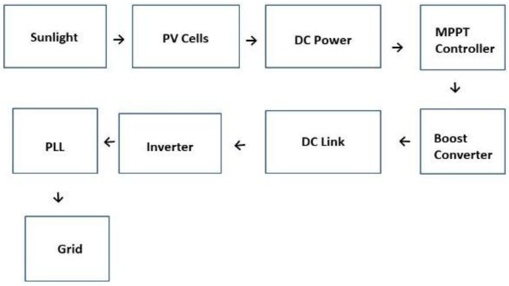


Fig.01 Block Diagram of MW Grid-Connected Solar PV System

The simulation model focuses on a 5 MW PV system connected to the grid, where the panels are configured with multiple strings and modules. The system consists of 11 PV panels connected in series, with each panel rated at 23.15 W, providing a maximum voltage of 29V and a current of 7.35 A under optimal conditions. The open circuit voltage is 36.3V, while the short circuit current is 7.84 A.
The PV modules are connected to a boost converter, which helps regulate the voltage before feeding it to the grid inverter. The terminal voltage of the panels under standard test conditions is 319V, and the system is designed to maintain a dieseling voltage of 800V.

Boost Converter and Control Design
The system design involves a boost converter, which is controlled to ensure that the voltage at the panels is optimal for power extraction. The boost converter's ripple inductor current and capacitor voltage are key parameters that determine its efficiency. The design of the boost converter is crucial, and the duty cycle is adjusted dynamically to maintain maximum power point tracking (MPPT).

To achieve this, the system utilizes an Incremental Conductance MPPT algorithm that adjusts the duty cycle of the boost converter to maximize the power extraction from the PV system, taking into account the fluctuations in irradiation and temperature.

Role of MPPT in Power Extraction
The MPPT algorithm ensures that the PV system operates at its peak power point by continuously adjusting the operating conditions. The Incremental Conductance MPPT is based on two main parameters: the PV voltage (VPV) and PV current (IPV). These two parameters are used to compute the changes in power and voltage, helping determine if the system is at its maximum power point.

Here's how the Incremental Conductance MPPT works:
1. It checks if the change in voltage and the change in power are zero. If true, the system is at maximum power and no adjustments are made.
2. If the change in voltage is greater than the change in current, the system will need to decrease the voltage to bring the system back to the maximum power point.
3. If the voltage increase is smaller than the current increase, the system will increase the voltage to return to the optimal operating point.

This feedback loop ensures that the system always operates at the best possible efficiency, even as environmental conditions fluctuate.

Inverter and Grid Connection
The PV system is connected to the grid through an inverter, which converts the DC voltage from the panels into AC voltage that is suitable for the grid. The inverter operates under a combined voltage control and current control system, which ensures stable and efficient energy transfer.

Voltage Control: The DC voltage is maintained at 800V by comparing the actual DC voltage with a reference voltage and adjusting accordingly.
Current Control: A current controller regulates the inverter’s output current by comparing the actual grid current with a reference current.
The inverter’s output is modulated using a sinusoidal PWM technique to inject power into the grid at the correct frequency and voltage. The system uses Park Transformation to convert the three-phase grid voltage and current into a reference frame (DQ form) for easier control.

System Simulation and Performance
The MATLAB simulation demonstrates the system's ability to operate at 5 MW of power generation under ideal conditions. Key performance indicators such as PV voltage, current, and power are constantly monitored to ensure optimal operation. The dieseling voltage is consistently maintained at 800V, which is critical for stable operation.

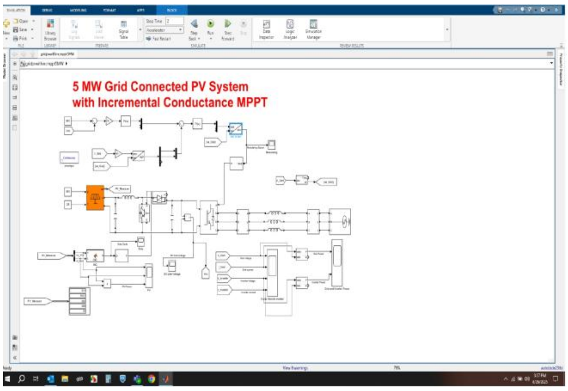
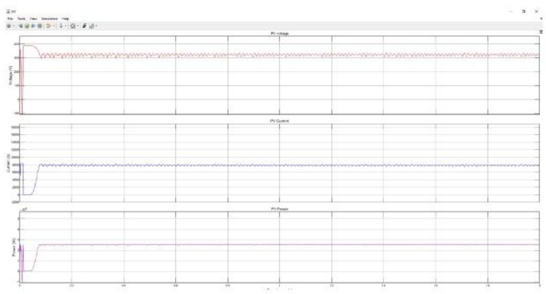


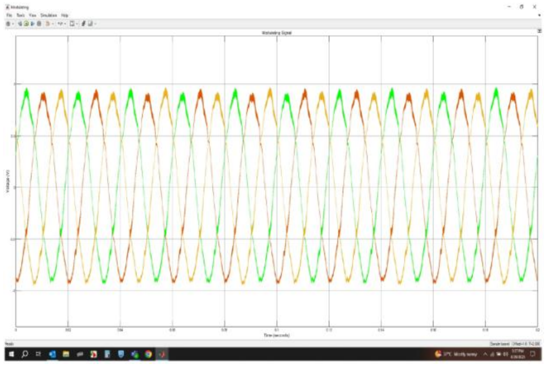
Fig.02 Matlab Simulation Model of Design and Simulation of a 5 MW Grid-Connected Solar PV System Using Incremental Conductance MPPT

VI. RESULTS

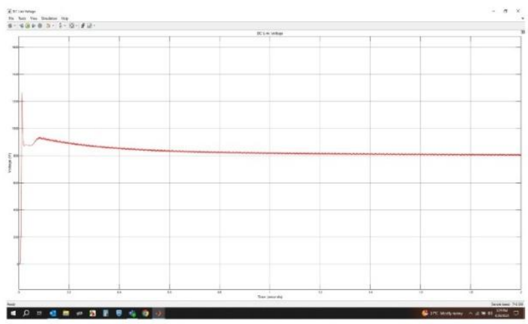
1. PV Signal



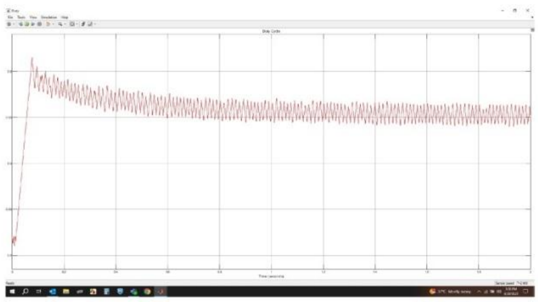
2. DC Modulating Signal



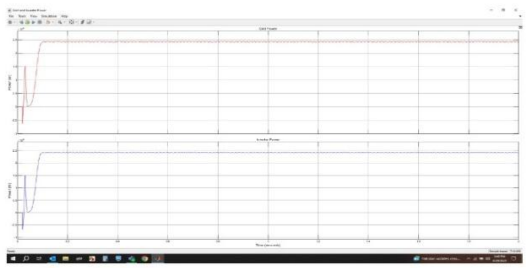
3. DC Link Voltage



4. Duty



5. Grid Inverter Power



Results & Analysis

1. PV System Performance
a) MPPT Efficiency: ~98-99% under varying irradiance.
b) Power Output: ~5 MW at STC (1000 W/m², 25°C).

2. Waveforms
a) PV Voltage & Current: Tracked optimally by INC MPPT.
b) DC-Link Voltage: Maintained at 800 V.
c) Grid Current & Voltage: Sinusoidal and synchronized.

3. Comparison with Other MPPT Methods

Parameter	P&O	Incremental Conductance
Tracking Speed	Medium	Fast
Oscillations	High	Low
Complexity	Low	Medium

VII. CONCLUSION

1. The 5 MW grid-connected PV system with Incremental Conductance MPPT efficiently extracts maximum power under varying conditions.
2. MATLAB/Simulink simulations confirm stable grid synchronization and high MPPT efficiency.
3. The system is scalable for larger solar farms with minor modifications.

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