Performance Analysis of a Buck–Boost Converter-Based 3 MW Grid-Integrated Solar Photovoltaic System

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***Abstract*—The integration of large-scale photovoltaic (PV) systems with the utility grid requires a reliable power electronic interface to regulate the DC-link voltage while extracting maximum power from the PV array. This paper investigates the use of a Buck–Boost converter in a 3 MW grid-connected PV System. The Buck–Boost converter provides the dual functionality of voltage step-up and step-down operation, thus ensuring stable DC-link voltage under a wide range of PV operating conditions. The converter design is carried out considering inductor current ripple, capacitor voltage ripple, and semiconductor device stresses at full load. Simulation studies are performed in MATLAB/Simulink to validate the performance of the proposed system under varying solar irradiation and temperature conditions. The results confirm that the Buck–Boost converter enhances voltage regulation capability, ensures effective maximum power point tracking (MPPT), and provides improved operational flexibility.**

***Index Terms*—solar photo voltaic, Buck-boost converter, MPPT, Inverter, Grid system**

I. INTRODUCTION

The increasing global concern over fossil fuel depletion and environmental pollution has accelerated the transition toward renewable energy sources, with solar photovoltaic (PV) systems emerging as one of the most promising alternatives. Solar PV technology offers a clean, sustainable, and modular solution for electricity generation, making it highly suitable for both standalone and grid-connected applications. However, the intermittent nature of solar irradiation and temperature variations leads to fluctuating output voltage and power, posing challenges for maintaining stable operation and reliable grid integration. Therefore, the use of efficient power electronic converters becomes essential to regulate voltage levels and optimize energy transfer.

Among various converter topologies, the buck–boost converter has gained significant attention due to its unique ability to perform both step-up (boost) and step-down (buck) operations within a single framework. This flexibility allows the converter to maintain a constant DC-link voltage irrespective of variations in PV output, thus ensuring continuous and stable power flow to the grid. Additionally, when combined with Maximum Power Point Tracking (MPPT) techniques, the buck–boost converter effectively enhances energy extraction from the PV array under dynamic environmental conditions.

This research focuses on the performance analysis of a 3 MW grid-integrated solar PV system utilizing a buck–boost converter as the primary DC–DC stage. The study aims to evaluate key performance parameters such as converter efficiency, DC-link voltage regulation, grid-side power quality, and dynamic response under variable solar and load conditions. Simulation studies are carried out to validate the system's effectiveness in maintaining grid stability and achieving high power conversion efficiency. The results highlight the suitability of the buck–boost converter for large-scale grid-connected PV applications, demonstrating its potential for improving the reliability and performance of renewable energy systems.

II. LITERATURE REVIEW

Grid-connected solar photovoltaic (PV) plants have become a significant contributor to modern power systems, with multi-megawatt installations forming an integral part of renewable energy expansion worldwide. To ensure reliable integration of such large-scale plants, appropriate power conditioning units are required, typically consisting of a DC–DC converter stage followed by a grid-tied inverter and an

output filter. The DC–DC stage serves to regulate the operating point of the PV array and to track the maximum power point (MPP), while the inverter ensures proper synchronization and power injection into the grid with acceptable power quality. Early research focused on conventional buck, boost, and buck–boost converters for small-scale PV systems. The boost converter was widely adopted for its ability to step up voltage efficiently, as reported by several authors, but its performance degraded under low irradiation conditions where the PV voltage fell below the reference level. Conversely, the buck converter was effective in voltage step-down operation but lacked the flexibility to handle wide input voltage variations. To overcome these limitations, researchers proposed the buck–boost converter, which can operate in both step-up and step-down modes, providing a stable DC-link voltage across varying environmental conditions.

III. METHODOLOGY

The PV system is designed using A10 Green Technology A10J-S72-175 modules, each rated at 175.091 W under STC (irradiance of 1000 W/m² and cell temperature of 25 °C) The configuration of 11 series modules per string and 1300 parallel strings is maintained to achieve the total rated capacity of 3 MW. The I–V and P–V characteristics of the PV array are analysed in MATLAB/Simulink to establish baseline performance.

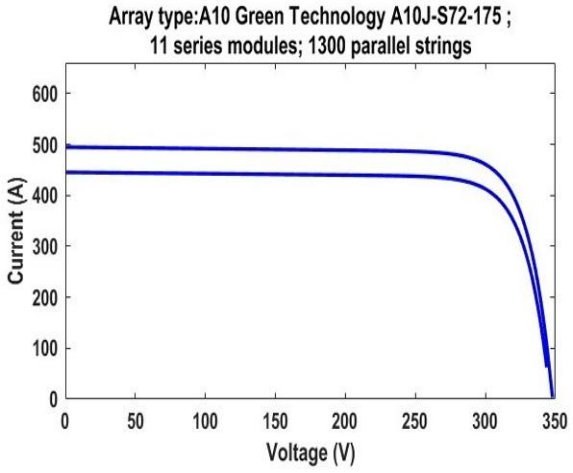


Figure. 1 I-V Characteristics of PV Array

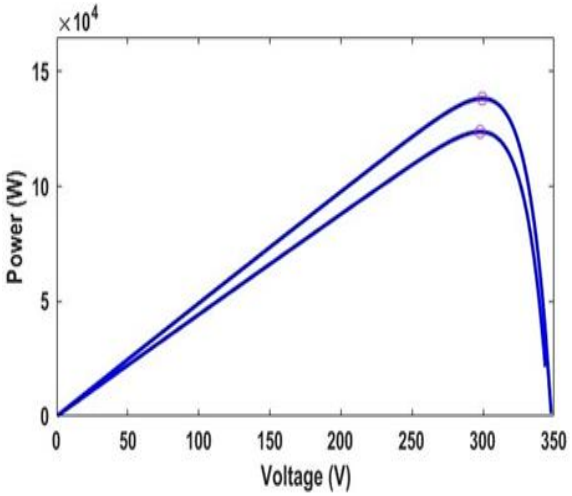


Figure. 2 P-V Characteristics of PV Array

The buck–boost converter provides flexibility to either step-up or step-down the PV output voltage, depending on irradiance and load conditions. This allows the system to handle fluctuations more effectively. The converter is modelled using a controlled switch (MOSFET), diode, inductor, and capacitor.

The design parameters are computed using the following standard relations:

$$V_{Out} = \frac{D}{1-D} V_{in} \quad (1)$$

$$L = \frac{V_{in} \cdot D}{\Delta I_l \cdot f_s} \quad (2)$$

$$C = \frac{I_{0ut} \cdot D}{\Delta v_{0ut} \cdot f_s} \quad (3)$$

An MPPT algorithm is integrated with the buck–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.

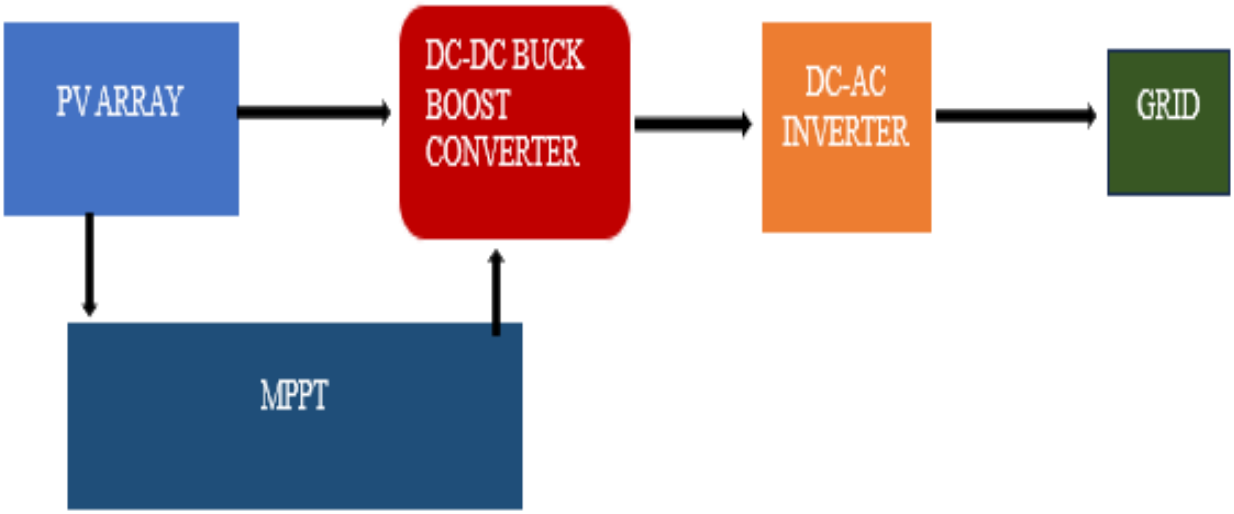
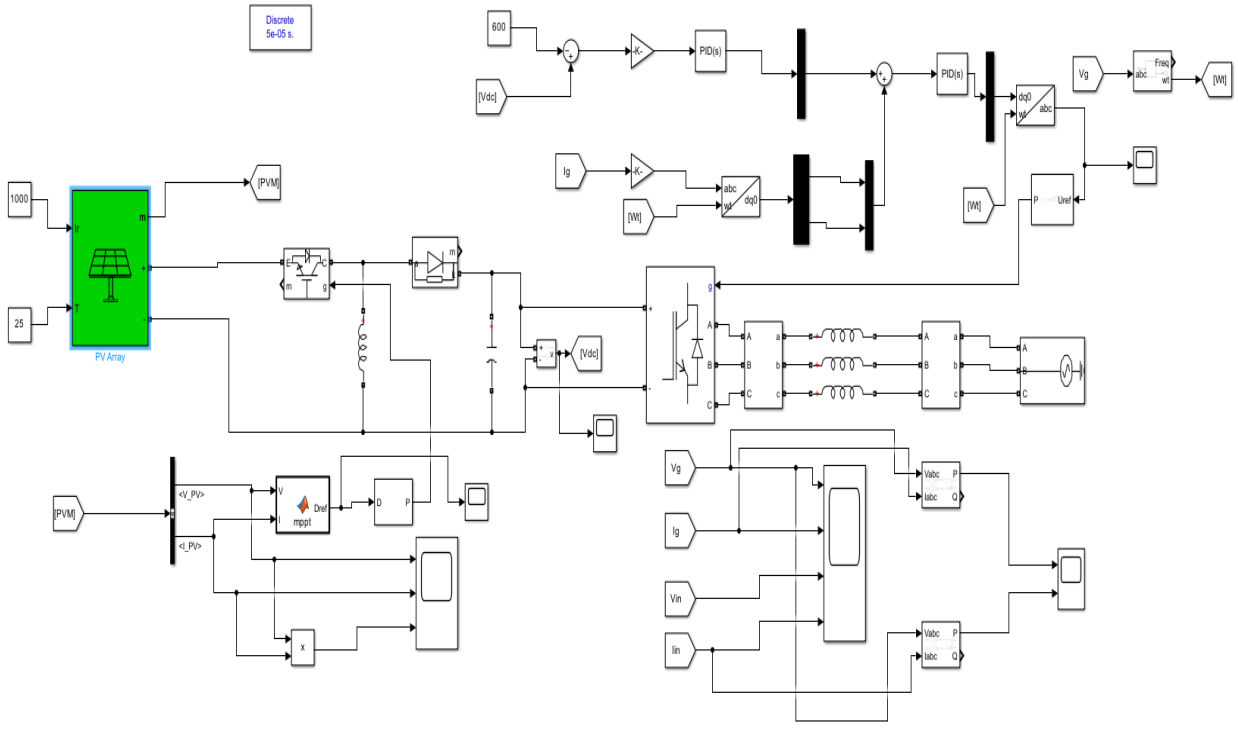


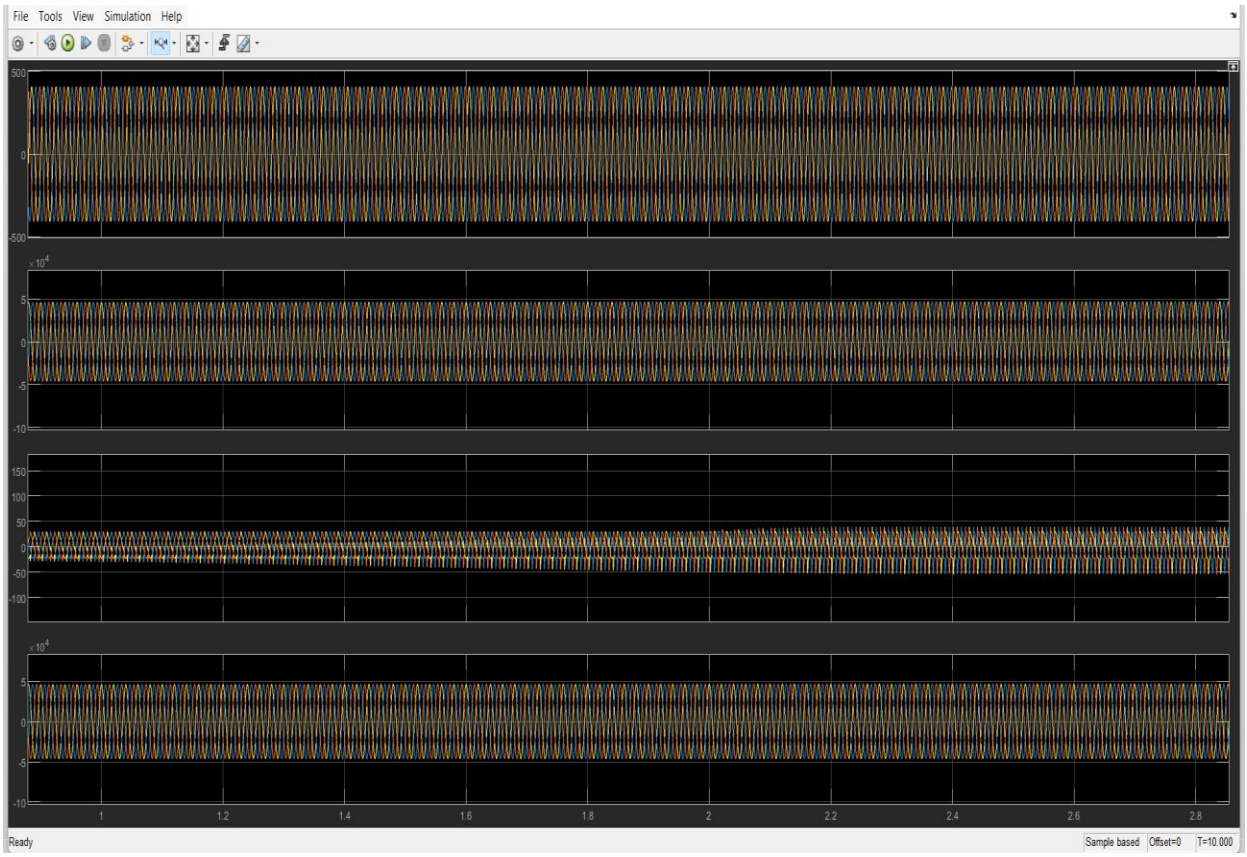
Figure.3 Basic Block diagram of PV Array connected to grid

IV. RESULT

The buck–boost converter maintained a stable DC link voltage by stepping up and stepping down as required, ensuring smooth inverter operation. The system consistently delivered 3 MW power to the grid even under varying irradiance conditions.



Grid output graphs shown below



V. CONCLUSION

In this study, the performance of a 3 MW grid-integrated solar photovoltaic system employing a buck–boost converter has been analyzed to assess its effectiveness in maintaining stable and efficient power transfer under varying environmental conditions. The simulation results confirm that the buck–boost converter provides superior voltage regulation by operating efficiently in both step-up and step-down modes, ensuring a consistent DC-link voltage despite fluctuations in solar irradiance and temperature.

The system demonstrated improved conversion efficiency, power quality, and dynamic stability, indicating the converter's capability to support large-scale grid-connected PV applications. Furthermore, the integration of Maximum Power Point Tracking (MPPT) techniques enhances the energy extraction from the PV array, leading to optimal utilization of solar resources. Overall, the proposed configuration proves to be a reliable and flexible solution for high-capacity solar power generation, offering improved operational stability and contributing to the sustainable development of renewable energy-based power systems.

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