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Dynamic Modeling and Performance Evaluation of a 3 MW Grid-Connected by Using Boost Converter

Krupavathi.Kandisa[1], Dr. R.Srinu Naik[2]
[1,2]*Department of Electrical Engineering,*
Andhra University College of Engineering, Visakhapatnam, India

***Abstract*—The growing global demand for clean and sustainable energy has made solar photovoltaic (PV) technology a key contributor to modern power generation. This paper presents the design and simulation of a 3 MW grid-connected solar PV system using MATLAB/Simulink. The proposed model integrates a PV array, a DC–DC boost converter controlled by a Maximum Power Point Tracking (MPPT) algorithm based on the Perturb-and-Observe (P&O) method, and a three-phase voltage source inverter synchronized with the utility grid through a Phase-Locked Loop (PLL). The boost converter regulates the PV array output voltage and maintains a stable DC-link voltage while the inverter converts the regulated DC power into high-quality, sinusoidal AC power at 400 V, 50 Hz.**

***Index Terms*—Solar photo voltaic, Boost converter, MPPT, Inverter, Grid system**

I. INTRODUCTION

The rapid depletion of conventional fossil-fuel resources and the escalating concerns over environmental pollution have accelerated the global shift toward renewable energy technologies. Among various renewable sources, solar photovoltaic (PV) energy has emerged as one of the most promising, clean, and sustainable options for large-scale electricity generation. With the continuous reduction in PV module costs and advances in power electronic converters, solar energy systems have become increasingly feasible for both distributed and utility-scale applications. In a grid-connected PV system, solar radiation is directly converted into electrical energy by photovoltaic modules and then integrated into the power grid through suitable DC–DC converters and DC–AC inverters. These converters play a critical role in voltage regulation, power conditioning, and synchronization with the grid. To extract maximum energy from the solar array under varying environmental conditions of irradiance and temperature, Maximum Power Point Tracking (MPPT) algorithms such as Perturb-and-Observe (P&O) or Incremental Conductance (INC) are employed. The combination of MPPT and efficient converter control ensures high system performance and stability This paper presents the design and simulation of a 3 MW grid-connected solar PV system using MATLAB/Simulink. The proposed system consists of a PV array, a DC–DC boost converter regulated by an MPPT controller, a three-phase voltage source inverter, and the grid connection interface. The model is analyzed to evaluate its steady-state and dynamic performance in terms of voltage, current, power, and overall efficiency. Simulation results demonstrate that the designed system can deliver rated power to the grid with minimal losses, unity power factor, and excellent voltage regulation. The study validates the feasibility of implementing large-scale solar PV systems for utility integration and provides a foundation for future enhancement through advanced converter topologies and intelligent control algorithms.

II. LITERATURE REVIEW

1. *Photovoltaic modeling*

Accurate modeling of PV cells and arrays is fundamental for reliable simulation and performance prediction of grid-connected PV plants. The single-diode equivalent circuit and its parameter extraction remain the most widely used approaches due to their balance of accuracy and computational simplicity. Recent reviews summarize variations of equivalent-circuit models (single- and double-diode), parameter identification techniques, and the sensitivity of models to irradiance and temperature, emphasizing the need for careful parameter selection when scaling from cell to module and array levels.

2. *Maximum Power Point Tracking (MPPT) algorithms*

MPPT is a central control task in PV systems to maximize energy extraction under changing irradiance and temperature. Classical algorithms such as Perturb & Observe (P&O) and Incremental Conductance (IncCond) are popular for their simplicity, but they suffer under rapidly varying or partially shaded conditions. Over the past decade there has been substantial interest in advanced and intelligent MPPT methods — fuzzy logic, neural networks, swarm intelligence and hybrid approaches — which improve tracking speed and robustness at the cost of increased complexity and computation. Comparative surveys and benchmarks highlight trade-offs between convergence speed, steady-state oscillation, and implementation complexity.

3. *Inverter topologies and control for grid integration*

Power electronic converters (inverters) are the interface between PV arrays and the utility grid; their topology and control strategy directly affect efficiency, power quality, and grid-support capabilities. Studies have examined two-stage vs. single-stage designs, three-phase PWM implementations, and multilevel inverter topologies for large installations. Control objectives commonly include grid-current injection with low harmonic distortion, dc-link regulation, reactive power control, and compliance with grid codes (e.g., low-voltage ride-through and fault-ride-through requirements). Recent reviews stress the role of advanced control schemes (PI/PR controllers, model-predictive control, and fractional-order controllers) to meet stringent grid-integration requirements.

4. *Power quality, harmonics mitigation and ancillary services*

Interconnection of large PV plants can affect power quality (voltage fluctuations, harmonics, and reactive power imbalance). Modern grid-connected inverters are therefore designed not only to inject active power but also to provide ancillary services such as reactive power compensation, active harmonic filtering, and voltage regulation. Research shows that active filtering techniques and coordinated inverter control can substantially reduce harmonics and manage reactive power for both linear and nonlinear loads, improving overall grid stability.

5. *Simulation platforms and system-level studies*

MATLAB/Simulink remains the dominant environment for PV system modeling, controller design, and performance studies because of its rich libraries for PV modules, power electronics, and control blocks. System-level reviews of grid-connected PV outline best practices for validating models, selecting test scenarios (irradiance profiles, temperature variations, partial shading), and evaluating metrics such as energy yield, power quality, and grid interaction. Several survey papers also document case studies of utility-scale plants and discuss how simulation results translate into field performance.

III. METHODOLOGY

The methodology adopted in this study involves the systematic design, modeling, and simulation of a 3 MW grid-connected photovoltaic (PV) system using MATLAB/Simulink R2024a. The process is divided into several stages, including PV array modeling, MPPT control, inverter design, grid integration, and performance analysis under varying environmental conditions.

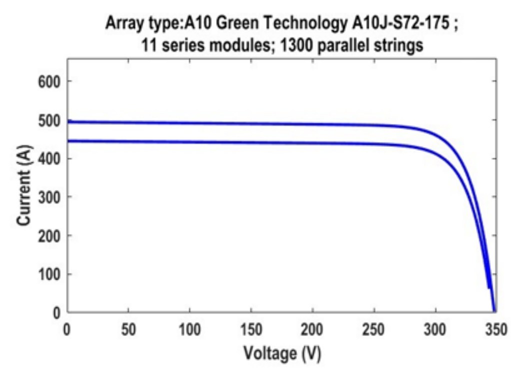


Figure. 1 I-V Characteristics of PV Array

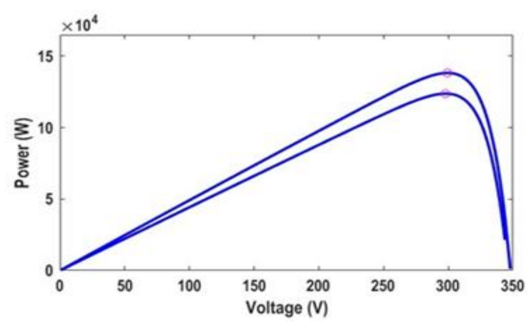


Figure. 2 P-V Characteristics of PV Array

The overall structure of the proposed system is represented in the simulation block diagram, which includes the PV array, DC–DC boost converter, DC–AC inverter, and grid connection. Each subsystem plays a crucial role in the conversion and regulation of power within the grid-connected PV framework.

Initially, solar irradiance and cell temperature act as the primary inputs to the PV array, which converts solar energy into direct current (DC) electricity. To ensure optimal energy extraction, a Maximum Power Point Tracking (MPPT) algorithm is employed. The MPPT controller dynamically adjusts the operating point of the PV array to achieve maximum power output under varying environmental conditions.

The generated DC power from the PV array is then supplied to a DC–DC boost converter, which steps up the voltage to the required level. The boosted DC voltage is subsequently fed into the DC link (Boost Le32 DC Source) that provides a stable voltage reference for the inverter stage.

Next, a three-phase voltage source inverter (VSI), modeled as a universal bridge, converts the regulated DC power into alternating current (AC) suitable for grid integration. The inverter produces a three-phase AC output, which is synchronized with the grid parameters such as voltage, frequency, and phase using a Phase-Locked Loop (PLL).

A PID controller is implemented to regulate system performance and maintain voltage and current stability throughout the power conversion process. The controller ensures smooth transitions between stages and minimizes fluctuations in output parameters. The scope blocks in MATLAB/Simulink are used to monitor various performance parameters such as PV voltage and current, converter output, inverter output waveform, and grid-side voltage and current.

The proposed system is designed to accommodate different load types connected to the grid. For AC loads, the inverter output can be directly utilized, while DC loads require individual inverters or converters for operation. This flexibility makes the model suitable for both standalone and grid-connected applications.

The design parameters are computed using the following standard relation:

1). $$V_{out} = \frac{V\ in}{1-D} \qquad \ldots(1)$$

Where,

$$D = \frac{V_{out} - V_{in}}{V_{out}}$$

2). $$C = \frac{I_{out\max} D}{\Delta V_{out} f_s} \qquad ..(2)$$

3). $$L = \frac{V_{in} D}{\Delta I_L f_s} \qquad ..(3)$$

An MPPT algorithm is integrated with the boost converter to dynamically adjust the duty cycle and operate the PV array at its maximum power point. The Perturb and Observe (P&O) method is adopted due to its simplicity and effectiveness under changing irradiance.

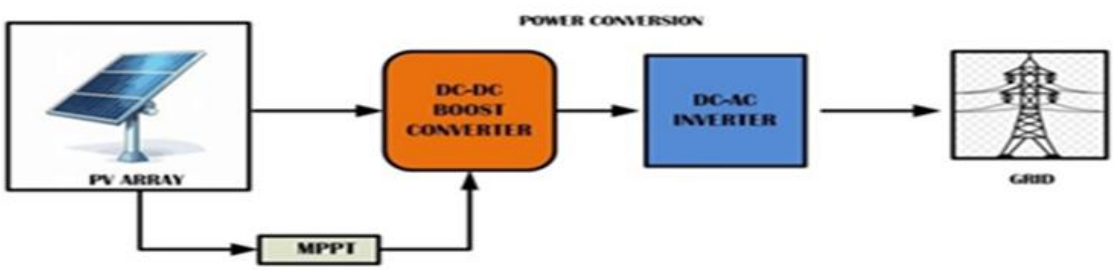
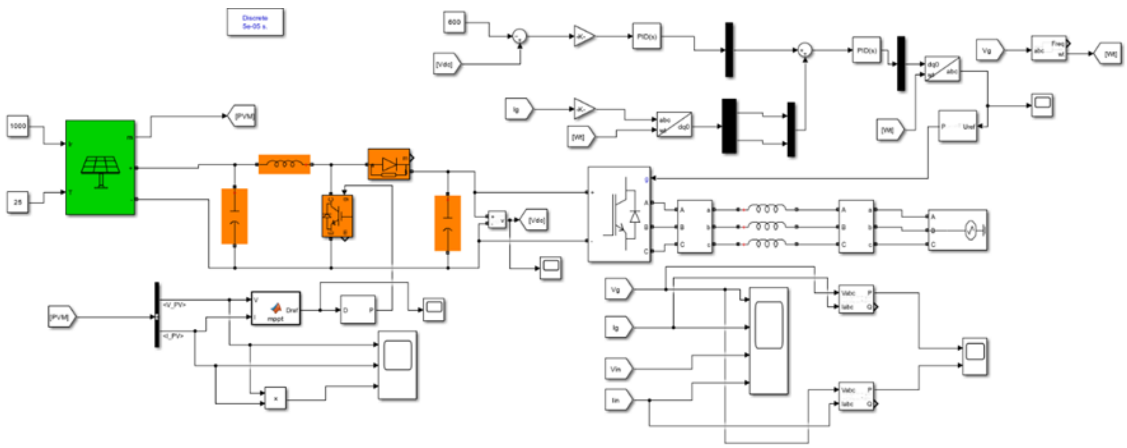
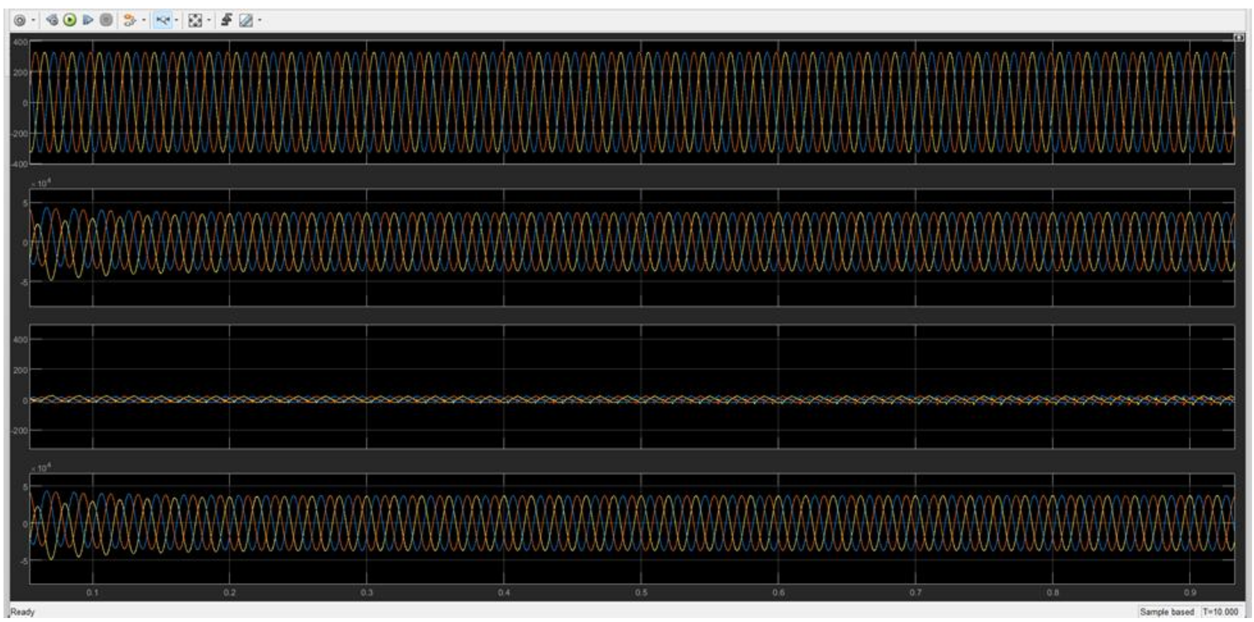


Figure.4 Basic Block diagram of PV Array connected to grid

IV. RESULT

The simulated 3 MW grid-connected solar PV system successfully converts solar energy into stable AC power synchronized with the utility grid. The MPPT algorithm maintains maximum power extraction with high efficiency (~99%), and the boost converter effectively regulates DC-link voltage. The inverter output shows balanced three phase sinusoidal waveforms with unity power factor and minimal distortion.





Grid output Waveforms

V. CONCLUSION

In this work, a 3 MW grid-connected solar photovoltaic (PV) power system was designed and simulated using MATLAB/Simulink to analyze its performance under standard environmental conditions.

The complete system—including the PV array, DC–DC boost converter, maximum power point tracking (MPPT) control, three-phase inverter, and grid interface—was successfully modeled to study the dynamic and steady-state behavior of each subsystem.

The MPPT algorithm (Perturb and Observe method) efficiently tracked the maximum power point of the PV array, ensuring optimum power extraction with an efficiency of about 98–99 %.

The boost converter stepped up the PV array voltage (≈ 320 V) to a stable DC-link voltage of around 700 V, maintaining smooth operation with minimal voltage ripple.

The inverter converted this regulated DC voltage to a balanced three-phase AC output synchronized with the grid through a Phase-Locked Loop (PLL), achieving unity power factor and high-quality sinusoidal waveforms.

Simulation results confirmed that the system can reliably deliver 3 MW of active power to the grid with negligible distortion and excellent voltage regulation.

The study demonstrates that large-scale solar PV systems can be effectively modeled and optimized in MATLAB/Simulink for real-world grid integration, validating the feasibility of renewable energy-based power generation on a utility scale.

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