ISSN: 2454-9940

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

E-Mail :
editor.ijasem@gmail.com
editor@ijasem.org

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN 2454-9940

www.ijasem.org

Vol 19, Issue 1, 2025

Optimized PI-Controlled High-Gain Reboost-Luo Converter for Efficient PV Grid Integration

R.Sowmya Deepika[1], P.Manisha[2], Y.Manoj[3], K.Sravani

[1]Department of EEE, Godavari institute of Engineering and Technology(A), sowmyadeepikarayudu@gmail.com
[2]Department of EEE, Godavari institute of Engineering and Technology(A), manishaputtagunta90@gmail.com
[3]Department of EEE, Godavari institute of Engineering and Technology(A), ,manojyadla666@gmail.com
[4]Assistant Professor, Department of EEE, Godavari institute of Engineering and Technology(A), emandisravani@giet.ac.in

Abstract

The rising demand for renewable energy has led to advancements in solar energy systems. This paper develops an optimized solar energy conversion system for efficient power extraction and grid integration. A solar panel generates DC power, boosted using a high-gain modified Re-Boost Luo converter. A Voltage Source Inverter (VSI) controlled by Pulse Width Modulation (PWM) converts DC to three-phase AC for grid connection. Maximum Power Point Tracking (MPPT) is achieved using a Jellyfish-optimized Adaptive Neuro-Fuzzy Inference System (ANFIS). An LC filter smooths the inverter output before supplying it to the grid. A Proportional-Integral (PI) controller regulates active and reactive power, ensuring stability and responsiveness. This approach enhances efficiency and supports sustainable energy solutions. The system is modeled and simulated using MATLAB 2021a Simulink.

Keywords: Renewable Energy, Solar Energy Conversion, Maximum Power Point Tracking (MPPT), Adaptive Neuro-Fuzzy Inference System (ANFIS), Jellyfish Optimization, Re-Boost Luo Converter, Voltage Source Inverter (VSI)

1. INTRODUCTION

Solar energy, harnessed through photovoltaic (PV) systems, is a key component of sustainable energy solutions [1,2]. As concerns about fossil fuel depletion and environmental impact grow, the transition to renewable energy has become essential. PV systems stand out due to their scalability, adaptability, and minimal environmental footprint. Solar power, an abundant resource, reduces reliance on fossil fuels and lowers carbon emissions, contributing to climate change mitigation and energy security [4,5].

PV systems convert sunlight into electricity through the photovoltaic effect, where semiconductor materials generate an electric current when exposed to light [6]. Advances in materials, manufacturing, and system integration have significantly improved PV efficiency and affordability, making solar energy a competitive power source, particularly in high-irradiance regions [7-9].

PV technology varies by type, including monocrystalline, polycrystalline, and thin-film solar cells [10]. Monocrystalline cells offer high efficiency and durability, making them ideal for residential and commercial use. Polycrystalline cells provide a cost-effective solution for large-scale installations, while thin-film cells, though less efficient, are lightweight and flexible, suitable for unconventional surfaces and portable applications [11,12].

PV systems are also classified based on their configuration. Grid-connected systems integrate with the utility grid, allowing excess power to be exported, reducing electricity costs and supporting local energy supplies [13]. Off-grid systems, used in remote locations, rely on battery storage to maintain power availability during low sunlight conditions. Hybrid systems, which combine PV with wind power or storage solutions, enhance reliability and efficiency.

The continuous development of PV technology, alongside supportive policies and economic incentives, is driving widespread adoption [14]. Solar energy's role in achieving energy sustainability and reducing carbon footprints makes it a cornerstone of the global transition toward cleaner, more resilient power systems [15].

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT
ISSN 2454-9940
www.ijasem.org
Vol 19, Issue 1, 2025

2. SYSTEM DESCRIPTION

The proposed system integrates a high-gain modified Re-Boost Luo converter with an optimized PI controller for efficient PV-grid integration. The process starts with a solar panel generating DC voltage, which is boosted to the required level using the modified Re-Boost converter. A three-phase Voltage Source Inverter (VSI) then converts this DC voltage into AC using Pulse Width Modulation (PWM) techniques. Two PWM generators control the switching sequence, creating a stable three-phase output.

A Proportional-Integral (PI) controller regulates the PWM signals, optimizing power and reactive power management. An LC filter minimizes harmonics, ensuring a clean sinusoidal waveform before the AC power is supplied to the grid. The system continuously monitors and adjusts output to meet grid standards, enhancing energy conversion efficiency. Additionally, an adaptive neuro-fuzzy inference system (ANFIS) is used for Maximum Power Point Tracking (MPPT), ensuring optimal solar energy utilization while maintaining grid stability.

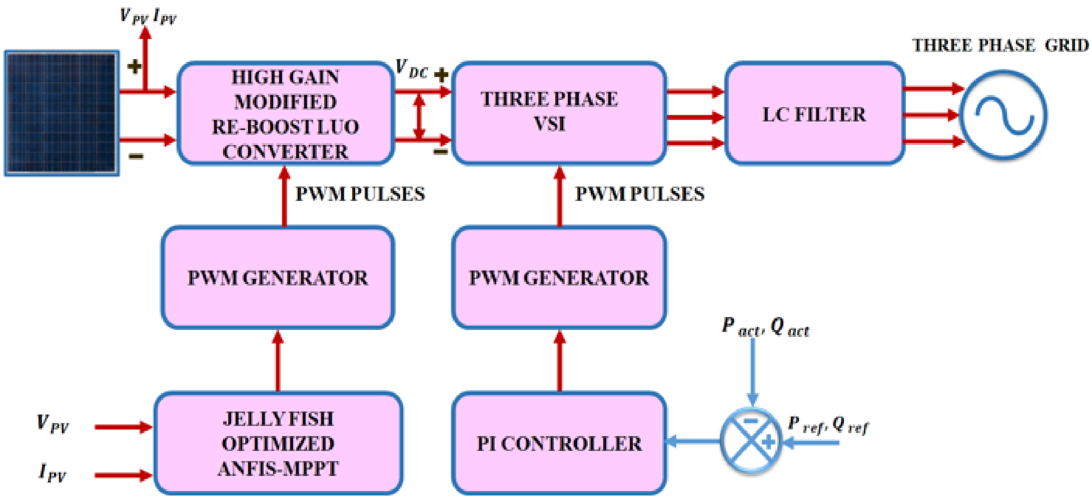


Figure 1 Block Diagram of Proposed system

2.1 PV SYSTEM

Photovoltaic (PV) technology converts sunlight into electricity using semiconductor materials. A PV system consists of several key components that work together to capture and convert solar energy into usable power. The process begins with solar panels, which are made up of multiple photovoltaic cells, typically composed of silicon. These cells absorb sunlight and generate electricity through the photovoltaic effect.

When sunlight strikes the semiconductor material, it excites electrons, creating an electric current. This results in the generation of direct current (DC) electricity. The DC power can either be stored in batteries for later use or converted into alternating current (AC) using an inverter, making it suitable for powering homes, businesses, and electrical appliances. This efficient conversion process enables the effective utilization of solar energy, reducing dependence on non-renewable sources and promoting sustainable power generation.

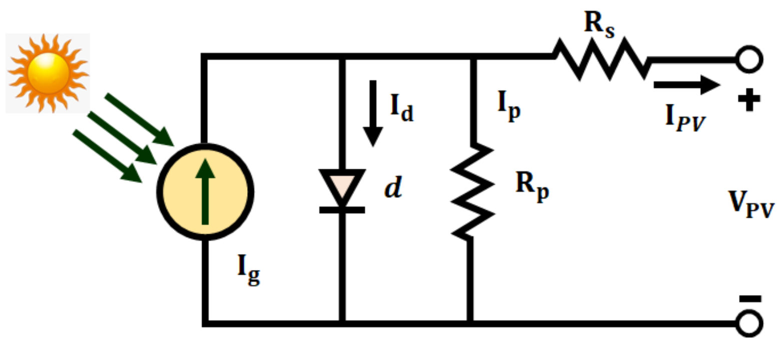


Figure 2 Equivalent circuit of a PV cell

2.2 HIGH GAIN MODIFIED RE-BOOST LUO CONVERTER

The High Gain Modified Re-Boost Luo Converter is designed to efficiently step up low DC voltage to a higher output with minimal losses, making it ideal for photovoltaic (PV) and energy storage systems. As an advanced version of the traditional Luo converter, it enhances voltage gain while using fewer components, improving overall efficiency. This makes it particularly suitable for integrating renewable energy sources into the grid or energy storage solutions.

The converter operates using inductors, capacitors, and switching elements like MOSFETs or IGBTs. It follows a boost topology, where energy is stored in an inductor and transferred to the output through a capacitor. A key innovation is its ability to achieve higher voltage gain, making it useful for PV applications where solar panel outputs (12V–48V) must be increased to levels suitable for grid connection (e.g., 220V AC) or battery charging (e.g., 48V).

The conversion process occurs in two stages: energy storage and power conversion. During energy storage, a switch opens, allowing current to flow through the inductor, which stores energy in its magnetic field. When the switch closes, the inductor releases its energy to the capacitor, boosting the output voltage. The modified Re-Boost Luo converter optimizes this process, ensuring high efficiency and reduced losses, making it a valuable component in modern renewable energy systems.

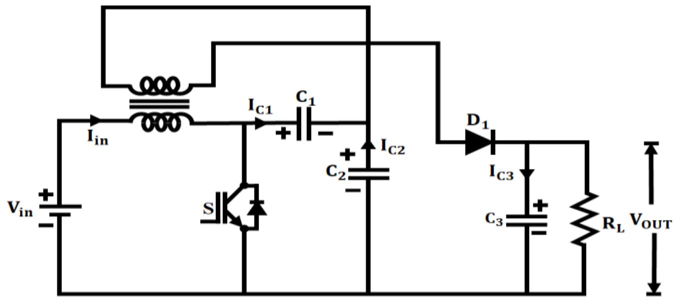


Figure 3 Structure of Improved RBLC

Mode 1:

In Mode 1 (Figure 4), switch **S** is ON, allowing current through inductor **I**. The primary inductor magnetizes, $\mathbf{C_1}$ charges, and $\mathbf{C_2}$ discharges, while the diode blocks reverse current. $\mathbf{C_3}$ releases stored energy to power the load, ensuring efficient energy transmission and storage for the next operation cycle.

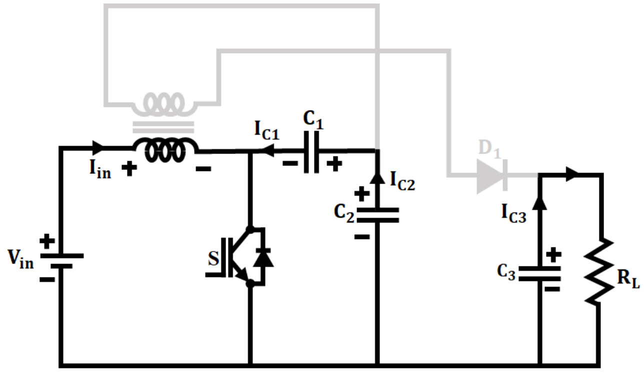


Figure 4 Mode 1

Mode 2:

In Mode 2 (Figure 5), switch **S** is OFF, releasing stored inductor energy through the transformer. $\mathbf{C_2}$ charges, $\mathbf{C_1}$ discharges, and the diode becomes forward-biased, allowing current to the load. $\mathbf{C_3}$ stabilizes output voltage by releasing energy, ensuring continuous power delivery and efficient system operation.

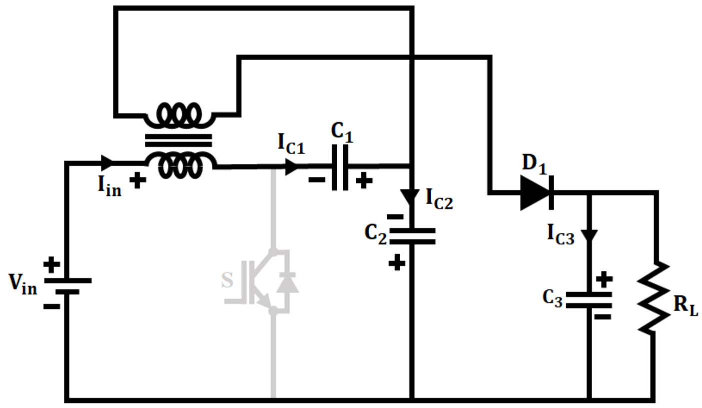


Figure 5 Mode 2

2.3 THREE PHASE VSI

The Three-Phase Voltage Source Inverter (VSI) converts DC power into AC, widely used in motor drives, renewable energy systems, and uninterruptible power supplies (UPS). It consists of six power semiconductor switches (MOSFETs, IGBTs, or GTOs) arranged in a three-phase bridge configuration. These switches are controlled using Pulse Width Modulation (PWM) to shape the AC output waveform.

The VSI operates by taking DC input from sources like batteries or solar panels and converting it into three-phase AC. The switches alternate between "on" and "off" states, modulated by PWM to generate sinusoidal or quasi-sinusoidal waveforms. Each phase of the output voltage is shifted by 120 degrees, ensuring a balanced three-phase system.

PWM adjusts the duty cycle of each switch to control output voltage and frequency while minimizing harmonics. A controller continuously regulates these switching patterns to maintain stable output despite variations in input voltage or load conditions.

This precise control mechanism makes the three-phase VSI essential for grid integration of renewable energy and motor-driven applications, where a stable AC supply is required. Its efficiency, adaptability, and ability to generate clean power make it a critical component in modern power electronics.

2.4 JELLY FISH OPTIMIZED ANFIS-MPPT

Jellyfish Optimization ANFIS-MPPT is an advanced technique for maximizing energy extraction in photovoltaic (PV) systems under varying environmental conditions. It integrates the Adaptive Neuro-Fuzzy Inference System (ANFIS), which combines neural networks and fuzzy logic, with Maximum Power Point Tracking (MPPT) to optimize PV performance.

The key innovation lies in the Jellyfish Search Algorithm (JSA), which enhances ANFIS-MPPT by overcoming traditional drawbacks like slow convergence and local maxima. This hybrid approach efficiently tracks the Maximum Power Point (MPP), ensuring optimal energy harvesting.

MPPT adjusts the PV system’s operating point to maximize power output, compensating for variations in irradiance and temperature. Traditional MPPT methods, such as Perturb & Observe (P&O) and Incremental Conductance (IncCond), often struggle with accuracy and speed in rapidly changing conditions. The Jellyfish Optimization ANFIS-MPPT improves upon these by dynamically refining voltage and current adjustments, achieving faster convergence and higher efficiency.

By leveraging intelligent optimization and adaptive learning, this method significantly enhances PV system performance, making it ideal for real-time applications in renewable energy.

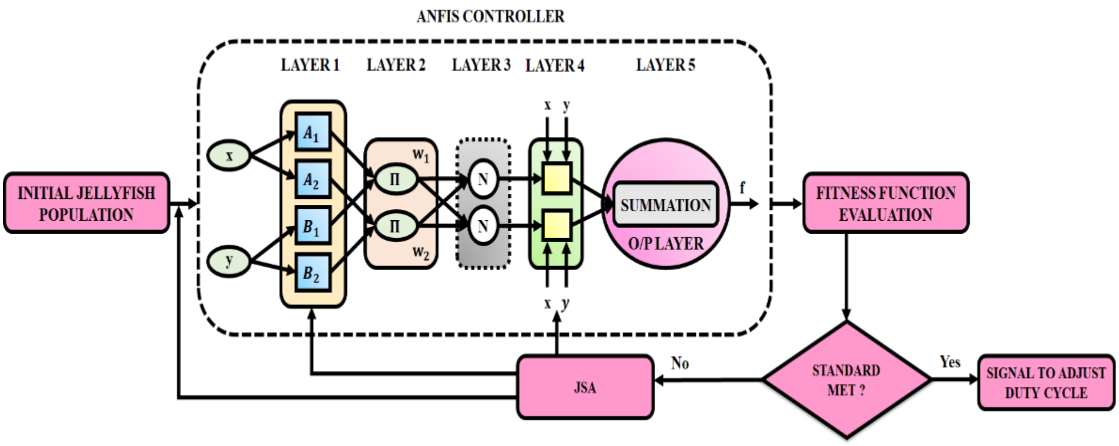


Figure 6 Architecture of optimized ANFIS

An ANFIS controller is highly effective for Maximum Power Point Tracking (MPPT) in renewable energy systems (RES) due to its ability to combine the benefits of fuzzy logic control (FLC) and neural networks. Its unique architecture allows it to handle uncertainties and nonlinearities commonly encountered in solar power systems. Compared to other intelligent MPPT methods, the ANFIS controller provides faster convergence and higher tracking accuracy, ensuring optimal energy extraction from solar panels.

By integrating the ANFIS controller, the power conversion system becomes more efficient, particularly in generating the ideal duty ratio for a High Gain Modified Boost Luo Converter. The controller adjusts its membership parameters using fuzzy membership functions, converting linguistic variables into numerical values. This improves the precision of the FLC operation, enhancing the overall efficiency and performance of the system.

he proposed work optimizes the ANFIS controller using the JSA-ANFIS MPPT technique, a hybrid algorithm combining ANFIS's adaptability with jellyfish-inspired dynamic exploration. By using back-propagation and least squares algorithms, the membership functions are fine-tuned for optimal performance. The JSA, influenced by jellyfish foraging, adjusts ANFIS parameters to improve tracking, simulating food search by producing random values between 0 and 1.

2.5 LC FILTER

An LC filter is an electronic component that uses an inductor (L) and a capacitor (C) to filter out specific frequencies from a signal. It is commonly used in electronics and signal processing to reduce noise and smooth signals. LC filters can be configured as low-pass, high-pass, band-pass, or band-reject filters, depending on the arrangement of the inductor and capacitor.

The main function of an LC filter is to allow desired frequencies to pass while blocking unwanted ones. Inductors and capacitors behave differently at various frequencies—inductors increase impedance with frequency, while capacitors decrease impedance as the frequency rises. This difference in impedance enables the filter to selectively pass or block certain frequencies.

In a low-pass LC filter, an inductor is placed in series with the input signal, and a capacitor is parallel to the output load. At low frequencies, the inductor has low impedance, allowing most of the signal to pass, while the capacitor blocks DC and very low frequencies. At higher frequencies, the capacitor becomes a short circuit, bypassing high-frequency components, while the inductor’s impedance increases, attenuating high-frequency signals. This configuration ensures that only lower frequencies pass through to the output.

2.6 PWM GENERATOR

PWM (Pulse Width Modulation) generators are essential in modern electronic systems, including power management, communications, and electrical installations. These generators create signals that alternate between high and low states at a specific frequency, controlling the power sent to devices like motors, LEDs, and heating elements. The key feature of a PWM signal is its varying pulse width, while the frequency remains constant.

The PWM generator controls the average power delivered to the load by adjusting the duty cycle, which is the ratio of the time the signal is high to the total period. A higher duty cycle means more power is delivered to the

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN 2454-9940

www.ijasem.org

Vol 19, Issue 1, 2025

load, while a lower duty cycle reduces power output, improving energy efficiency. PWM is based on square wave signals with high and low states, each lasting a certain duration.

The duty cycle, which represents how long the signal stays high during each cycle, is crucial for regulating power. A high duty cycle means the signal stays high longer, delivering more power, whereas a low duty cycle reduces energy consumption. The frequency of the PWM signal, or how quickly the state switches between high and low, can be adjusted to meet specific application needs.

3. RESULTS AND DISCUSSIONS

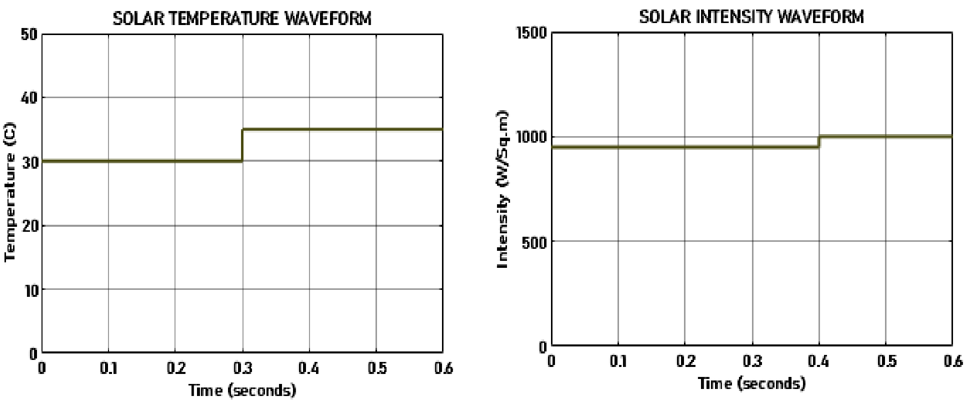


Figure 7 Temperature and Intensity waveform of solar panel

Figure 7 shows the temperature stabilizing at 35°C in the waveform. Maintaining this constant temperature is crucial for optimal performance, as temperature fluctuations can negatively affect the efficiency of PV modules. Additionally, at 1000 W/m², the standard irradiance level for peak sunlight, the solar irradiation stabilizes.

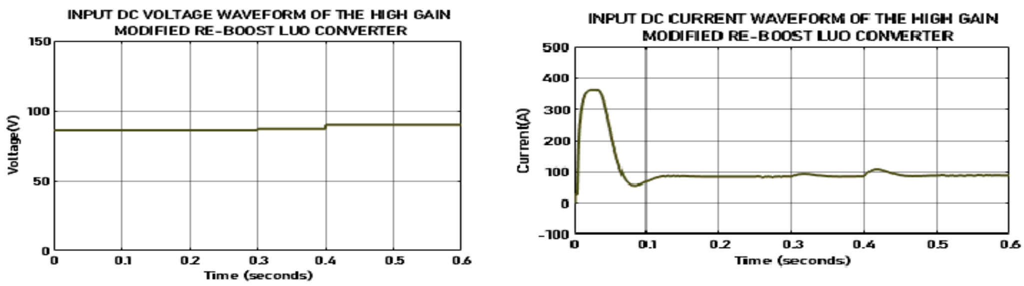
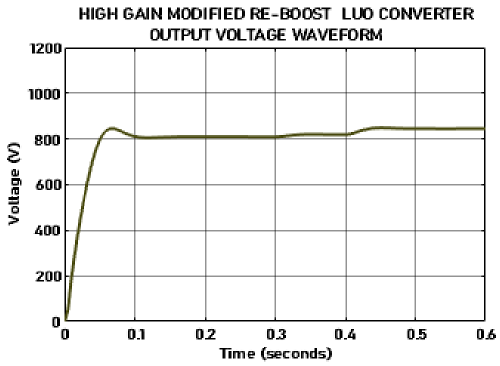


Figure 8 Voltage and Current waveform of solar panel

Figure 8 illustrates that the PV system's voltage remains consistently at 80V, ensuring the power conversion process operates within the optimal voltage range. Additionally, after a brief interval of 0.51 seconds, the current stabilizes at 88A with minimal fluctuations. The minor current variations after stabilization are negligible, indicating that the control procedures effectively managed the system's behavior.



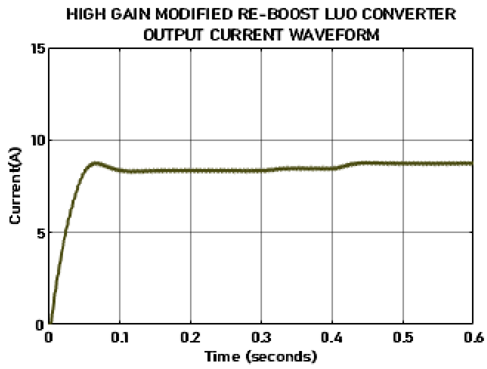
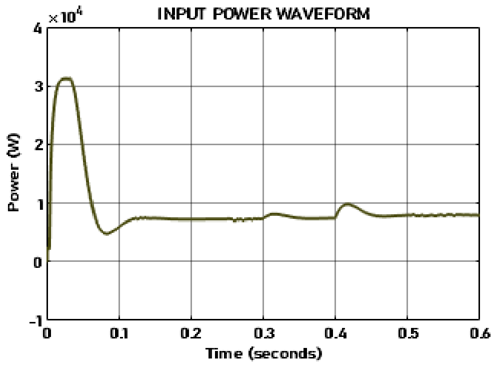


Figure 9 Converter output (a) Voltage (b) Current

Figure 9 shows the output voltage and current of the proposed HG-MRBL Converter. The voltage quickly stabilizes at 830V, and the current settles at 8A, both reaching steady-state within 0.1s. The minimal fluctuations demonstrate the converter's stability and efficiency in achieving high voltage gain. These results confirm its reliability for grid-tied renewable energy applications.



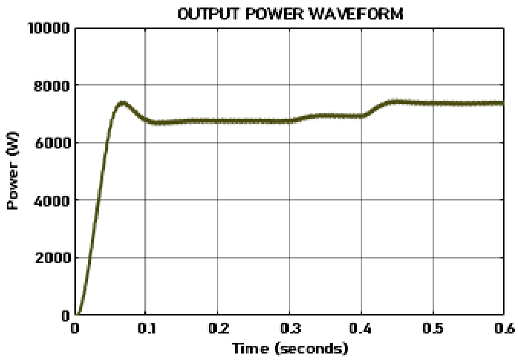


Figure 10 Waveforms of input and output power

Figure 10 depicts the dynamic behavior of the input power, which initially peaks at 3.1×10^4 W before sharply declining to 800W. This illustrates the converter's ability to control and maximize energy output from the PV source. The output power increases slightly to 7000W, indicating the system's adaptability. The converter's capability to maintain a steady output, despite input power variations, is shown when the output power eventually stabilizes at 7800W.

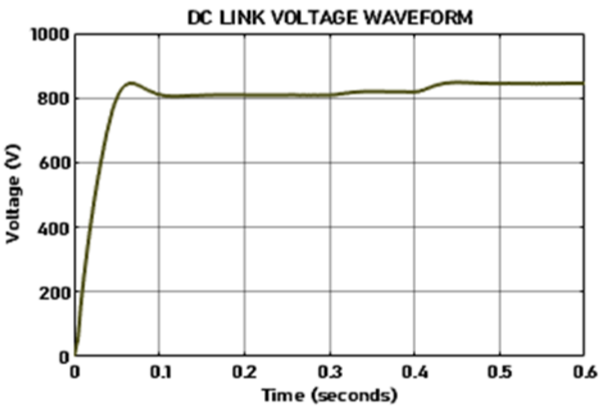


Figure 11 DC link voltage waveform

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN 2454-9940

www.ijasem.org

Vol 19, Issue 1, 2025

Figure 11 illustrates the voltage variation over time. It shows that, compared to the input, the proposed converter provides a boosted voltage. After a brief transient period, the waveform stabilizes, indicating that the voltage has reached its steady-state value of approximately 800–900 V.

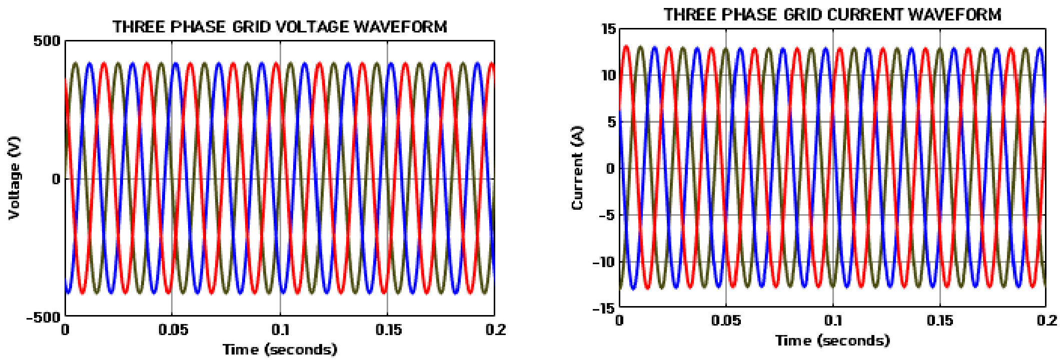


Figure 12 Grid output Voltage and Current

Figure 12 illustrates the grid system's performance. The grid voltage stabilizes at 415V, with the current consistently maintained at 12A, free from distortions. This stability ensures efficient and balanced power distribution across all phases.

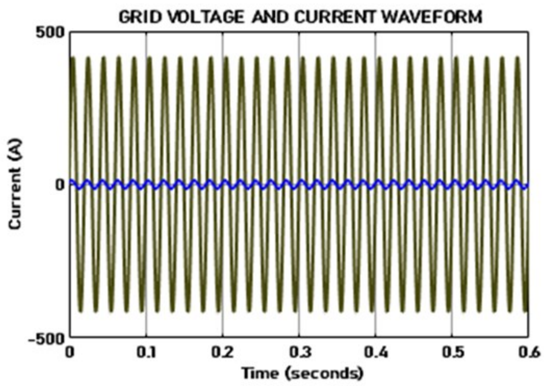


Figure 13 Grid in phase waveform

Figure 13 displays the grid phase waveform, with an output voltage of 415V and a current of 12A. This illustrates the system's stability, showcasing smooth operation without distortion, which enhances power quality.

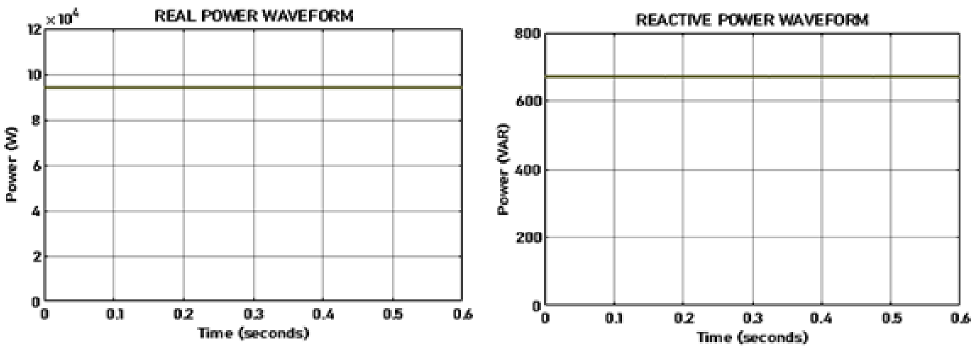


Figure 14 Power waveform (a) Real (b) Reactive

Figure 14 shows the real and reactive power waveforms, with real power remaining steady at 9×10^4 W over time. Meanwhile, the reactive power stabilizes at 660 VAR, demonstrating the system's effectiveness in managing reactive power for grid integration.

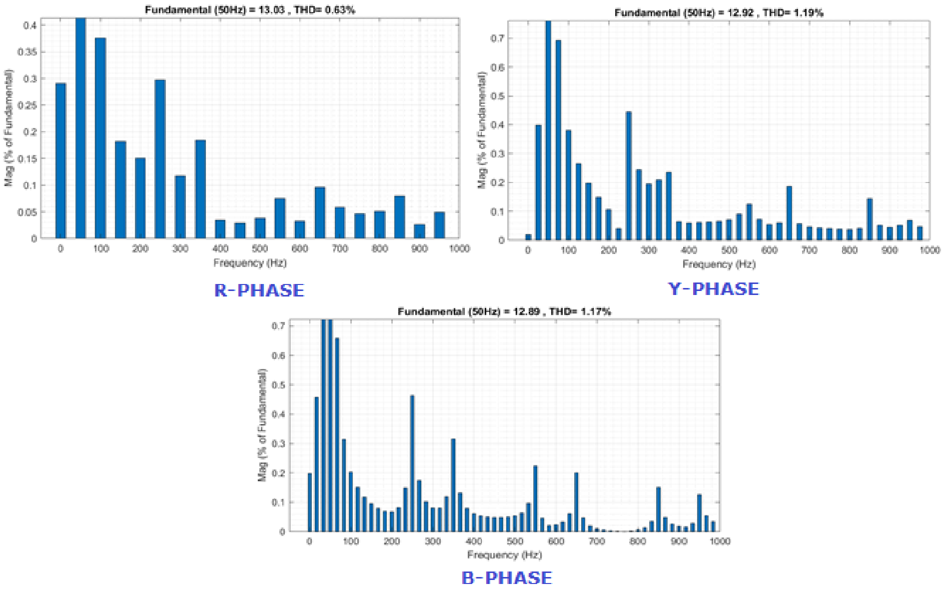


Figure 15 THD waveform

Figure 15 presents the Total Harmonic Distortion (THD) values for the R, Y, and B phases. The proposed system achieves a reduced THD of 0.63%, 1.19%, and 1.17% for each phase. By maintaining low THD, the system ensures stable and reliable power supply to connected loads, resulting in higher efficiency, longer equipment lifespan, and fewer disruptions.

4. CONCLUSION

In conclusion, the proposed advanced solar energy conversion system provides an efficient and reliable solution for integrating solar power into the grid. Utilizing a high-gain modified Re-Boost Luo converter, PWM-controlled VSI, and an adaptive ANFIS-based MPPT, the system optimizes energy extraction from solar panels and ensures stable, high-quality power output. The LC filter smooths the waveform, while the PI controller maintains system stability and responsiveness to dynamic grid conditions. This comprehensive approach enhances energy efficiency and strengthens the integration of renewable energy, marking a significant advancement in solar power technology for grid-connected applications.

REFERENCES:

1. E. Mokaramian, H. Shayeghi, F. Sedaghati, A. Safari and H. H. Alhelou, "An Optimal Energy Hub Management Integrated EVs and RES Based on Three-Stage Model Considering Various Uncertainties," in IEEE Access, vol. 10, pp. 17349-17365, 2022.
2. H. Padullaparti, J. Wang, S. Veda, M. Baggu and A. Golnas, "Evaluation of Data-Enhanced Hierarchical Control for Distribution Feeders With High PV Penetration," in IEEE Access, vol. 10, pp. 42860-42872, 2022.
3. A. Al-Sorour, M. Fazeli, M. Monfared, A. Fahmy, J. R. Searle and R. P. Lewis, "Enhancing PV Self-Consumption Within an Energy Community Using MILP-Based P2P Trading," in IEEE Access, vol. 10, pp. 93760-93772, 2022.
4. R. Grab, F. Hans, M. I. R. Flores, H. Schmidt, S. Rogalla and B. Engel, "Modeling of Photovoltaic Inverter Losses for Reactive Power Provision," in IEEE Access, vol. 10, pp. 108506-108516, 2022.
5. A. Sorour, M. Fazeli, M. Monfared, A. A. Fahmy, J. R. Searle and R. P. Lewis, "MILP Optimized Management of Domestic PV-Battery Using Two Days-Ahead Forecasts," in IEEE Access, vol. 10, pp. 29357-29366, 2022.
6. N. Shabbir, L. Kütt, V. Astapov, M. Jawad, A. Allik and O. Husev, "Battery Size Optimization With Customer PV Installations and Domestic Load Profile," in IEEE Access, vol. 10, pp. 13012-13025, 2022.
7. Y. Son et al., "Levelized Cost of Energy-Oriented Modular String Inverter Design Optimization for PV Generation System Using Geometric Programming," in IEEE Access, vol. 10, pp. 27561-27578, 2022.

ISSN 2454-9940
www.ijasem.org
Vol 19, Issue 1, 2025

8. N. Zanib, M. Batool, S. Riaz and F. Nawaz, "Performance Analysis of Renewable Energy Based Distributed Generation System Using ANN Tuned UPQC," in IEEE Access, vol. 10, pp. 110034-110049, 2022.
9. A. Gundogdu "System Identification Based ARV-MPPT Technique for PV Systems Under Variable Atmospheric Conditions," in IEEE Access, vol. 10, pp. 51325-51342, 2022.
10. S. R. Kiran, C. H. H. Basha, V. P. Singh, C. Dhanamjayulu, B. R. Prusty and B. Khan, "Reduced Simulative Performance Analysis of Variable Step Size ANN Based MPPT Techniques for Partially Shaded Solar PV Systems," in IEEE Access, vol. 10, pp. 48875-48889, 2022.
11. M. A. Ismeil, A. Alfouly, H. S. Hussein and I. Hamdan, "Improved Inverter Control Techniques in Terms of Hosting Capacity for Solar Photovoltaic Energy With Battery Energy Storage System," in IEEE Access, vol. 11, pp. 140161-140173, 2023.
12. C. Breyer, A. S. Oyewo, A. Kunkar and R. Satymov, "Role of Solar Photovoltaics for a Sustainable Energy System in Puerto Rico in the Context of the Entire Caribbean Featuring the Value of Offshore Floating Systems," in IEEE Journal of Photovoltaics, vol. 13, no. 6, pp. 842-848, Nov. 2023.
13. F. Blaabjerg, Y. Yang, K. A. Kim and J. Rodriguez, "Power Electronics Technology for Large-Scale Renewable Energy Generation," in Proceedings of the IEEE, vol. 111, no. 4, pp. 335-355, April 2023.
14. M. I. Hossain, W. M. Hamanah, M. S. Alam, M. Shafiullah and M. A. Abido, "Fault Ride Through and Intermittency Improvement of Renewable Energy Integrated MMC-HVDC System Employing Flywheel Energy Storage," in IEEE Access, vol. 11, pp. 50528-50546, 2023.
15. M. M. Gulzar, A. Iqbal, D. Sibtain and M. Khalid, "An Innovative Converterless Solar PV Control Strategy for a Grid Connected Hybrid PV/Wind/Fuel-Cell System Coupled With Battery Energy Storage," in IEEE Access, vol. 11, pp. 23245-23259, 2023.