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Analysis of Grid Connected Solar PV System using Matlab/Simulink

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ABSTRACT: This paper presents an easier approach for modelling a 3 MW grid connected photovoltaic (PV) system using MATLAB/Simulink. This system employing a DC-DC boost converter and a DC/AC inverter to supply electric power to the utility grid. The model includes the primary components: a 3 MW solar array, boost converter, and grid-side inverter. The paper begins with a comprehensive system description, providing definitions and detailed overviews of each component used in the system, discussed individually. The PV cell model is designed to be straightforward, accurate, and takes into account external temperature and solar radiation. Additionally, it introduces a maximum power point tracking (MPPT) algorithm implemented in the DC/DC converter to optimize the PV cell's power output. Finally, a three-level DC/AC inverter is utilized to regulate the output voltage of the DC/DC converter and facilitate connection of the PV array to the grid. Simulation results demonstrate how changes in solar radiation can impact the power output of any PV system, as well as showcasing the control performance and dynamic behavior of the grid-connected photovoltaic system. Modelling method is quite simple and can be adopted easily to study system characteristics at different conditions of temperature and solar insolation.

KEYWORDS: Grid-connected, DC-DC boost converter, DC/AC inverter, Solar array, Maximum power point tracking (MPPT) algorithm

I. INTRODUCTION

Most of the world's energy is derived from fossil fuels mainly by burning of coal. But this traditional way of electricity generation is a challenging issue as it contributes to greenhouse gas emissions. Besides, Fossil fuels and all the non-renewable resources to generate electricity are also depleting with time and the population is increasing. On the other hand, renewable energy resources offer promising alternate solutions for these problems as they are believed to be permanent and clean sources. Therefore, at present these issues are being handled by adopting renewable resources which includes Solar photovoltaic, wind, tidal, wave and biomass as alternate sources to produce electricity [1].

From past few decades, solar photovoltaic energy has turned into one of the important sources of renewable energy as it requires less maintenance and is noise and pollution free. Solar PV panels are used with power converters to deliver power efficiently. This forms a photovoltaic system. There are various configurations of PV systems. Among these standalone and grid connected system configurations are the most important ones [1].

A grid connected solar system has more advantages than a standalone PV system as in it electricity can be taken or send to the electric grid depending upon the load demand. It reduces bill cost as net electricity consumption can be reduced by sending extra electricity to the grid. They can also be installed without battery backup. Any photovoltaic system installed without battery backups produces more power as no storage losses are involved in the system [2].

In this paper, a 3 MW grid connected PV system has been modeled using MATLAB /Simulink. The presented system is composed of a solar PV array, maximum power point tracker to extract maximum power from the PV array, DC-DC boost converter to regulate and boost the PV array output, an inverter to convert DC power into AC power, an LC filter to filter current harmonics from the inverter output current.

The paper is structured as follows: Section II provides a detailed description of the proposed system model, encompassing all its components. Section III presents experimental results showing results of images tested. Finally, Section IV presents conclusion.

II. PROPOSED SYSTEM STRUCTURE

The proposed system described in this paper includes several key components: a PV array, a DC-DC converter, an MPPT controller, a DC-AC converter, an inverter logic controller, and grid connection equipment. In a grid-connected PV system, the inverter logic controller manages the operation of the inverter, facilitating grid interfacing.

Initially, the voltage generated by the PV array is boosted using a DC-DC boost converter before being supplied to the three-phase inverters. The inverter logic controller is responsible for controlling the inverters in this setup. The overall arrangement of this system is illustrated in Figure 1.

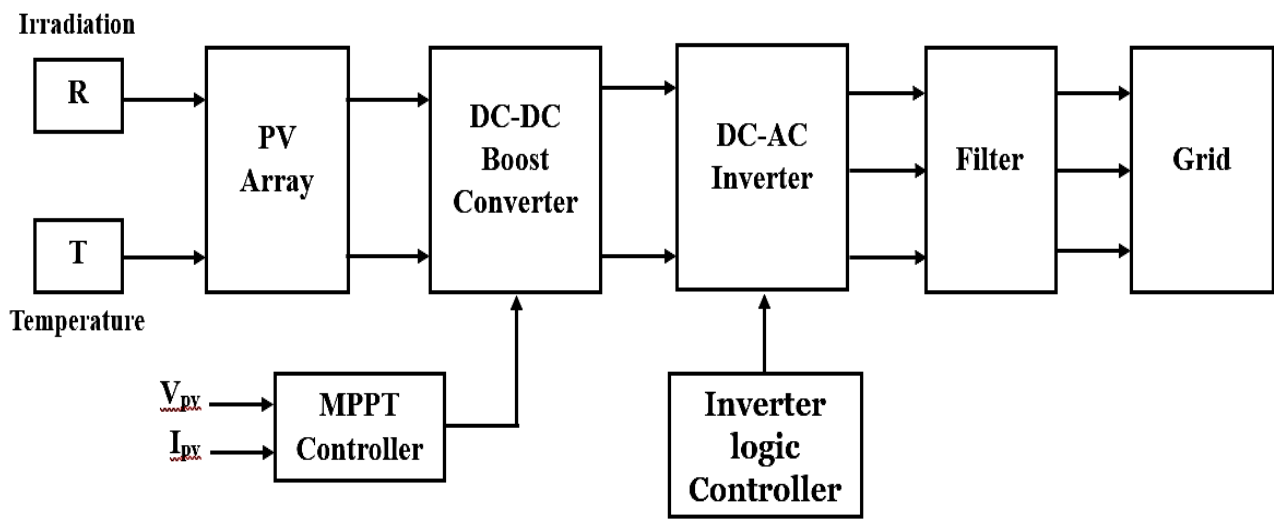


Figure 1. Block diagram of the proposed system

1. PV array modeling

A Solar cell is the basic unit of a photovoltaic (PV) system. Combination of solar cells in series forms a PV panel or PV module. These modules when connected in series and parallel form PV arrays. A photovoltaic panel is comprised of multiple photovoltaic cells interconnected in both series and parallel configurations. To grasp the functioning of a single photovoltaic cell [3]; solar cell is fundamentally a p-n junction that directly converts solar radiation into electricity. Its equivalent circuit includes a current source (I_L), a diode (I_D), a shunt resistance connected in parallel to the diode, and a series resistance. The schematic representation of this equivalent circuit is depicted in Figure 2.

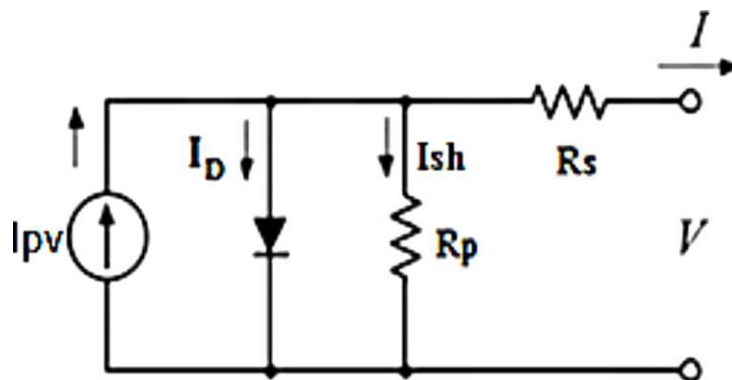


Figure 2. Represents the solar cell equivalent circuit.

A PV array is constituted by multiple modules interconnected in series and parallel configurations to produce the necessary current and voltage [3]. Solar radiation and atmospheric temperature serve as inputs to the solar array. In this study, the solar array operates under conditions of 1000 W/m^2 solar radiation and 25°C temperature. The output of the solar array varies in response to changes in these inputs, as illustrated in Figure 3.

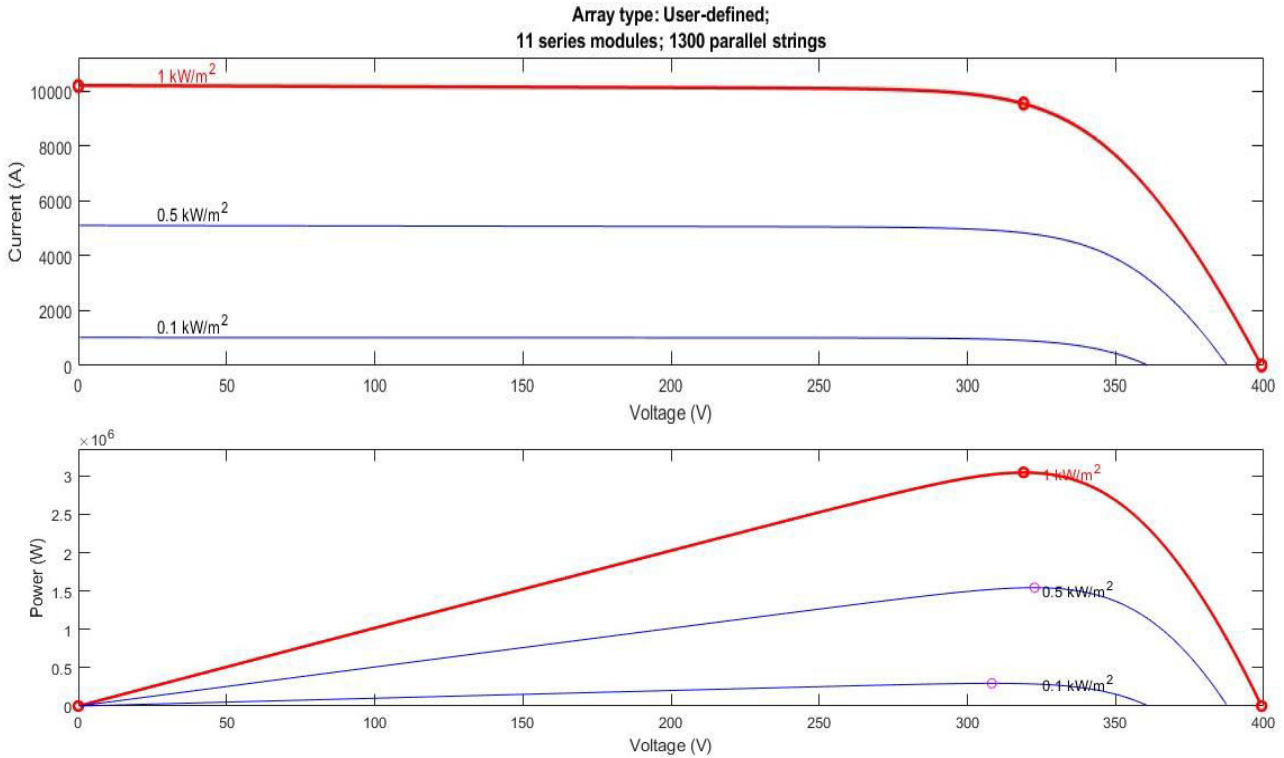


Figure 3. V-I and P-I characteristic of solar PV array.

2. MPPT controller

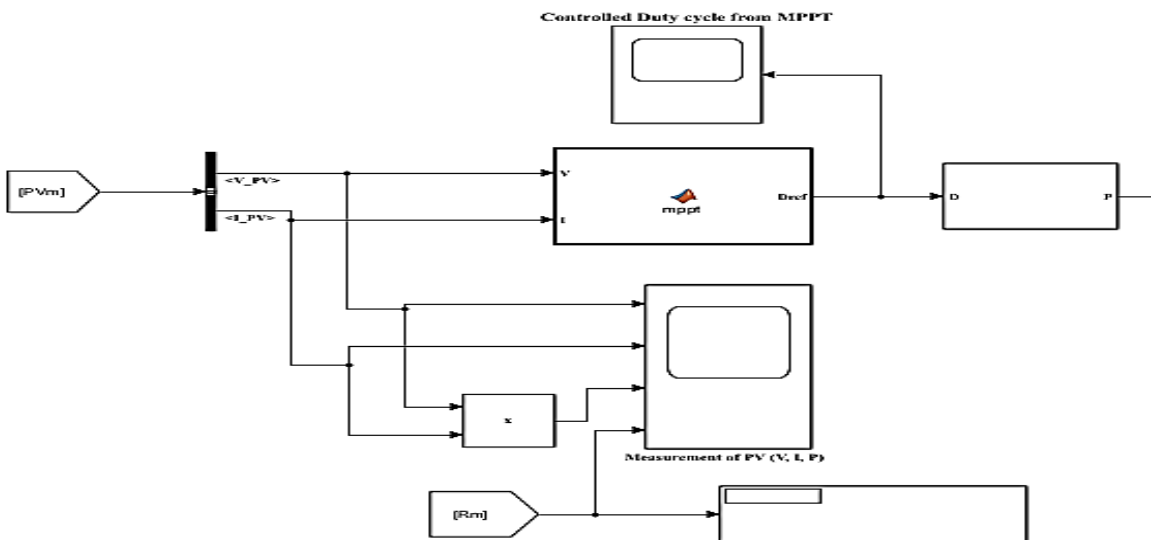


Figure 4. MPPT developed in MATLAB/Simulink.

Solar radiation and temperature vary continuously throughout the day due to changing climatic conditions. In response to these variations, the maximum power point of the PV array also fluctuates, necessitating the use of MPPT techniques to maintain the PV array at its Maximum Power Point (MPP) [4]. This paper employs the Perturb and Observe (P&O) technique for MPPT. P&O is widely recognized and utilized for its effectiveness in tracking the maximum power output from the array. The technique works by periodically perturbing (incrementing or decrementing) the voltage or current of the PV module and comparing the resulting output power with that of the previous cycle. If the output power increases due to the change in operating voltage, the control system adjusts the PV array operating point in that direction. Conversely, if the output power decreases, the operating point is adjusted in the opposite direction. This iterative process continues in subsequent cycles. The P&O MPPT technique presented in this paper is implemented using MATLAB software, as depicted in Figure 4.

3. DC-DC boost converter

The output from the PV array is fed into the DC-DC boost converter, which steps up the voltage while stepping down the current. This boost converter is crucial for implementing maximum power point tracking (MPPT) and controlling the output voltage of the PV array [6]. According to maximum power transfer theory, the most efficient power transfer occurs when the source impedance matches the load impedance, achieved by adjusting the duty cycle of the DC-DC boost converter. The duty cycle represents the ratio of the switch-on time of the converter switch to the total switching period. In response to continuously changing environmental conditions, such as varying solar radiation and temperature, the duty cycle of the DC-DC boost converter must be dynamically adjusted to extract the maximum power from the PV array [5]. The boost converter offers several advantages including simplicity, low cost, high efficiency [7], and reliability compared to other configurations. In Figure 7, a boost converter circuit is developed using MATLAB software, featuring a diode (D) for protecting the PV array against negative currents, and a capacitor (C) to mitigate high-frequency harmonics [5].

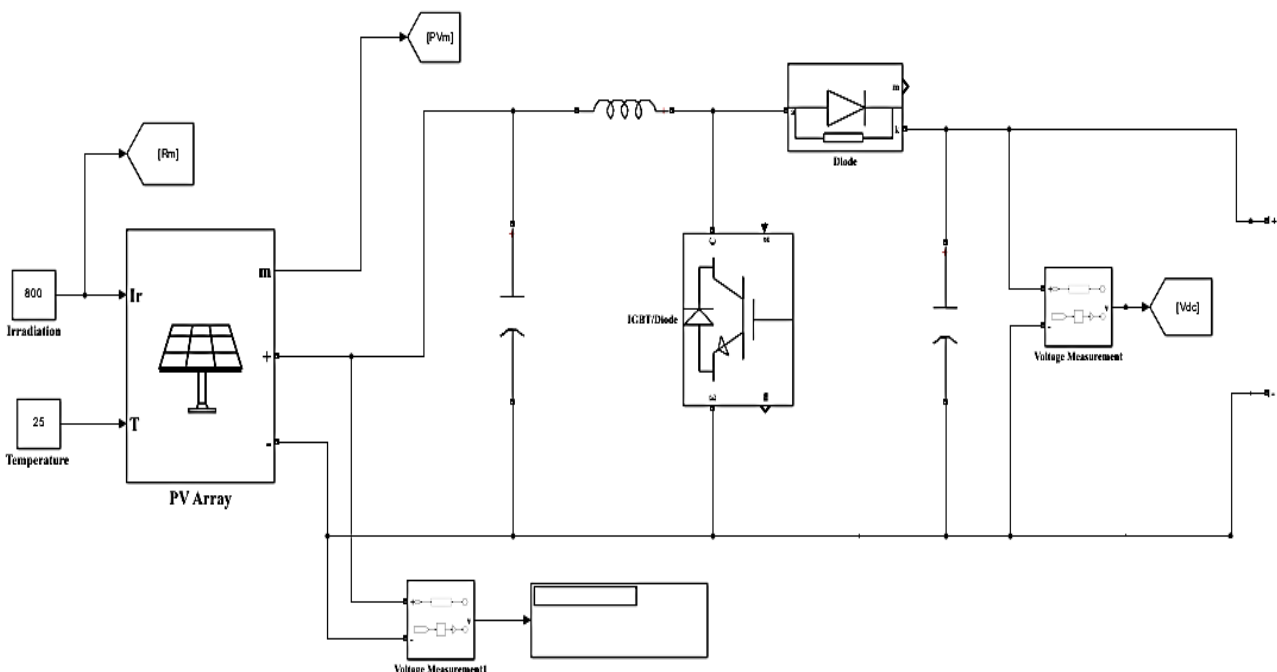


Figure 5. PV array with boost converter.

4. Three phase inverters

The output from the Boost converter is then fed into an inverter, an electrical device that converts DC to AC power. For high-power applications, three-phase inverters are commonly employed. Inverter design utilizes IGBT (Insulated Gate Bipolar Transistor) power switches due to their high voltage capability and fast switching characteristics compared to other types of switches. This paper utilizes an inverter logic controller for managing the inverter's operation.

In power electronic circuits, current control methods are crucial, particularly in applications such as AC motor drives and continuous AC power supplies, where the goal is to produce a sinusoidal AC output [8]. The inverter logic controller offers advantages such as rapid response, high tracking accuracy, and simplicity. This control technique can be implemented with either constant or variable switching frequencies. Constant switching frequency is achieved through a modified bandwidth approach based on the inductance value, while variable switching frequency utilizes a constant bandwidth ILC technique to control current within defined limits [9].

The proposed technique involves setting upper and lower hysteresis band limits. In open-loop control strategies, variations in DC output voltage due to load changes are common issues, mitigated by employing closed-loop control. In closed-loop control, a comparator compares the output current signal with a reference signal to minimize current output errors and achieve the desired output. A PI (Proportional-Integral) controller is used to generate gate pulses based on the current error. Switches are turned off when the current exceeds the upper band limit and turned on when it drops below the the lower band limit [10]. The controller implementation is developed in MATLAB, as shown in Figure 8.

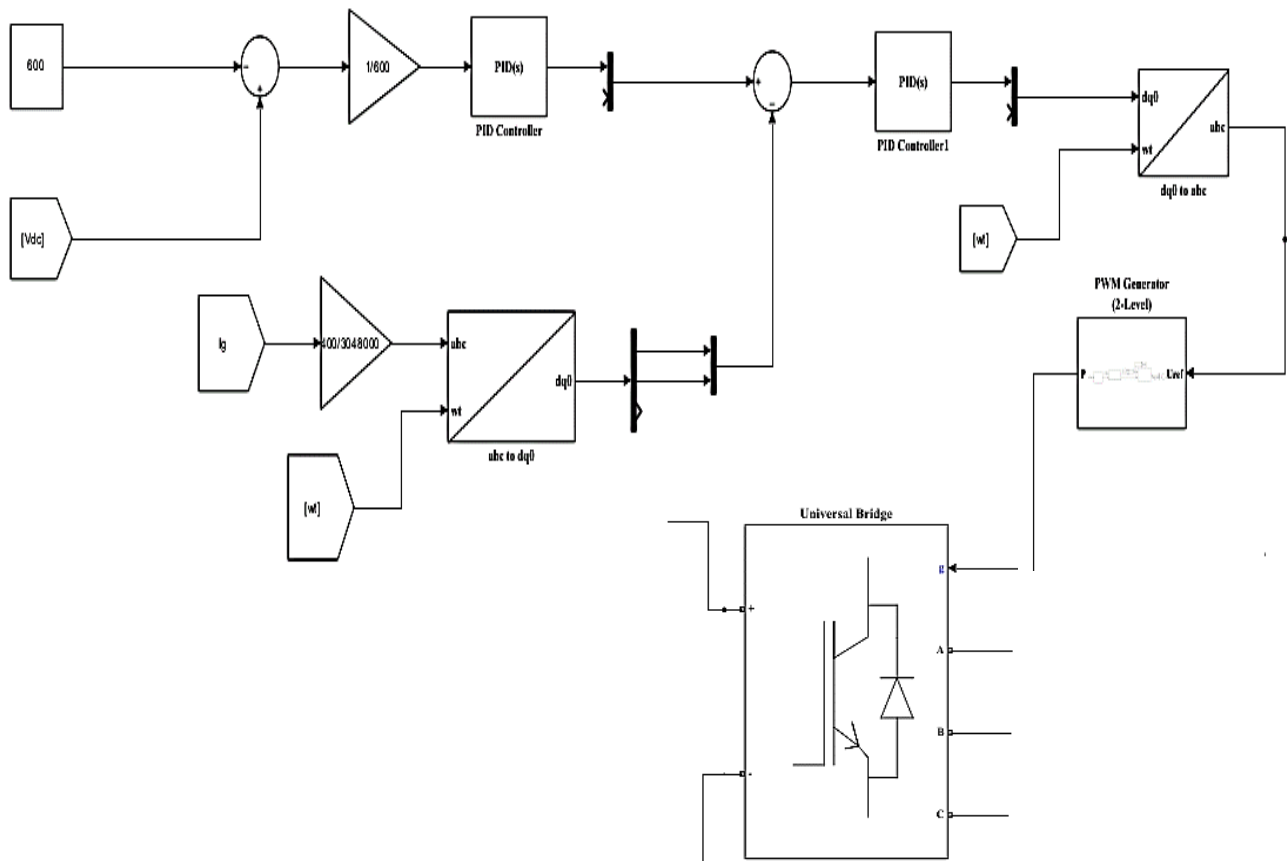


Figure 6. Matlab/simulink inverter model.

5. LC filter

LC filter at the output of the inverter is used to reduce inverter current harmonics. 50 Hz was selected as cut off frequency of the filter. Suitable inductor and capacitor values are selected using

$$f = 1 / 2\pi\sqrt{LC}$$

Where,

L is inductor inductance and

C is capacitor capacitance.

Complete grid connected system is shown in the Figure 7.

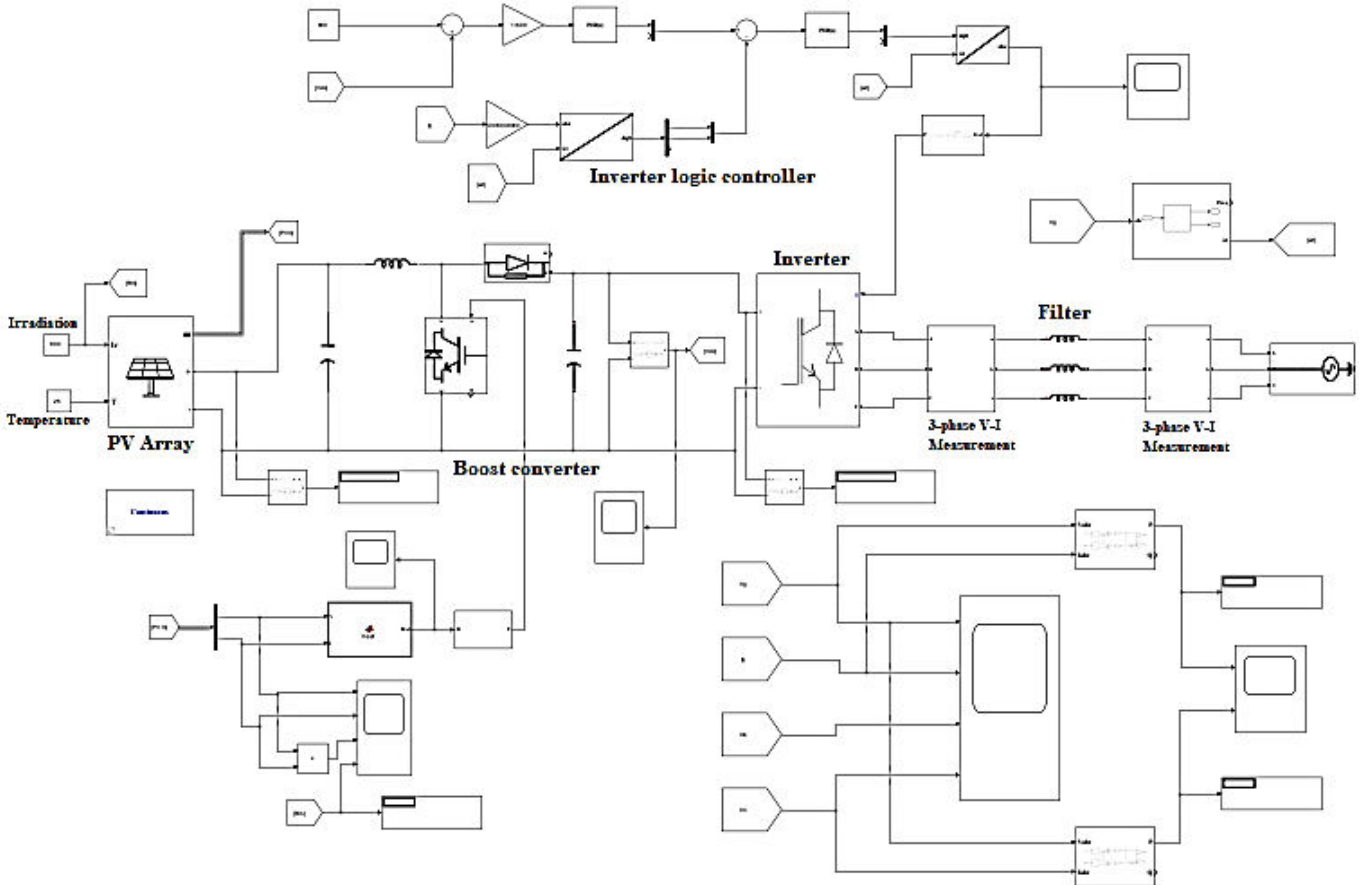
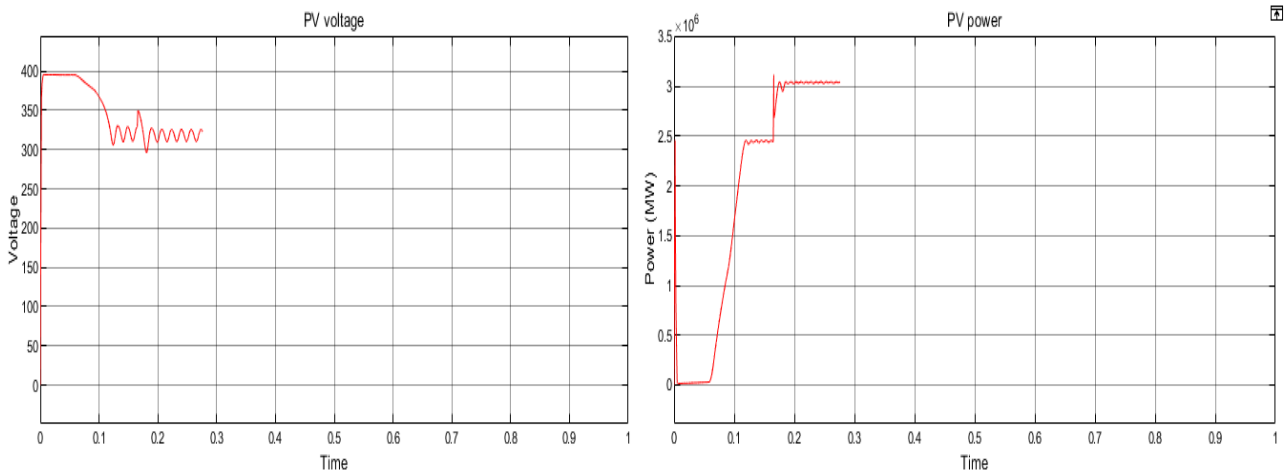


Figure 7. Complete model of grid connected PV system.

III. RESULTS AND DISCUSSION

In this simulation model, a 3MW grid-connected PV system is proposed using MATLAB software. The PV array operates optimally under 1000 W/m² solar radiation and 25°C temperature conditions. The array is configured with 1300 parallel strings and 11 series strings, each string comprising 60 modules. The voltage and current generated by the PV array are depicted in waveform in Figure 8.



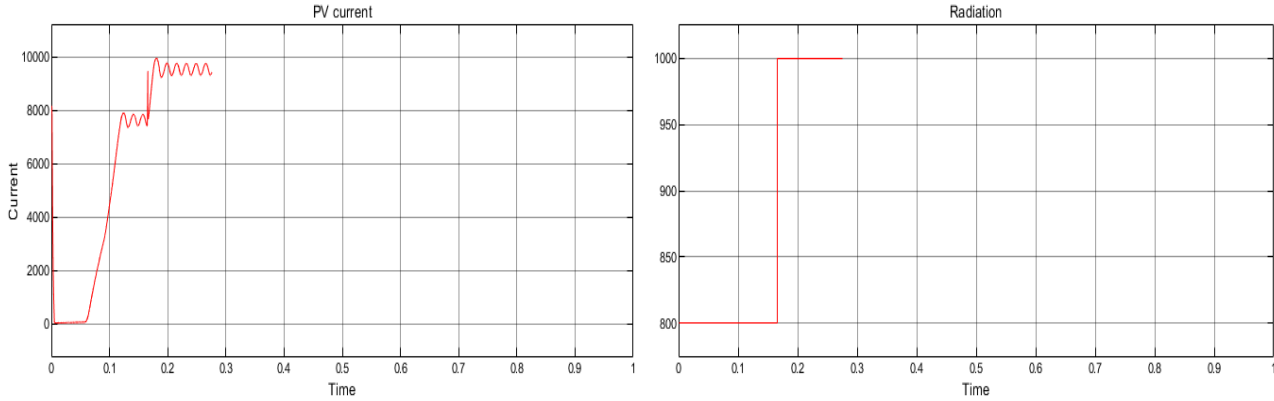


Figure 8. Voltage, Current and Power Waveform of the PV Array.

An MPPT controller is employed to continuously track the maximum power point of the PV array. The output from the MPPT controller is then directed to a boost converter, which increases the voltage by adjusting the duty cycle. The output characteristics of the boost converter are illustrated in Figure 10.

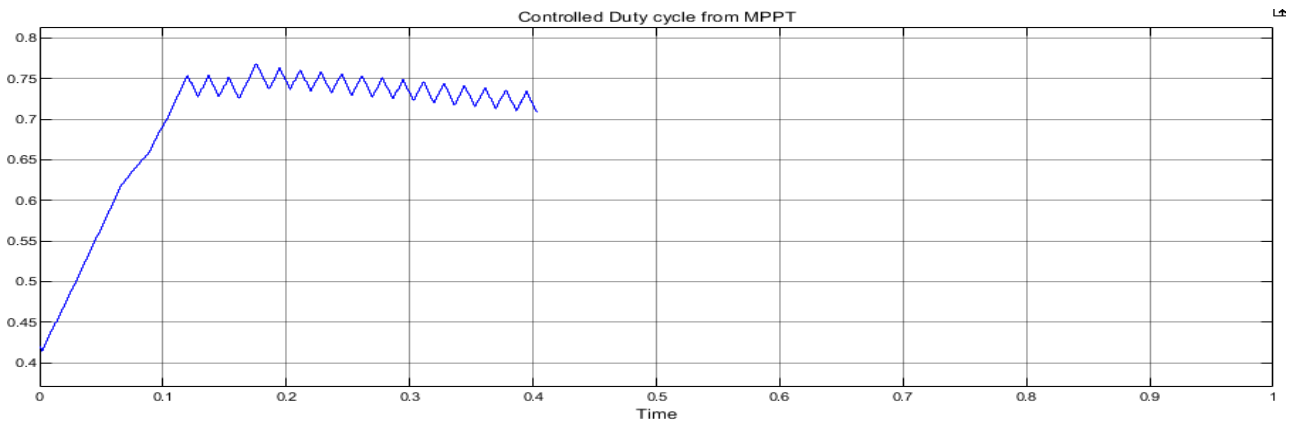


Figure 9. Duty cycle Waveform of the MPPT.

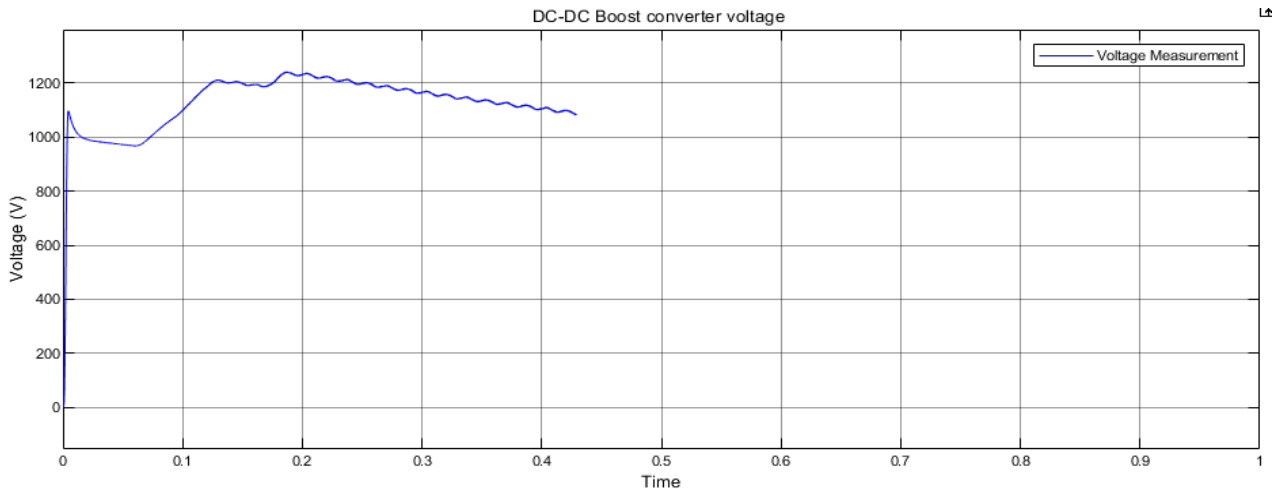


Figure 10. Output Waveform of the Boost converter

The output from the boost converter is directed to the DC-AC three-phase inverter, where an Inverter Current Limiter (ICL) is employed to manage and restrict the inverter current. Additionally, an LC filter is incorporated to effectively eliminate unwanted frequency components from the inverter output.

The voltage, current, and power characteristics at the grid connection are depicted in Figures 11 and 12.

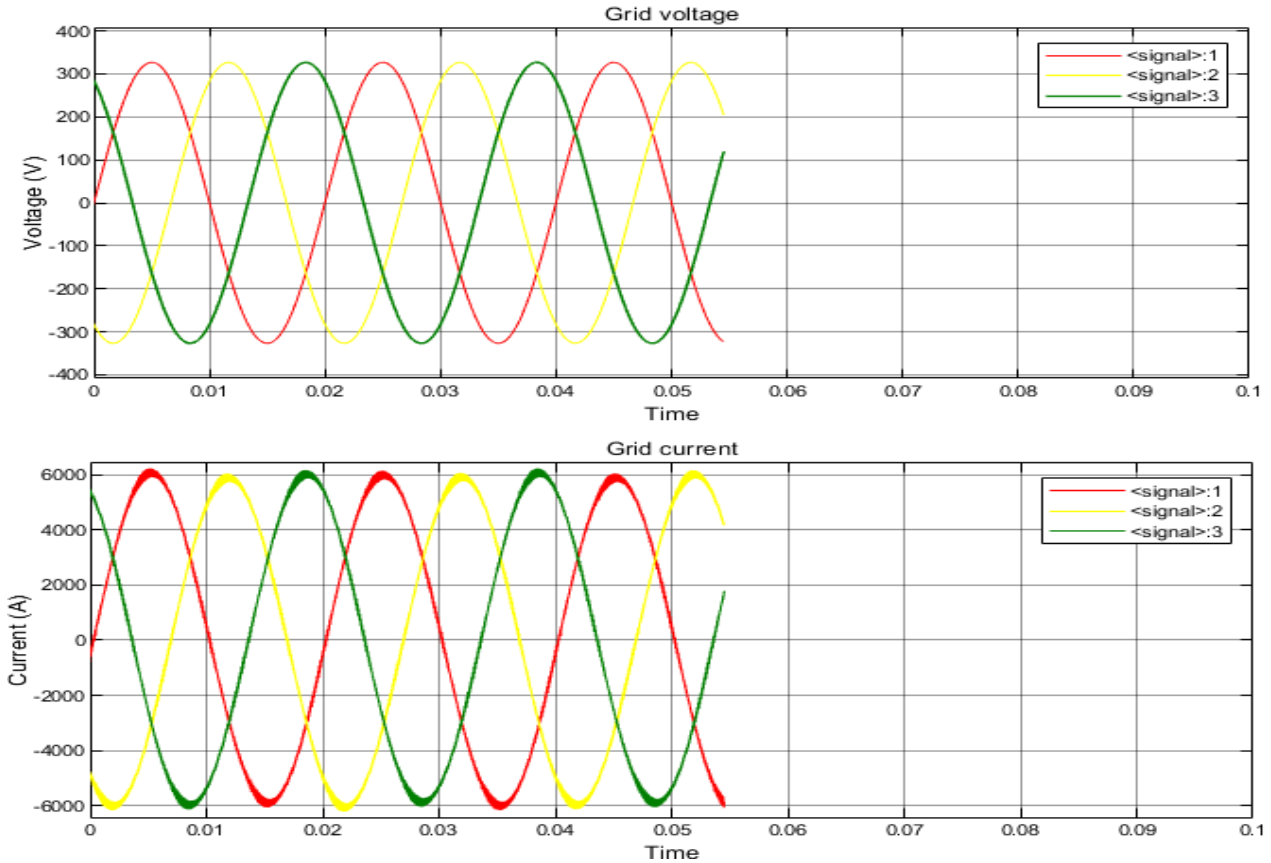


Figure 11. Grid side Output voltage and current waveform.

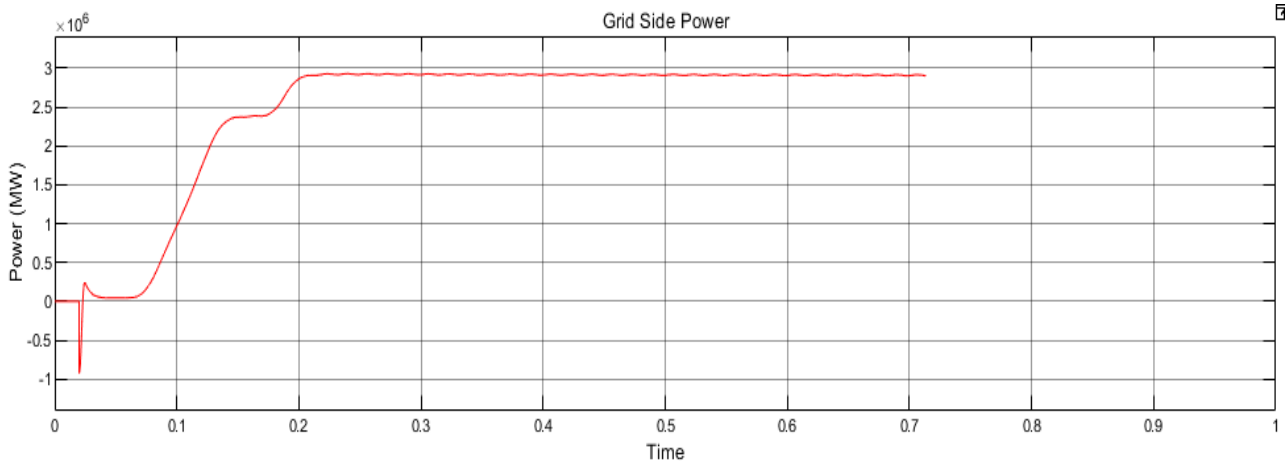


Figure 12. Grid side Output power waveform.

IV. CONCLUSION

The paper proposes a model for a grid-connected PV system, providing detailed descriptions of the system components. The PV array is modeled using datasheet values, and to maximize its output power, an incremental conductance algorithm with internal regulation is employed in conjunction with a DC-DC boost converter. A DC to AC PV inverter, coupled with an LC filter, is designed to convert DC voltage and current into AC values. Inverter logic controller modulation techniques are utilized to generate reference signals for the inverter IGBT switches. The system is tested through simulations under varying temperatures and solar irradiance levels. It is observed that changes in solar irradiance have a greater impact on the system's output power than variations in temperature. The presented model is valuable for studying the output characteristics of the system under different environmental conditions, including temperature and solar irradiance variations.

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