



EMPOWERING DC MICROGRID FLEXIBILITY WITH NON-ISOLATED HYBRID DC-DC CONVERTER AND CASCADED ANFIS MPPT

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Abstract: The reliance on renewable energy sources grows, optimizing the flexibility and efficiency of DC microgrids becomes crucial. DC microgrids, known for their potential to integrate various renewable energy sources and provide stable power, face significant challenges such as limited adaptability to fluctuating power demands, inefficient energy conversion, and difficulties in maximizing power output from renewable sources. Traditional solutions often fall short in addressing these issues, leading to suboptimal performance and increased operational costs. This project proposes a novel approach to enhancing the flexibility of DC microgrids through the integration of a non-isolated hybrid DC-DC converter and cascaded Adaptive Neuro-Fuzzy Inference System (ANFIS) Maximum Power Point Tracking (MPPT). The proposed hybrid DC-DC converter, combining Boost and Buck functionalities, provides efficient energy management and adaptive voltage regulation, crucial for optimizing performance in dynamic microgrid environments. To further improve energy harvesting and system stability, the cascaded ANFIS MPPT algorithm is implemented. This advanced MPPT technique adapts to varying environmental conditions and load demands, ensuring that the microgrid operates at its maximum efficiency. The interaction between the hybrid converter and ANFIS-based MPPT not only enhances the overall flexibility and efficiency of the DC microgrid but also contributes to more reliable and sustainable energy distribution.

Index Terms - Distributed Energy Resources (DERs); Energy Storage Systems; Control and Management Systems; Power Distribution Infrastructure; Advanced Communication Technologies.

I. INTRODUCTION

In terms of changing the energy landscape, microgrids represent a revolutionary approach to energy production and distribution that meets the urgent need for energy solutions. Strong and resilient. Microgrids are a critical resource that can operate independently or in conjunction with a larger grid, giving communities greater control over their energy resources. Microgrids consist of decentralized energy resources (DERs) such as solar panels, wind turbines, energy storage, and even demand-side control technologies designed to optimize energy use and increase reliability, especially in areas where electricity is scarce or poor. The increasing interest in microgrids is due to several factors, including the rapid adoption of the technology, increasing energy demand, and increasing awareness of the impact of climate change. As urbanization continues to rise, so does the strain on traditional power grids, which often struggle to meet peak demands and maintain stability.

Microgrids offer a solution by decentralizing power generation, allowing energy to be produced closer to where it is consumed. This not only reduces transmission, but also increases the power of the energy supply by reducing the risks associated with centralized generation and distribution. One of the key benefits of microgrids is their ability to integrate renewable energy. By using local resources such as solar and wind energy, microgrids can reduce reliance on fossil fuels, thereby reducing greenhouse gas emissions and improving environmental sustainability. In addition, advances in energy technology allow microgrids to store much of the energy produced during peak production times, which can be used when demand is high or less new energy is being produced. This capability not only enhances energy reliability but also supports grid stability by mitigating fluctuations associated with variable renewable generation. Microgrids also promote energy independence, allowing communities to take control of their energy futures. This is particularly important in remote or underserved areas, where access to reliable electricity may be limited. By establishing local energy systems, these communities can reduce their dependence on external energy suppliers, leading to increased resilience and self-sufficiency [1].

Furthermore, microgrids can facilitate economic development by creating local jobs in renewable energy generation, maintenance, and management. The technological backbone of microgrids includes advanced control systems, smart meters, and real-time data analytics, enabling optimal management of energy flows and resource allocation. This process helps support strategic needs that allow clients to adjust energy used for emergencies, thereby improving overall results.

II. LITERATURE SURVEY

Recently, with the development of more and more power plants (DG) and power plants, the concept of microgrid has evolved to provide efficient and robust projects. Generally speaking, the motor control, electrical connection and electronic equipment in the distribution can be divided into AC motor control cabinet and DC motor control cabinet, according to the frequency synchronization and other inherent problems, it is more efficient. Control is easier than electric machines, and can be sequential or island type.

Hyun-Jun Choi et al [2022] presented hybrid switching modulation of an isolated bidirectional DC-DC converter for energy storage systems in DC microgrids offers a versatile solution for efficient power transfer and energy management. This type of converter is essential in scenarios where energy must flow between storage systems, such as batteries, and the microgrid.

B. Sri Revathi et al [2022] developed Solar PV-fed DC microgrids are increasingly being adopted as a sustainable solution for powering various applications, particularly in off-grid and remote areas. These microgrids integrate photovoltaic (PV) panels as their primary energy source, converting solar energy directly into electricity to power DC loads or charge energy storage systems.

Noushin Poursafar et al [2022] developed Distributed DC-bus signaling control in photovoltaic (PV) systems for islanded DC microgrids offers an effective way to manage energy flow and ensure grid stability without relying on centralized communication systems.

Miguel Jiménez Carrizosa et al [2022] proposed Droop-inspired nonlinear control in DC microgrids offers a new way to control the power of electric vehicles (EVs) and the grid, being used to integrate power movement and provide additional services to the main AC grid. This control system allows electric vehicles to be connected in a way that saves energy and to participate in support projects such as frequency control and voltage measurement.

Muhammad Umair Mutarraf et al [2022] introduced Adaptive power management in hierarchical controlled hybrid shipboard microgrids optimizes energy distribution across various sources such as diesel generators, batteries, and renewable systems to meet dynamic load demands.

Rodrigo Aliaga et al [2022] implemented exact linearization technique for modeling and control of DC/DC converters in rural PV microgrid applications offers a precise approach to managing power flow and enhancing system stability.

Jingfeng Mao et al [2022] developed Multivariable coordinated nonlinear gain droop control for PV-battery hybrid DC microgrid access systems, utilizing a Takagi-Sugeno (T-S) fuzzy decision approach, presents an innovative solution for managing the complexities of energy distribution in microgrids.

Objectives:

- To implement empowering DC microgrid flexibility with a non-isolated hybrid DC-DC converter and cascaded ANFIS MPPT.
- To enhance energy conversion efficiency, implement a non-isolated hybrid DC-DC converter to improve efficiency and reduce power losses in DC microgrids.
- To optimize maximum power extraction, utilize cascaded ANFIS-based MPPT to dynamically adjust to environmental changes and maximize energy capture from renewable sources.
- To regulate the output voltage and current of the system for stable power delivery to the grid.

III. MODELING AND CONFIGURATION OF EMPOWERING DC MICROGRID FLEXIBILITY

In order to meet the increasing demand for clean and sustainable energy, the integration of renewable energy sources into the power system has gained importance. Among these, photovoltaic (PV) systems play an important role in the use of DC microgrids due to their scalability, modularity and environmental benefits. However, the interconnected nature of solar energy creates challenges in maintaining system efficiency, stability and reliability. To solve these problems, advanced power technology and MPPT algorithms are the key features of modern photovoltaic systems. This study focuses on increasing the capacity of DC microgrids using hybrid non-isolated DC-DC converters and MPPT algorithms based on cascade adaptive neuro-fuzzy inference systems (ANFIS) shown in figure 1. The hybrid DC-DC converter, comprising buck-boost and boost Cuk converter topologies, enables seamless power conversion and ensures flexibility in adapting to varying PV output conditions. These converters are designed to handle fluctuations in voltage and current while maximizing power extraction from PV modules. The non-isolated configuration further contributes to reducing system complexity, enhancing efficiency, and minimizing conversion losses [9,10].

The Cascaded ANFIS MPPT algorithm is a key innovation in this system. Traditional MPPT techniques, such as Perturb and Observe (P&O) or Incremental Conductance (IC), often face limitations in dynamic and partial shading conditions. In contrast, the ANFIS-based approach combines the strengths of fuzzy logic and neural networks, enabling it to learn and adapt to non-linear and complex relationships in real-time. The cascaded architecture further enhances the tracking accuracy and responsiveness by dividing the control process into multiple stages, each optimized for specific operational parameters. To ensure effective power injection into the grid, a single-phase voltage source inverter (1 ϕ VSI) is integrated, coupled with a robust LC filter to reduce harmonic distortions.

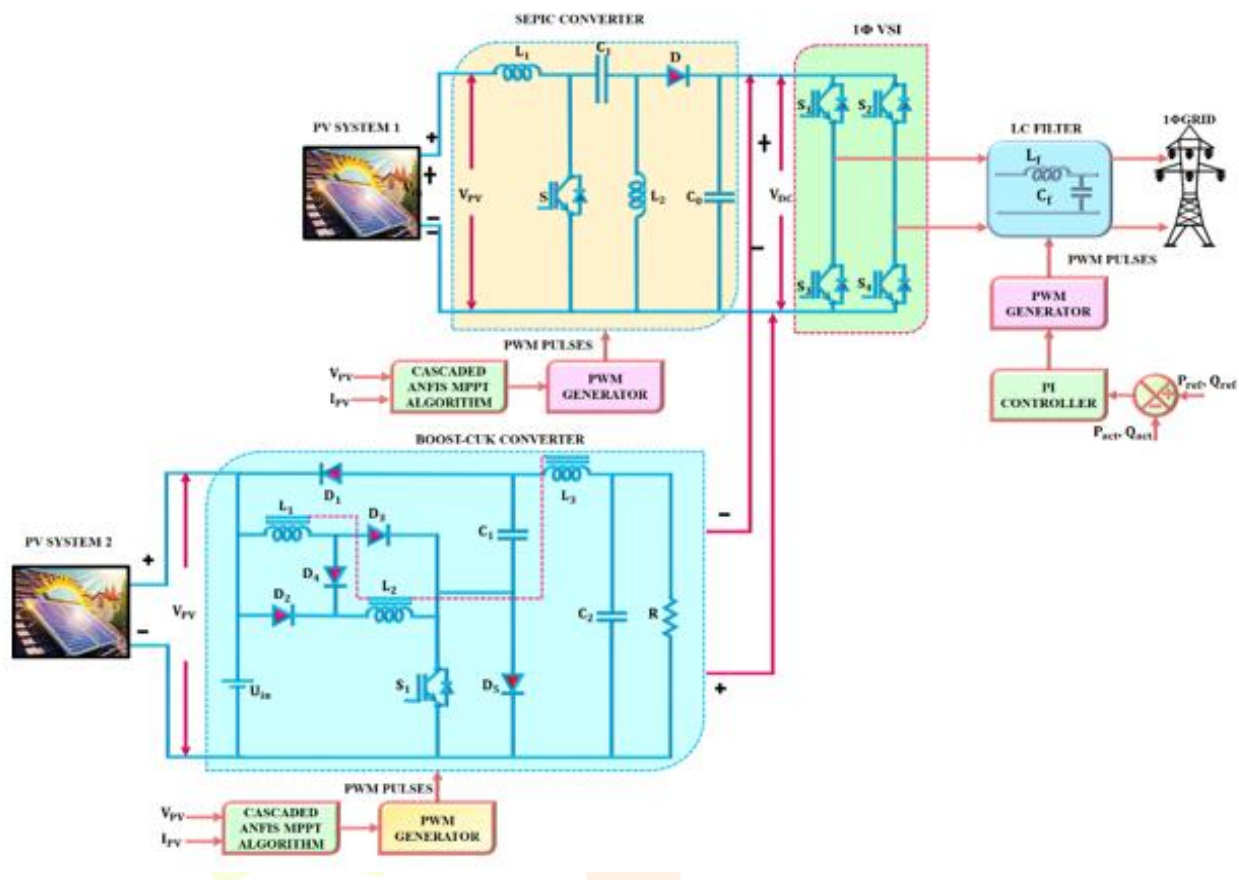


Figure 1: Block diagram of Single-Ended Primary Inductor Converter

In this paper, DC microgrid flexibility with non-isolated hybrid dc-dc converter and cascaded ANFIS MPPT is proposed. The system begins with two photovoltaic (PV) systems generating electricity. Each PV system is connected to a SEPIC (Single-Ended Primary Inductor Converter) converter, which utilizes a cascaded algorithm to optimize power output through Maximum Power Point Tracking (MPPT). The SEPIC converter adjusts the voltage levels to ensure efficient energy transfer. The generated pulses are filtered using an LC filter to smooth the output waveform. Next, the filtered output feeds into a Boost converter, which further increases the voltage. The Boost converter also employs a PWM (Pulse Width Modulation) generator for precise control. The system controller monitors the output power and adjusts parameters accordingly to maintain optimal performance. Finally, the combined output is directed to the grid, ensuring a stable and efficient supply of energy. This integration enhances the efficiency of renewable energy generation with advanced power electronics.

A. Cascaded ANFIS-Based MPPT Algorithm

The Cascaded ANFIS MPPT is an advanced hybrid algorithm that integrates Fuzzy Logic (FL) with Neural Networks (NNs), building upon the Adaptive Neuro-Fuzzy Inference System (ANFIS) to achieve improved precision in tracking the Maximum Power Point (MPP) of photovoltaic (PV) systems shown in figure 2. This cascaded approach offers better performance than traditional MPPT methods by reducing computational complexity while enhancing the accuracy of MPP estimation. The precise MPP value is determined based on various factors such as the PV system's output voltage, current, power, temperature, and solar irradiance. The system adjusts the duty cycle of the converters accordingly, ensuring that the maximum power is transmitted efficiently.

The pair selection and training methods of the cascaded ANFIS MPPT utilize a 1-output, 2-input ANFIS model. In the pair selection method, this model is employed to identify the optimal match for each input variable. Meanwhile, in the training process, it ensures that the system minimizes the Root Mean Square Error (RMSE) and improves current output generation. The final output is determined by comparing the RMSE against a predefined target error, allowing for efficient and accurate tracking of the Maximum Power Point (MPP).

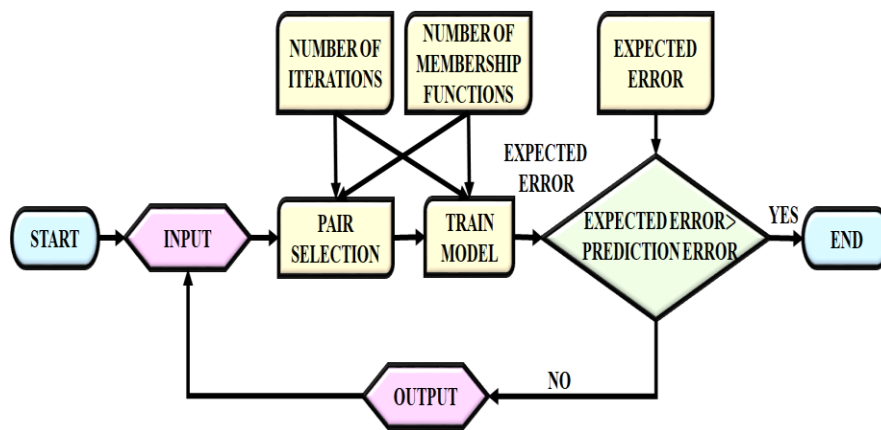


Figure 2: Flowchart of cascaded ANFIS MPPT

IV. RESULTS AND DISCUSSIONS

The proposed work is implemented in MATLAB simulation and the following results are obtained. The overall simulation diagram is shown in figure 3.

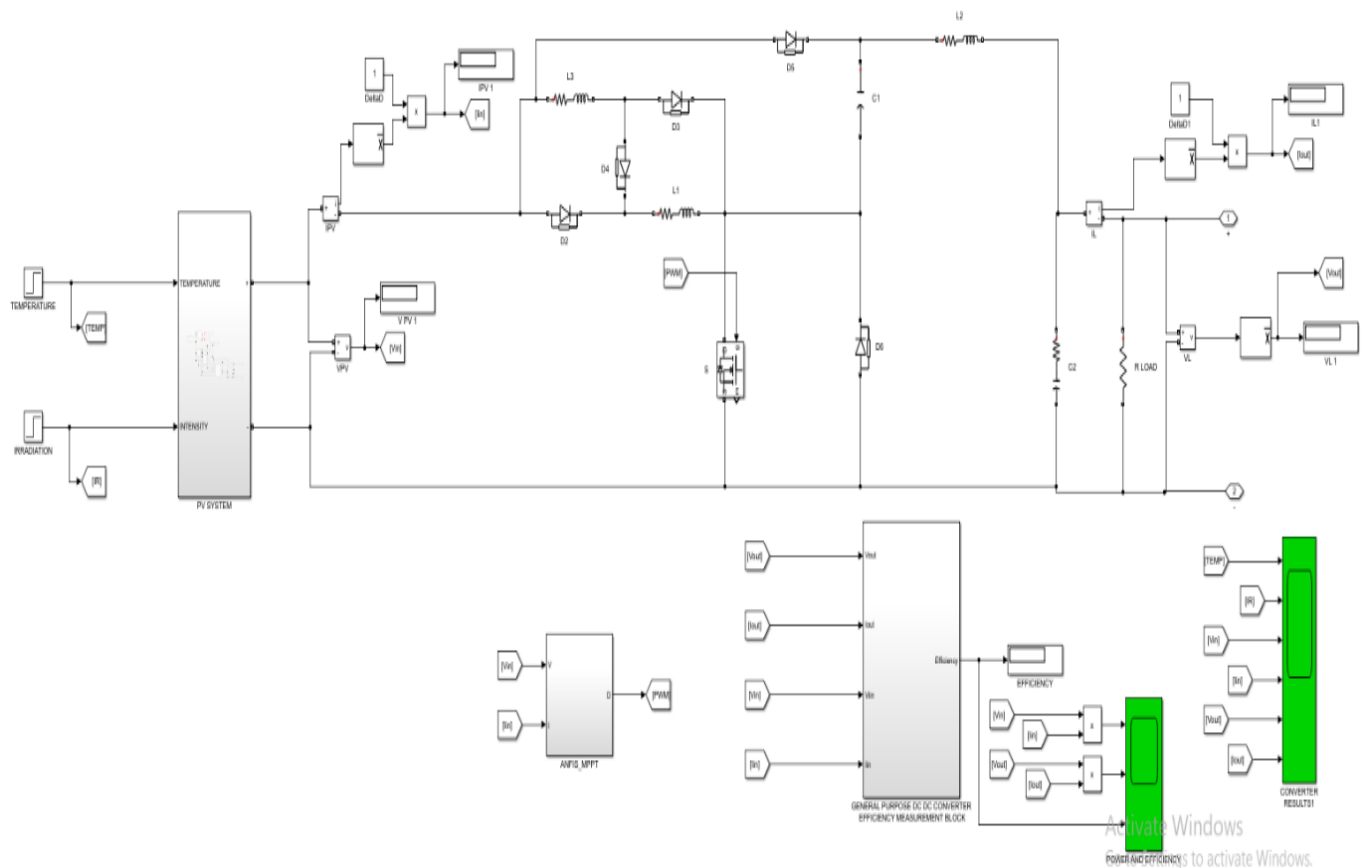


Figure 3: Overall Stimulation Diagram

Figure 4 illustrates a temperature control system. It includes sensors to measure temperature, a microcontroller for processing, and output controls for managing heating or cooling. The components work together to maintain a desired temperature, ensuring efficient climate control in a specified environment while monitoring system performance.

Figure 4 shows the output voltage and current waveforms of a SEPIC converter using ANFIS for Maximum Power Point Tracking (MPPT). The top graph illustrates initial voltage fluctuations stabilizing over time, while the bottom graph reflects consistent current output, indicating effective power conversion and regulation by the converter.

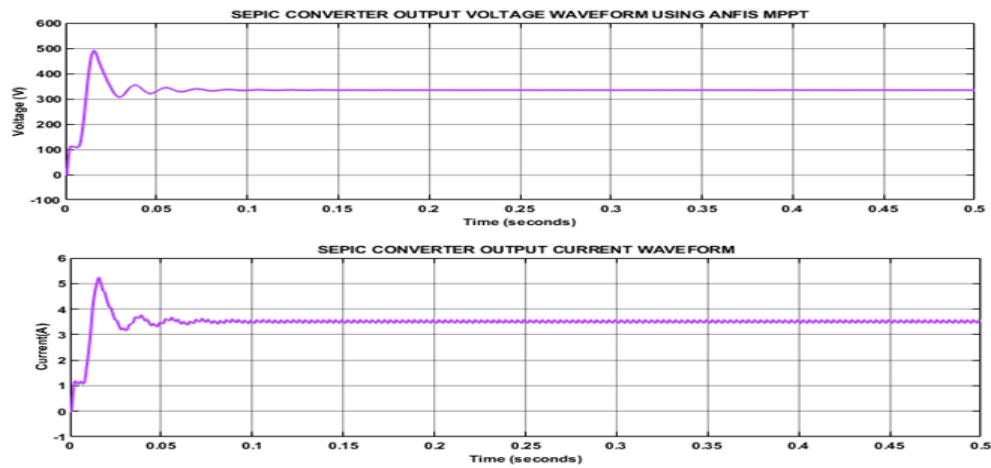


Figure 4: SEPIC Converter

Figure 5 displays the input power, output power, and efficiency waveforms of a SEPIC converter. The left graph shows fluctuating input power stabilizing around zero, while the center graph indicates steady output power at approximately 500 W. The bottom graph demonstrates consistent efficiency, illustrating effective power conversion throughout operation.

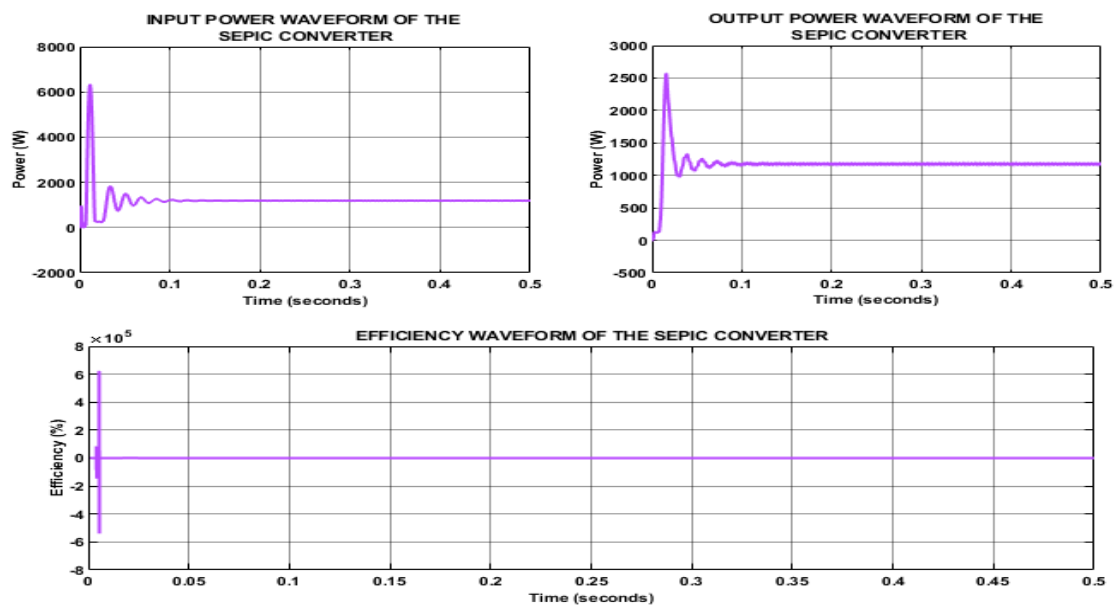


Figure 5: SEPIC Converter

Figure 6 illustrates the output voltage and current waveforms of a Boost CUK converter using ANFIS for Maximum Power Point Tracking (MPPT). The top graph shows a stable output voltage around 300 V, while the bottom graph displays a consistent output current, indicating effective power conversion and regulation.

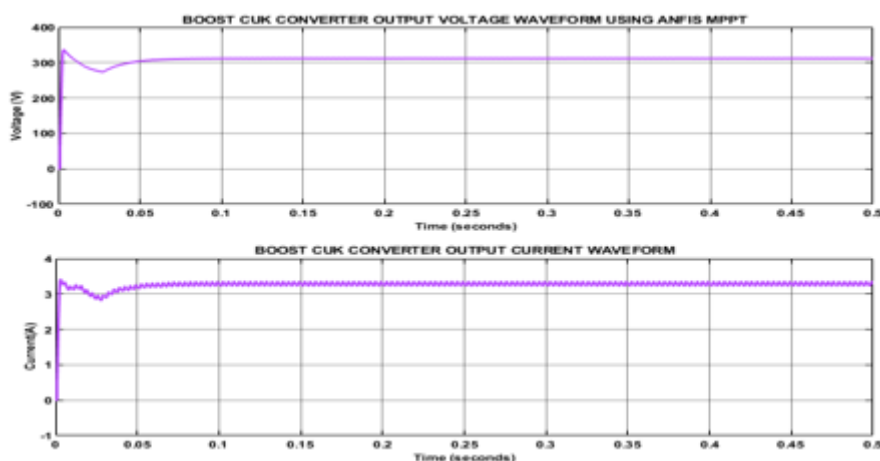


Figure 6: Boost CUK Converter

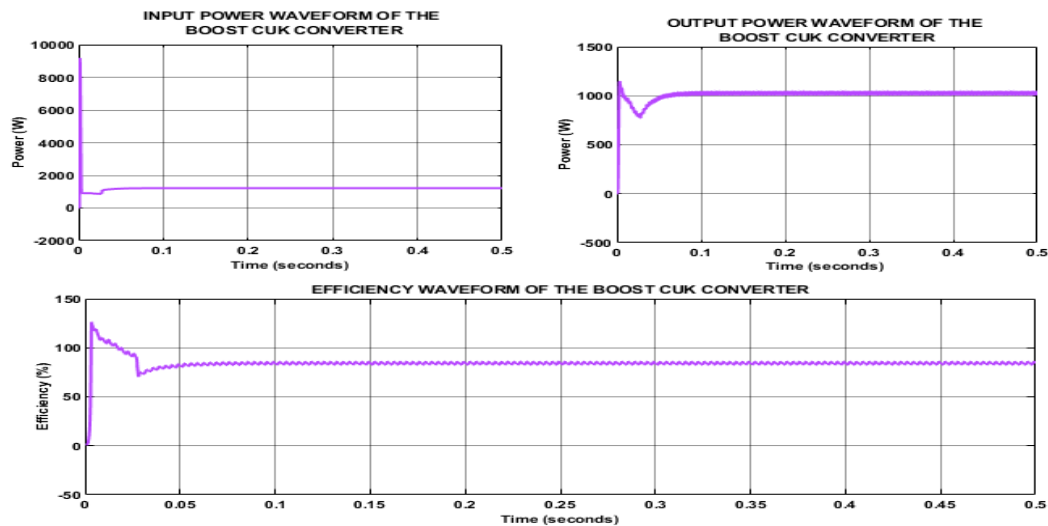


Figure 7: Boost CUK Converter

Figure 7 depicts the power and efficiency waveforms of a Boost CUK converter. The left graph shows stable input power, while the right graph illustrates consistent output power around 1000 W. The bottom graph indicates efficiency levels stabilizing around 100%, reflecting effective energy conversion and minimal losses.

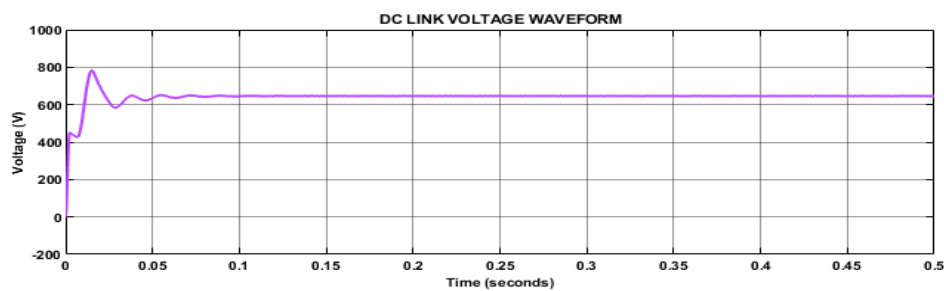


Figure 8: DC Link Voltage Waveform

Figure 8 illustrates the DC link voltage over time. Initially, there are fluctuations, but the voltage stabilizes around 600 V after a brief period. These fluctuations may result from system dynamics during startup or load changes, while the steady state indicates effective voltage regulation within the converter system.

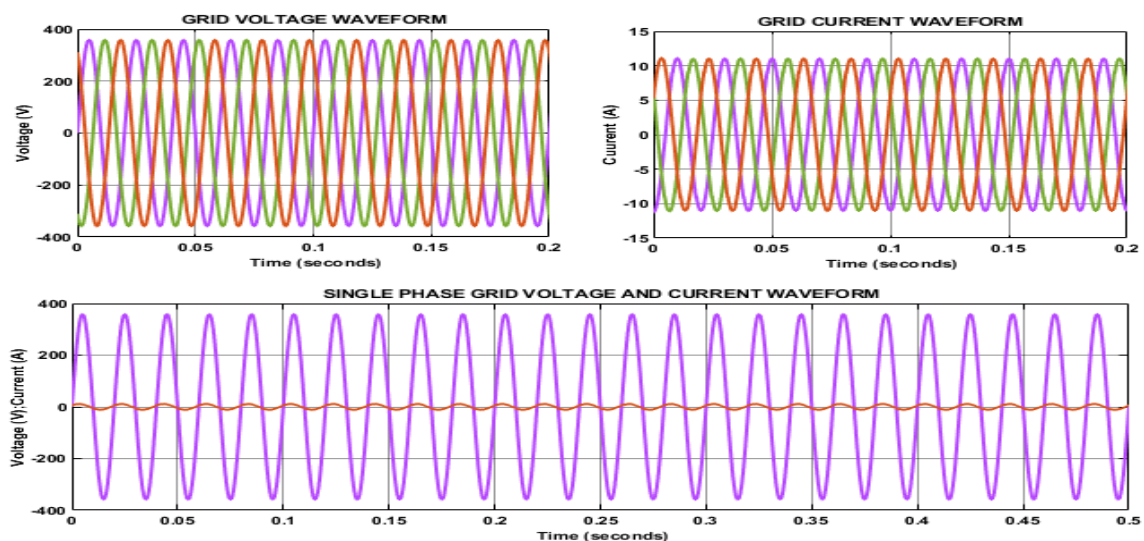


Figure 9: Grid Waveform

Figure 9 shows the relationship between grid voltage and current over time. The left graph depicts the voltage waveform, while the right shows the current waveform, both oscillating in a sinusoidal pattern. The bottom graph combines these, illustrating their phase relationship, crucial for understanding power flow and system efficiency.

V. CONCLUSION

The proposed non-isolated hybrid DC-DC converter paired with cascaded ANFIS-based MPPT demonstrates a transformative approach to enhancing the flexibility and performance of DC microgrids. The hybrid converter topology ensures efficient power conditioning, high voltage gain, and reduced component stress, making it suitable for renewable energy systems with fluctuating outputs. The cascaded ANFIS MPPT offers precise and adaptive tracking of maximum power points, even under rapidly changing environmental conditions, thereby optimizing energy harvesting from photovoltaic sources. The integrated system addresses key challenges in DC microgrid operation, including energy intermittency and stability, while maintaining high efficiency and reliability. Experimental and simulation results validate the effectiveness of the proposed scheme in achieving stable operation and superior power management. This paper underscores the potential of advanced converter designs and intelligent MPPT strategies to empower next-generation DC microgrids, paving the way for scalable and sustainable energy solutions.

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