



## Optimized Design And Simulation Of A Solar Photovoltaic Power Generation System With Enhanced Power Conversion Efficiency For Residential Applications

Vijayalakshmi R

Department of Robotics And Automation  
B.E Robotics And Automation PSG College Of  
Technology  
Coimbatore

Dhivyabharathi N

Department of Robotics And Automation  
B.E Robotics And Automation  
PSG College Of Technology  
Coimbatore

Dr.Anbarasi MP

Department of Robotics And  
Automation  
B.E Robotics And Automation  
PSG College Of Technology  
Coimbatore

**Abstract**—The optimized design and simulation of a solar photovoltaic (PV) power generation system tailored for residential applications. Through MATLAB Simulink, key components including PV panels, a DC-DC boost converter, an inverter, and a passive filter are modeled and integrated to efficiently harness solar energy. Emphasis is placed on enhancing power conversion efficiency while considering the influence of solar irradiation and temperature. The design intricacies of the DC-DC boost converter and inverter facilitate seamless DC to AC power conversion, addressing residential load requirements. Integration of a passive filter ensures grid compatibility by mitigating harmonics. Optimization techniques are applied to maximize solar power utilization, resulting in an efficient and reliable system. Simulation results validate the system's performance, which is further confirmed through experimental validation. This study contributes insights into sustainable energy solutions, offering a refined approach to residential solar PV systems.

**Keywords**—Solar Photovoltaic System, MATLAB Simulink, Residential Applications, Power Conversion Efficiency, DC-DC Boost Converter, Inverter Design, Passive Filter Integration, Solar Irradiation, Temperature Effects, Optimization Techniques.

### I.INTRODUCTION

This paper presents an optimized design and simulation approach for a solar photovoltaic (PV) power generation system tailored specifically for residential applications. The focus lies on maximizing power conversion efficiency and

reliability, crucial aspects in meeting the increasing demand for sustainable residential energy solutions. By utilizing MATLAB Simulink, an integrated modeling and analysis framework is employed to simulate the behavior of various system components. These include PV panels, DC-DC boost converters, inverters, and passive filters. The primary objective is to develop innovative strategies that enhance energy output while minimizing system losses. Efficient power conversion is central to the performance of solar PV systems, with DC-DC boost converters and inverters facilitating the conversion of variable DC output from PV panels into stable AC power suitable for household consumption[1].

Furthermore, the paper addresses challenges related to harmonic distortion and grid compatibility through the integration of passive filters. These filters mitigate issues arising from fluctuations in solar irradiation and temperature effects, ensuring smooth system operation within residential environments. By carefully designing and optimizing system components, the paper aims to establish a robust foundation for sustainable residential energy solutions. The study emphasizes the significance of efficient power conversion and highlights the role of advanced simulation techniques in exploring innovative strategies for enhancing system performance[2].

The operational modes of photovoltaic generation systems, which can either operate in isolated systems or be connected to the grid to form integrated systems as shown in Figure 1. Additionally, it explores the potential of combining photovoltaic systems with other electrical renewable energy sources to form distributed renewable energy generation networks. Through comprehensive modeling and analysis, the paper provides insights into the design and optimization of solar PV systems for residential applications, contributing to the advancement of sustainable energy solutions.

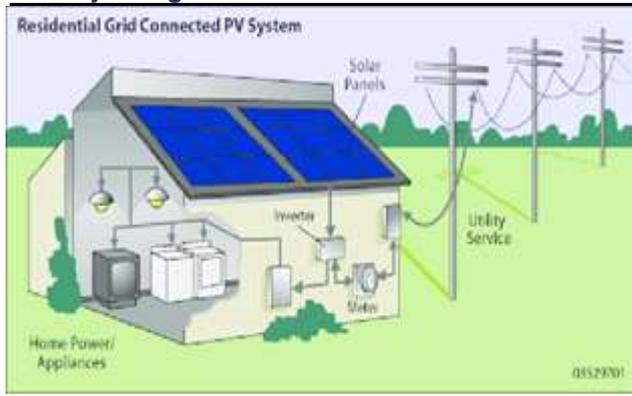


Figure 1. Residential Grid tied PV System

that are separated at the junction. Figure 3 shows the solar panel diagram.

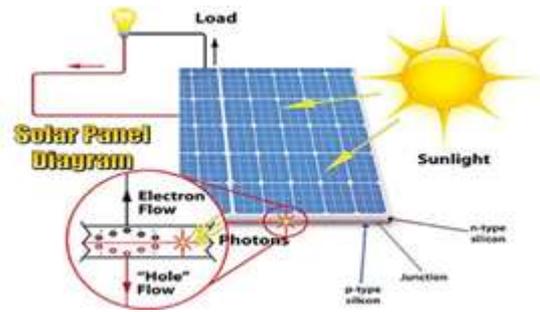


Figure 3. Solar panel working diagram.

II. MODELING APPROACH

A. Modeling of Photovoltaic Panels

Photovoltaic (PV) modules consist of numbers of photovoltaic cells that are connected in series and parallel used to generate electricity from solar energy. The characteristics of PV modules are different based on the model and environment factors. In this paper, simulation of a photovoltaic module using Matlab Simulink approach is presented. The method is used to determine the characteristics of a PV module in various conditions especially in different levels of irradiations and temperature. By having different values of irradiations and temperature, the results showed the output power, voltage and current of the PV module can be determined. In addition, all results from Matlab Simulink are verified with theoretical calculation. This proposed model helps in better understanding of PV module characteristics in various environments. Current versus voltage (I-V) characteristics of the PV module can be defined in sunlight and under dark conditions. In the first quadrant, the top left of the I-V curve at zero voltage is called the short circuit current. This is the current measured with the output terminals shorted (zero voltage). The bottom right of the curve at zero current is called the open-circuit voltage. This is the voltage measured with the output terminals open (zero current). Figure 2 shows the (I-V) characteristics of the PV module[2].

B. Analysis of DC-DC Voltage Boosting Circuits

A DC-to-DC boost converter is also called a step-up converter. The power ( $P=VI$ ) must be conserved, the output current is smaller than the input current. From the proposed design, the boost converter is able to produce a constant output voltage of 12V from a variable voltage of the solar panel.

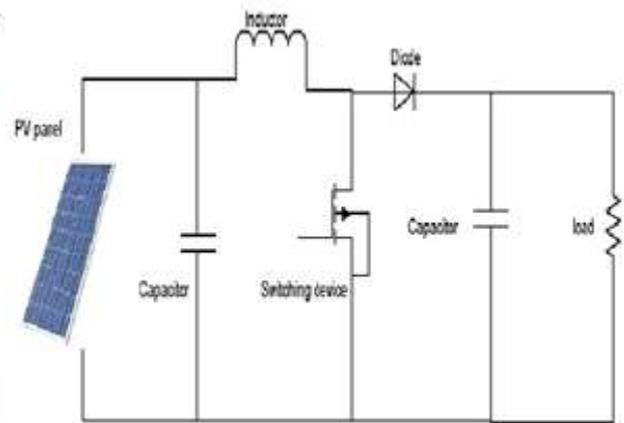


Figure 4. PV panel connected with dc-dc boost converter

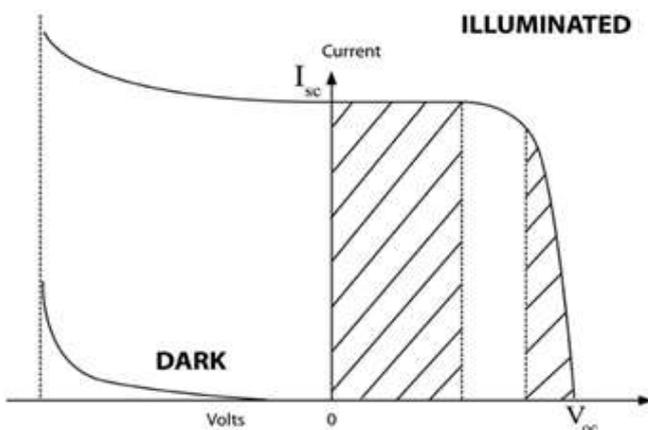


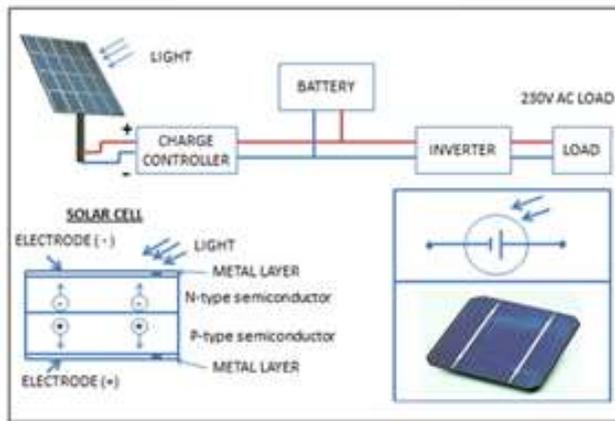
Figure 2. (I-V) characteristics of PV modules.

boost converters are mathematically described by equations that capture their nonlinear behavior. Control strategies like Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) are utilized to maintain output voltage stability. Figure 4 shows the PV panel connected with a dc-dc boost converter. The Key components such as inductors, capacitors, diodes, and switches are represented through mathematical models. Pulse Width Modulation (PWM) is employed to control the switching mechanism, ensuring precise voltage regulation. The inductor's dynamic behavior, involving energy storage and release, is crucial during switching cycles. Feedback control loops are integrated to stabilize output voltage across various load conditions. Through simulations in MATLAB Simulink, the efficiency, voltage ripple, and transient response of boost converters are thoroughly analyzed.

The physics of the PV cell is very similar to the classical p-n junction diode. When light is absorbed by the junction, the energy of the absorbed photons is transferred to the electron system of the material, resulting in the creation of charge carriers

### C. Modeling Inverter Circuits

An inverter is one of the most important pieces of equipment in a solar energy system. It's a device that converts direct current (DC) electricity, which is what a solar panel generates, to alternating current (AC) electricity, which the electrical grid uses. In DC, electricity is maintained at constant voltage in one direction. In AC, electricity flows in both directions in the circuit as the voltage changes from positive to negative. Inverters are just one example of a class of devices called power electronics that regulate the flow of electrical power.

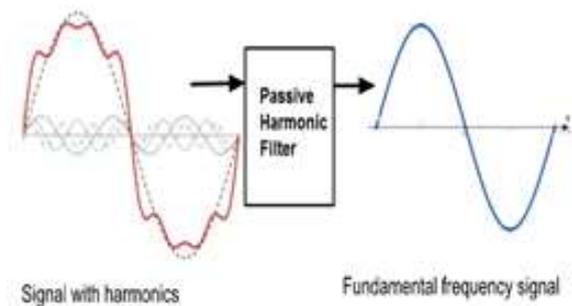


**Figure 5.** Solar inverter system

Fundamentally, an inverter accomplishes the DC-to-AC conversion by switching the direction of a DC input back and forth very rapidly. Figure 5 shows the working of the solar inverter system. As a result, a DC input becomes an AC output. In addition, filters and other electronics can be used to produce a voltage that varies as a clean, repeating sine wave that can be injected into the power grid. The sine wave is a shape or pattern the voltage makes over time, and it's the pattern of power that the grid can use without damaging electrical equipment, which is built to operate at certain frequencies and voltages. Simulation studies analyze the inverter's transient response, harmonic distortion, and overall efficiency within MATLAB Simulink. Feedback loops are utilized to regulate output voltage and frequency, ensuring stable and reliable operation under dynamic conditions. Experimental validation confirms the accuracy of the simulation model and verifies the inverter's performance in real-world scenarios.

### D. Designing Passive Filters

Passive filters are used to protect sensitive, expensive equipment from harmonics. Shunt passive filters block harmonic currents by diverting their path to the ground instead of the power system. Shunt passive filter components are rated for only a fraction of the power system-rated voltage. This rating decreases the size of the filter components and their cost.



**Figure 6.** passive harmonic filter signal

Harmonics are noises or disturbances in voltage or current. When a waveform consists of harmonics, apart from the fundamental frequency component, there will be components with frequencies equal to multiples of the fundamental frequency. For example, if the fundamental frequency of a voltage or current waveform is 60 Hz, then  $2 \times 60 = 120$  Hz and  $3 \times 60 = 180$  Hz frequency components present in the waveform correspond to the second and third voltage or current harmonics, respectively. Figure 6. A passive harmonic filter signal shows when a passive harmonic filter is applied to the signal with harmonics it will reduce the noises and provide the fundamental frequency signal without noise. Current harmonics are induced by non-linear loads such as variable speed drives, magnetic circuits, motors, etc. Voltage distortions result from the effect of harmonics using source impedance[6].

Devices that eliminate or minimize harmonics from reaching the system downstream are called harmonics filters. Harmonic filters can be classified based on the rating of voltage, power, and the number of phases. The major division of harmonic filters is active and passive filters. Integration of passive filters into the system model enhances grid compatibility and reduces the risk of equipment damage.

## III.SIMULATION SETUP

The simulation setup encompasses defining input parameters such as solar irradiance, temperature, and load profiles. Solar irradiance data is obtained from meteorological sources or modeled based on geographic location and time of day. Temperature variations are considered to accurately model the effect on photovoltaic panel performance. Load profiles represent the energy consumption patterns of residential appliances and devices.

### A. Modeling Solar Irradiance and Temperature Input

Solar irradiance and temperature data are crucial inputs for simulating the behavior of the photovoltaic (PV) panel. These data can be obtained from meteorological sources such as weather stations or satellite observations. Alternatively, solar irradiance and temperature can be modeled based on geographical location, time of day, and historical weather data using mathematical models. High temperatures can cause a decrease in panel efficiency due to increased resistance and thermal losses.

In MATLAB Simulink, blocks or functions are used to represent the solar irradiance and

temperature inputs. These inputs are connected to the PV panel model.

### B. Simulation of Photovoltaic Panel

A detailed model of the photovoltaic panel is developed, incorporating parameters such as temperature coefficients, cell characteristics, and shading effects. The model calculates the DC voltage output of the panel based on the incident solar irradiance and temperature.[3]

### C. Connection to DC-AC Inverter

The DC voltage output from the photovoltaic panel is fed into the DC-AC inverter model. The inverter model, typically based on pulse-width modulation (PWM) techniques, converts the DC voltage to AC voltage suitable for residential appliances[6].

### D. Integration of Passive Filter

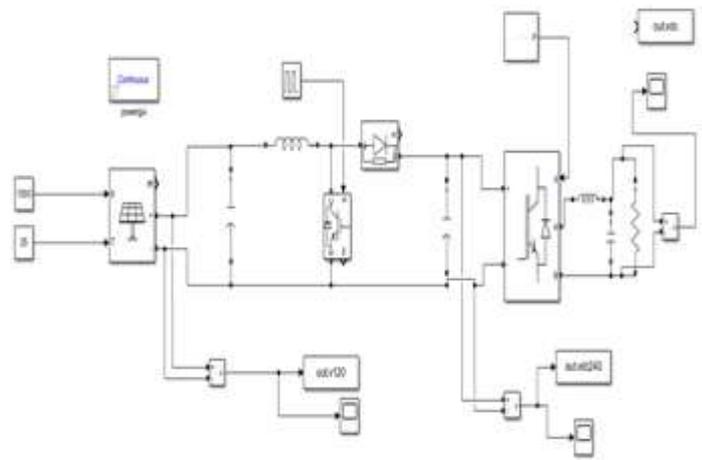
A passive filter, comprising capacitors and inductors, is connected to the output of the inverter to reduce harmonic distortion and improve power quality. The filter helps ensure compliance with grid standards and enhances the stability of the electrical network.

### E. Boost Converter Connection for Power Optimization

To maximize power generation efficiency, a boost converter is inserted between the photovoltaic panel and the inverter. The boost converter increases the voltage level of the DC output from the panel, optimizing power transfer to the inverter.

### F. Pulse Generation Between Solar Panel and Boost Converter

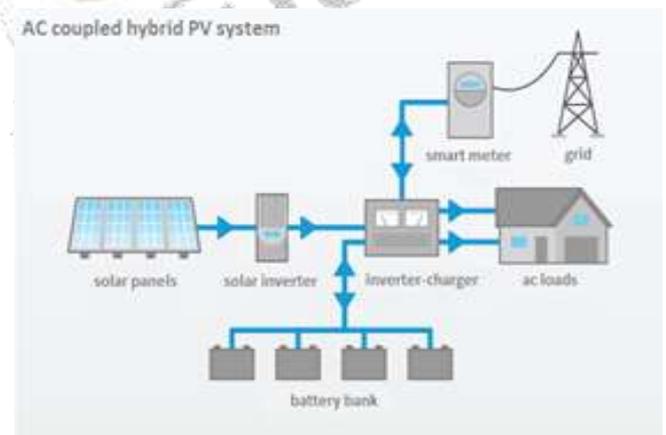
Pulse generation techniques, such as PWM control, are implemented to regulate the operation of the boost converter. By adjusting the duty cycle of the pulses, the boost converter maintains the desired output voltage level while maximizing power extraction from the solar panel. Connect a capacitor between the output of the PV panel and the input of the boost converter to reduce voltage ripple. Size the capacitor appropriately to smooth out fluctuations in the DC voltage output from the PV panel, improving the efficiency of the boost converter. Configure data logging in Simulink to capture simulation results, including voltage/current waveforms, power output, and system efficiency. Analyze simulation data to evaluate the performance of the solar PV system under different operating conditions and load scenarios.



**Figure 7.** Simulation of a Solar Photovoltaic Power Generation System

## IV. RESULTS

In the simulation setup, the boost converter simulated efficiently steps up the DC voltage from the solar panel to a level suitable for the inverter. The capacitor effectively reduces ripple in the DC voltage, ensuring a smoother input for the inverter. The inverter reliably converts the DC power to AC, providing a stable 240V supply for home use. The passive filter connected to the inverter output cleans up harmonics, ensuring the quality of the AC waveform. The below Figure 7. Shows the AC coupled solar PV systems with Battery Storage. Overall, the system demonstrates effective utilization of solar power, with minimal loss and high reliability in providing grid-compatible AC power.



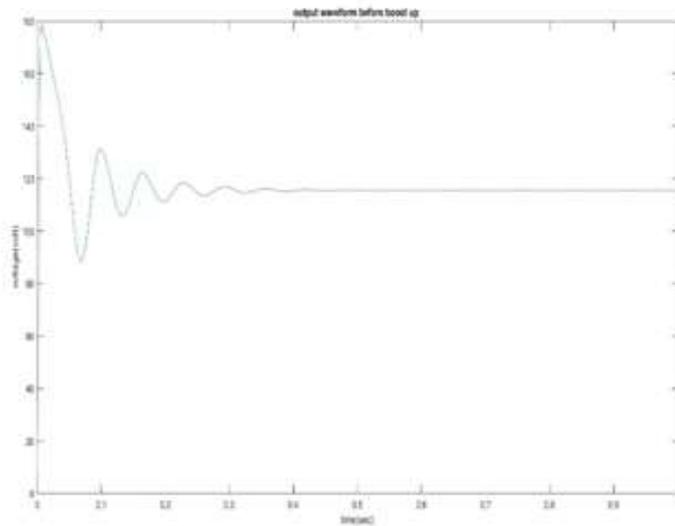
**Figure 7.** AC coupled solar PV systems with Battery Storage.

### A. Before applying passive filter

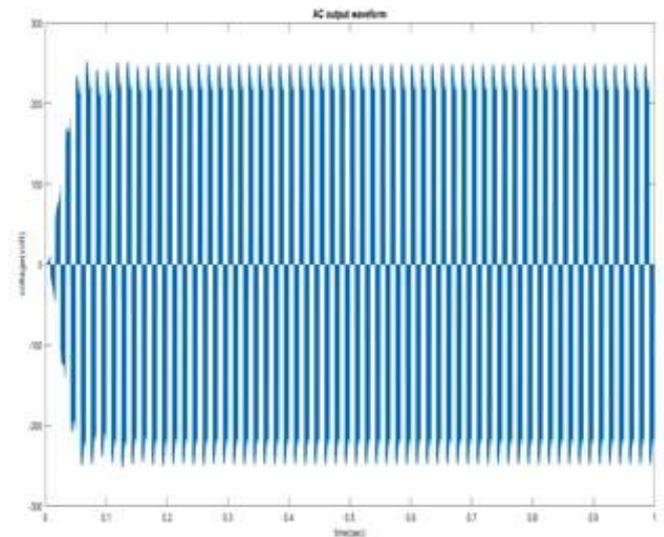
The output waveform directly from the solar panel depicts the DC voltage generated by the panel. This waveform serves as a direct representation of the voltage output over time. Variations in the output voltage are influenced by factors such as irradiation levels, temperature, and shading. High irradiation levels and optimal operating conditions may result in higher voltages, whereas low light conditions or shading can lead to voltage decreases. The

waveform exhibits both steady-state behavior, where the output voltage remains relatively constant, and transient behavior, characterized by fluctuations during changes in environmental or load conditions. The 120V DC output is expected to be observed before boosting, with the waveform hovering around this voltage level. Any deviations from this voltage level should be carefully analyzed to discern the factors influencing the solar panel's output voltage.

The presence of harmonics can distort the waveform and affect the quality of the AC power supplied to the load. Assess the voltage regulation of the waveform to ensure that it remains within acceptable limits under varying load conditions. Any significant deviations from the desired voltage level (240V AC) may indicate issues with the inverter's control or regulation mechanism. Ideally, the waveform should be free from harmonics and distortions. However, in practical scenarios, there may be some degree of harmonic distortion present. Analyze the waveform to ensure that any harmonic content is within acceptable limits.



**Figure 8.** Output waveform before boost up(120Vdc)

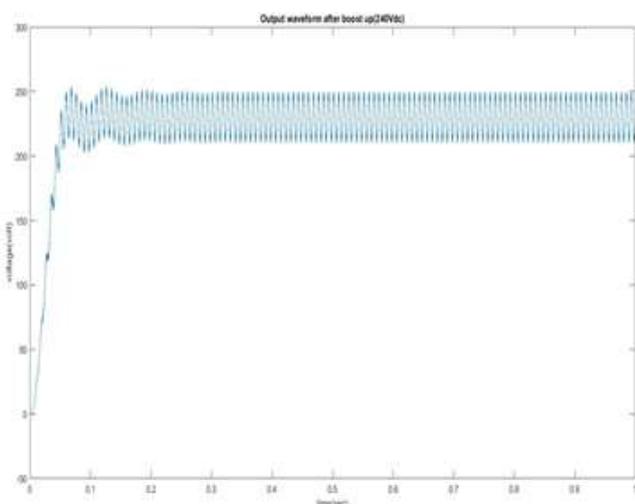


**Figure 10.** AC voltage Output waveform without filter

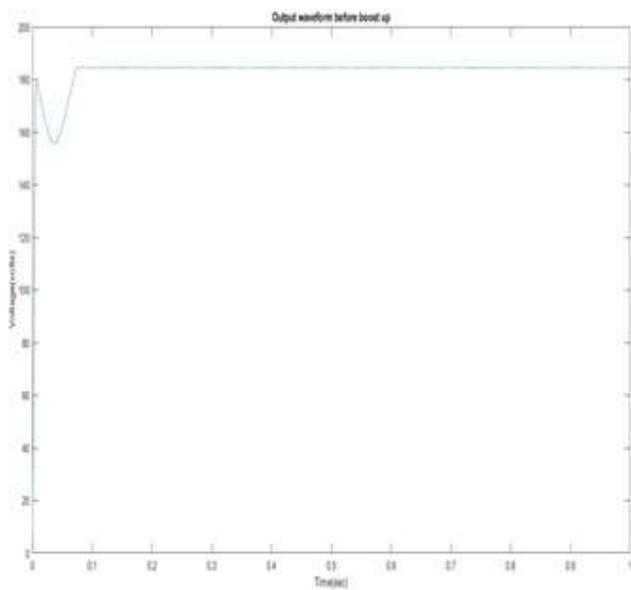
Applying the boost converter, the DC voltage output stepped up to a higher voltage level suitable for the inverter. Since there's no filter applied yet, the waveform is still a DC voltage waveform. If the AC output waveform is observed without a filter, it exhibits some distortion and ripple due to the switching action of the inverter. The AC output waveform may still resemble a sinusoidal shape, but it will likely exhibit some distortion or irregularities compared to a pure sinusoidal waveform. This distortion is caused by the switching behavior of the inverter and manifests as sharp edges or non-linearities in the waveform. The waveform may contain harmonics at frequencies that are multiples of the fundamental frequency (e.g., 50 Hz or 60 Hz).

*B. After applying passive filter*

Applying the passive filter to the output of the solar panel but before boosting the voltage, the resulting DC voltage waveform is smoother and more stable compared to the raw output from the solar panel. The output waveform shows the DC voltage from the solar panel after it has passed through the passive filter. The filter will have smoothed out any ripple or fluctuations present in the voltage, resulting in a more stable and consistent DC voltage level. The passive filter helps to stabilize the voltage output, ensuring that it remains within the desired range under varying irradiation levels, temperature variations, and load conditions. The passive filter also helps to improve voltage regulation by reducing the impact of transient disturbances and load variations on the DC voltage output. This results in a more stable and consistent voltage level, which is crucial for the reliable operation of the solar power system.

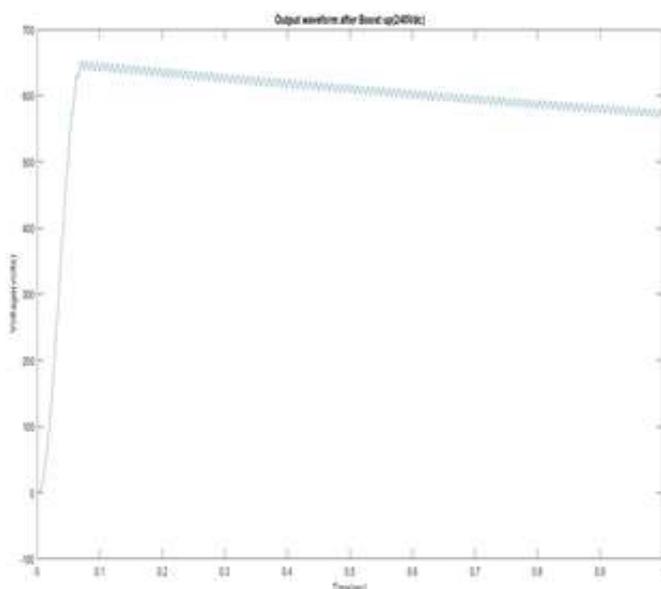


**Figure 9.** Output waveform after boost up (240Vdc)



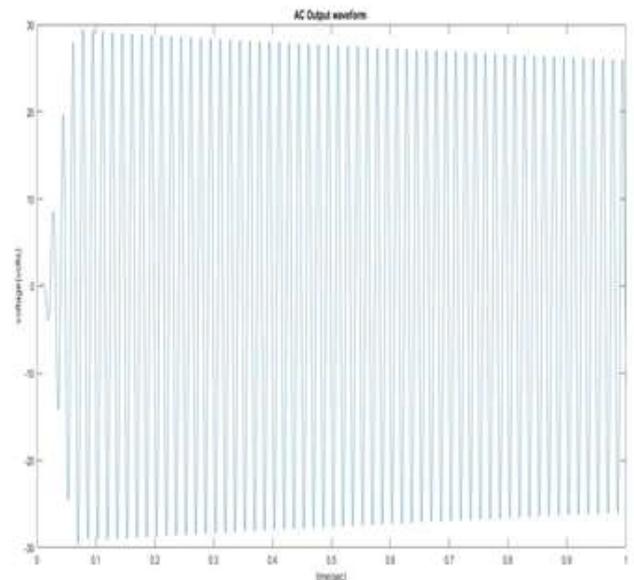
**Figure 11.** Output waveform before boost up(120Vdc)

Applying the boosted DC voltage (240V DC) from the boost converter, the passive filter is applied to smoothen the waveform and reduce any ripple or harmonics present. The output waveform exhibits significantly reduced ripple compared to the waveform before the filter was applied. The filter, typically consisting of an inductor and capacitor connected in parallel, helps to filter out high-frequency components, resulting in a smoother DC voltage waveform. Ripple, which refers to small variations or fluctuations in the amplitude of the waveform is minimized after the application of the passive filter. The filter attenuates high-frequency ripple components, resulting in a more stable and consistent DC voltage level. The waveform demonstrates the steady-state behavior with a relatively constant DC voltage level around 240V. The filter helps to stabilize the voltage output, ensuring that it remains within the desired range under varying load conditions. The passive filter helps to improve voltage regulation by reducing the impact of load variations and transient disturbances on the DC voltage output.



**Figure 12.** Output waveform after boost up(240Vdc)

DC voltage is converted into AC voltage by the inverter and passed through the passive filter, the resulting AC output waveform is smoother and cleaner compared to the unfiltered waveform. The AC output waveform appears as a sinusoidal curve oscillating between positive and negative voltages. However, after passing through the passive filter, the waveform is smoother with reduced harmonic content and ripple. The passive filter helps attenuate harmonics and ripple present in the AC voltage waveform. This results in a cleaner and more stable sinusoidal waveform, closer to the ideal sinusoidal shape.



**Figure 13.** AC voltage Output waveform with filter

The filtered AC waveform demonstrates improved quality, characterized by reduced distortion and smoother transitions between voltage peaks. This enhanced waveform quality is desirable for supplying clean and reliable AC power to connected loads. The filtered AC waveform maintains a stable voltage level around 240V AC, ensuring consistency in power delivery to the load. The passive filter contributes to voltage stabilization by reducing fluctuations and maintaining a steady output voltage.

## V.CONCLUSION

The experimentation and modeling conducted on a residential photovoltaic power generation system with the aid of MATLAB and Simulink have shown promising outcomes. Through the integration of photovoltaic panels, a DC-DC boost converter, inverter, and passive filter, the system showcases its ability to efficiently harness solar energy and convert it into usable AC power for residential applications. The detailed analysis and simulation conducted in this study have provided valuable insights into the system's performance, efficiency, and stability, affirming its suitability for practical implementation. The applications of this system are wide-ranging and impactful. Primarily, it addresses the growing need for sustainable energy solutions in residential settings, offering homeowners a reliable source of electricity while reducing their carbon footprint. Additionally, the system's adaptability makes it suitable for deployment in off-grid areas, where reliable electricity access is often limited. Furthermore, its integration into microgrid setups enhances grid resilience and stability, particularly during times of peak demand or grid disruptions. The benefits of adopting such a system are significant and far-reaching. Firstly, it promotes renewable

resource utilization, contributing to environmental sustainability and mitigating climate change. In conclusion, the development and simulation of a residential photovoltaic power generation system represent a crucial step towards achieving sustainable energy goals. By leveraging technological advancements and innovative design approaches, we can realize the full potential of solar energy for residential use.

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