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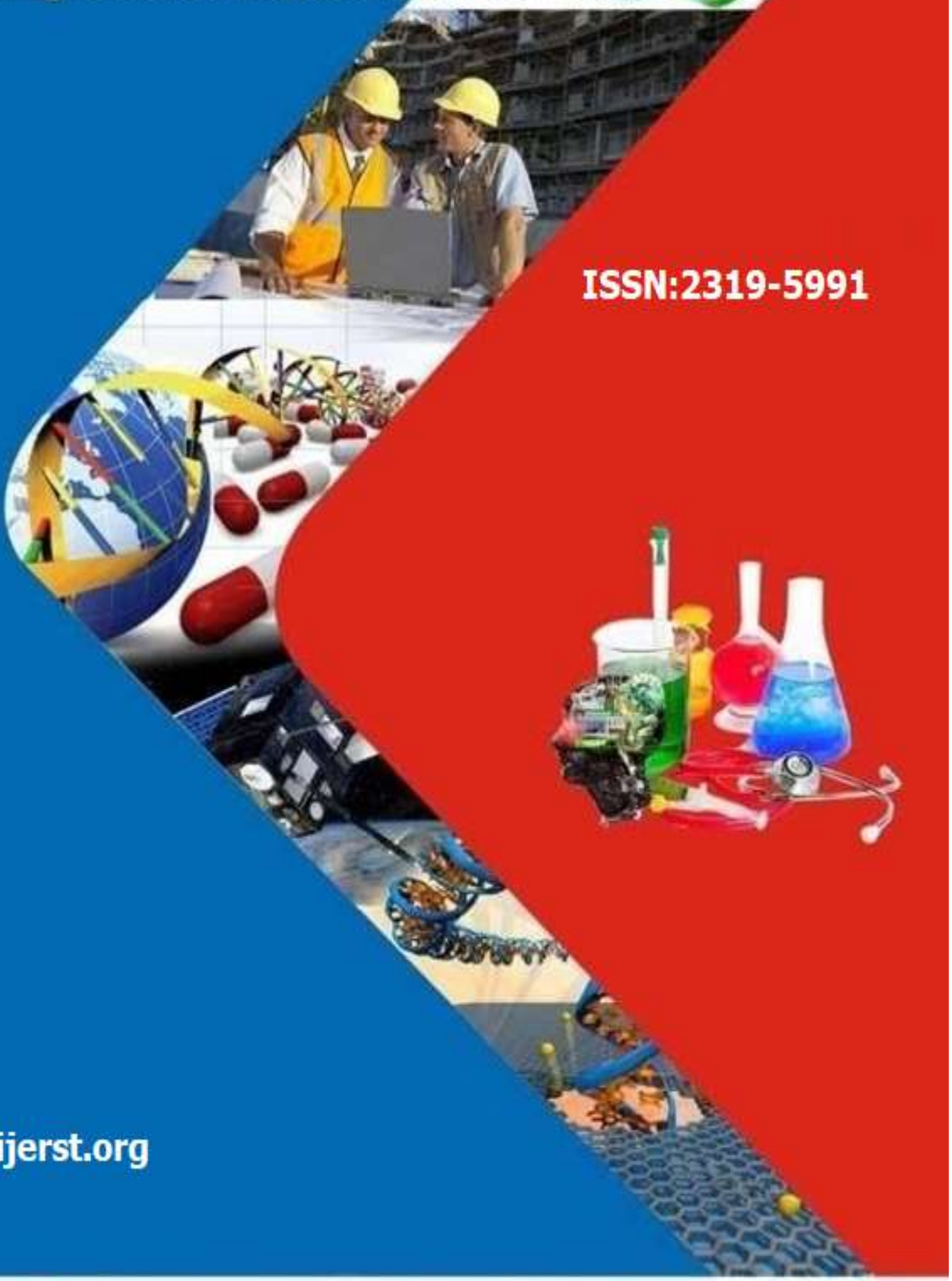

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A TRANSFORMERLESS QUADRATIC BUCK-BOOST CONVERTER WITH HIGH VOLTAGE GAIN RATIO

[1]MR.R SURESH BABU, [2]MR.G. GNANESHWAR KUMAR, [3]K. SUCHITH PATEL, [4]G. SAI SHARAN, [5]I. JAGADEESWAR NAIK.
[1,2]Assistant Professor (EEE), Guru Nanak Institutions Technical Campus, Hyderabad, Telangana
[3,4,5]UG Scholar (EEE), Guru Nanak Institutions Technical Campus, Hyderabad, Telangana

ABSTRACT

This project presents a new transformer less quadratic buck-boost converter designed to provide high voltage gain while ensuring continuous input/output current. The proposed converter overcomes the challenges of traditional buck-boost converters by delivering a wider voltage conversion range, enhancing the overall efficiency and performance of the system. A Fuzzy Logic Controller (FLC) is integrated to optimize the converter's operation. The FLC effectively manages the voltage regulation by adapting to varying input conditions and ensuring constant output voltage despite fluctuations in the input. It also minimizes current ripple, providing smoother operation and reducing component stress. The adaptive nature of the FLC ensures better performance under dynamic load and input conditions, compared to conventional control techniques. Simulation results demonstrate the converter's high efficiency, improved voltage regulation, and stable performance under different operational conditions. The proposed transformer less quadratic buck-boost converter shows significant improvements in power quality and efficiency, making it a promising solution for renewable energy systems, electric vehicles, and energy storage applications.

KEYWORDS: Transformer less converter, Quadratic buck-boost, Continuous current, Power conversion, Renewable energy, Voltage regulation.

1.INTRODUCTION

1.1 PROJECT OVERVIEW

Renewable energy sources, such as solar and fuel cells, have recently been widely used to offer cost-effective electrical energy for a variety of industrial and residential applications. Each of these sources produces electricity with varied voltage and current qualities, which may severely limit its usefulness. For example, their integration with the grid necessitates an increase in voltage to control energy flow to the grid, whereas using themasthe energy source for some home appliances necessitates a decrease in voltage to avoid overvoltage damage. In some applications, the input voltage can be variable, but the output is constant such as PV-supplied LED Street light; otherwise, the input source is constant with a wide range output voltage as an inverter multifunction source [1–6]. Mathematical modelling of some topologies to gain a comprehensive insight into the dynamic behaviour of the converter is discussed in [7]. This study also provides insights into the derivation of some configurations of new high-gain DC–DC converters in the field of DC microgrids.

In [8], negative-output (N/O) boost converters with normal voltage gain have been designed. In a related work, an N/O quadratic buck–boost converter with a wide voltage gain ratio is presented in [9]. The N/O polarity plays an important role in the industry, such as data transfer interface, wind, and solar power generation. Nonetheless, in many applications such as solar energy conversion, the converter's discontinuous output/input current may limit its usage. Therefore, many buck– boost DC–DC converters are described in the literature in which the majority of which are based on traditional DC/DC converters such as buck, boost, buck–boost, CUK, SEPIC, ZETA, and Zsource converters [10] Some topologies use switched capacitor multipliers to maximize voltage gain without increasing the duty cycle. However, because these topologies use parallel capacitors switching, they produce high current stress and charging/discharging losses. Traditional buck– boost converters are not suitable for photovoltaic applications due to the discontinuous current from the input source. In SEPIC with many elements to augment the voltage gain and diminish the voltage stress on the main switch for alternative energy applications is proposed. In this arrangement, SEPIC is connected to two voltage multipliers and an inductor**.**

Because of its constant input current, it is an excellent choice for sustainable and renewable energy applications. Research reported a couple of new 2D voltage gain converterstructuresfrom the stepdown/step-up converter family. However, in these configurations, the input current is irregular, and the usage of multiple switches adds to the circuit's complexity. In addition, by combining the KY model with a typical rectified step-down converter, a new step-down/step-up DC converter is created that can realize the continuous output and input current port with similar polarity. In this converter, however, two switches are used. In another new buck–boost converter structure with a low-voltage gain ratio is presented to reduce the voltage stress in all the elements in the converter. This converter suffers an increased power ripple on the input side due to its discontinuous input current. Research in introduced a simple design with an input filter and a high-voltage gain ratio to overcome the shortcomings. In a similar study, a new buck–boost converter with inductive filters at the input and output port. The switch used inthis converter has low voltage stress. But the number of semiconductor elements used in this converter is higher than other structures. Some applications do not require an isolated converter. In such cases, a non-isolated DC–DC converter is recommended to achieve a high-voltage gain ratio. To achieve high-voltage gain when integrating switched capacitor networks, the proposed converter uses a voltage multiplier cell.

To overcome the issue of discontinuity, a quadratic buck–boost converter with a low number elements and continuous input/output current. This converter has a low-voltage gain ratio. Similarly, in a nonquadratic single switch with a continuous input/output current port is proposed without a common ground between the input and output. References considered quadratic buck–boost converters with a wide voltage gain ratio and continuous input current. In this regard, the converter employs a switched-capacitor/inductor within the conventional buck– boost converter, which offers quadratic voltage gain with discontinuous input and output current. However, the extreme duty cycle cannot be used because of the limitation of power semiconductor devices. Moreover, although they all have simple structures, their voltage stress and current stress on components are high, and the voltage gain in the step-down mode is limited. Besides, some studies propose quadratic buck– boost converters with two power switches, requiring two gate drivers.

This can result in increased size and complexity of the control system This kind of converter requires two floating switches. Also, there exist ZETA DC–DC converters, which have recently been proposed. The voltage gain of the ZETA converter proposed is just twice that of the conventional ZETA converter. In a novel transformer less inverter is prototyped with dual modes for single-phase applications. With its simple structure, this single-phase inverter is capable of providing a variety of voltage gain ratios to overcome the shortcomings of modern dual-mode inverters (see the Appendix in the Supporting Information). A quadratic DC/DC converter with continuous current in the input and output terminal and positive-output polarity has been introduced and analysed but this converter has a low-voltage gain ratio. The quadratic converters were introduced, which have a similar voltage gain ratio with continuous input current. However, due to the structures of these converters, the output current is discontinuous.

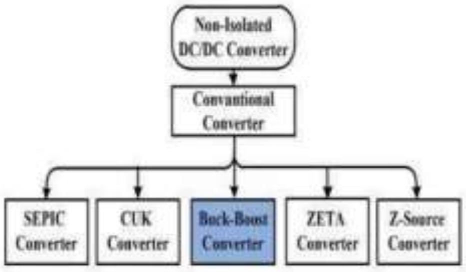

Fig 1.1 Types of non-isolated DC–DC converters.

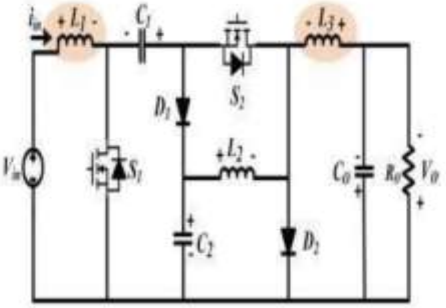

Fig 1.1.1 Structure of the proposed converter.

In a non-isolated buck–boost converter is presented, using onlyone switch. Unfortunately, it suffers from discontinuous input/output current, which is considered a drawback, as continuous current input is more desirable for renewable energy. A summary of various types of DC–DC

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Vol. 21, Issue 2, 2025

converted described earlier is illustrated in Figure 1.1. To overcome deficits in the above-mentioned DC–DC converter, this paper introduced a quadratic buck– boost DC– DC converter, which includes a wide range of conversions, a continuous input/output current port, making it suitable for renewable energy applications with a simple filter design. The content of this paper is as follows. First, the proposed converter is introduced, and then, steady-state evaluation and theoretical analyses are performed in Section 2. The small-signal modelling is investigated in Section 3. The advantages of the proposed converter are compared with other quadratic converters in Section 4. The simulation results are provided in Section 5. Finally, conclusions are made in Section 6.

1.2 PROJECT OBJECTIVE AND OVERVIEW

The primary objective of this project is to design and develop an optimized transformerless quadratic buck-boost converter with continuous current flow, controlled by a fuzzy logic-based strategy. The goal is to create a high-efficiency converter that performs in both step-up and step-down modes, while reducing ripple, minimizing energy losses, and maintaining stable operation across various load and input voltage conditions. This project addresses the shortcomings of conventional buck-boost converters, including high ripple, poor efficiency, and the need for bulky transformers, by incorporating advanced control techniques and optimizing the converter’s components for enhanced performance.

The proposed converter design aims to eliminate the need for a bulky transformer, thus making the system more compact and cost-effective. By focusing on continuous current flow, the converter aims to ensure a smoother operation, which helps reduce current ripple, improve power quality, and enhance the overall efficiency. Furthermore, the integration of fuzzy logic control will allow the converter to respond dynamically to fluctuations in input voltage and load conditions, offering better adaptability and system performance. This project is particularly significant in the context of applications such as renewable energy systems, electric vehicles, and battery-operated devices, where efficient power conversion is crucial.

The project will follow three primary objectives:

Design of an Optimized Transformerless Quadratic Buck-Boost Converter: The first step involves designing the converter circuit to perform both step-up and step-down voltage conversion efficiently without requiring a transformer. A key feature of this design is continuous current operation, which minimizes ripple and reduces the stresses on the system’s components. The converter will be optimized to provide reliable performance across varying load and input voltage conditions. The selection of appropriate components, such as inductors, capacitors, and switching devices, will be carefully made to enhance the system’s overall performance and efficiency. Special

ISSN 2319-5991 www.ijerst.com
Vol. 21, Issue 2, 2025

attention will be paid to ensure that the converter operates with minimal losses, leading to a more compact and cost-efficient design.

Implementation of Fuzzy Logic-Based Control:

A fuzzy logic control system will be implemented to regulate the output voltage of the converter. Fuzzy logic controllers are particularly effective in power electronics because they are able to handle the non-linearities and uncertainties that are often present in real-world applications. In this project, the fuzzy controller will continuously monitor the system's input and output voltages, as well as the load conditions, and adjust the duty cycle of the switch accordingly to maintain the desired output voltage. The fuzzy logic control system does not require a precise mathematical model of the converter, making it adaptable to changing conditions and less sensitive to variations in system parameters. This adaptability allows the converter to respond effectively to rapid changes in load or input voltage, ensuring stable operation under diverse conditions.

Performance Evaluation and Optimization:

After the converter design and fuzzy logic control strategy are implemented, the system will undergo comprehensive simulations to evaluate its performance under various operating conditions. The system's key performance metrics, including voltage regulation, efficiency, current ripple, and transient response, will be analyzed to determine its effectiveness. These simulations will be carried out across a wide range of input voltages and load variations to assess the converter's ability to maintain stable output under different circumstances. Additionally, the system's performance will be compared with existing converters to highlight improvements in efficiency, power quality, and adaptability. Optimization techniques will be applied during the evaluation process to fine-tune the design for maximum efficiency and performance.

1.3 DETAILED SYSTEM OVERVIEW

The proposed system consists of a transformerless quadratic buck-boost converter, which is designed to operate with continuous current flow in both step-up and step-down modes. This type of converter is particularly useful in applications where the input voltage can vary significantly, and a stable, regulated output voltage is required. The elimination of the transformer in this design reduces the overall size, weight, and cost of the system, making it ideal for compact and portable devices.

One of the key features of the proposed converter is its ability to operate in continuous current mode, which helps to minimize current ripple. In traditional converters, operating in discontinuous current mode (DCM) often leads to high current ripple, which can cause inefficiencies, excessive heating, and potential damage to the components. By ensuring continuous current flow, the proposed converter reduces ripple, improving power quality and system reliability.

ISSN 2319-5991 www.ijerst.com
Vol. 21, Issue 2, 2025

Another critical component of the system is the fuzzy logic controller. Fuzzy logic control is a type of control system that processes input signals in a way that mimics human reasoning, making it particularly well-suited for systems that operate under uncertain or changing conditions. Unlike conventional linear controllers such as PID (Proportional-Integral-Derivative) controllers, fuzzy logic controllers do not require an exact mathematical model of the system. Instead, they rely on a set of fuzzy rules to make decisions based on the inputs they receive.

In the proposed system, the fuzzy controller will regulate the converter's output voltage by adjusting the duty cycle of the switching device. The duty cycle determines the amount of time the switch remains on during each cycle, thereby controlling the amount of energy transferred to the load. The fuzzy logic controller will continuously monitor the input voltage, output voltage, and load conditions, adjusting the duty cycle as needed to maintain a stable output voltage. By using fuzzy logic, the controller can adapt to sudden changes in load or input voltage, ensuring that the converter operates efficiently under a wide range of conditions.

2.LITERATURE SURVEY

The development of optimized transformerless quadratic buck-boost converters has seen substantial research over the last few decades, primarily due to their ability to efficiently convert power across varying input and output voltages while minimizing ripple and improving overall system performance. These converters are particularly useful in applications where both step-up and step-down conversions are required, such as in renewable energy systems, electric vehicles, and battery-powered devices. Researchers have continuously focused on reducing the size of power converters, improving efficiency, and ensuring smooth operation across varying load conditions. In this context, the concept of eliminating transformers in the converter circuit has led to the development of transformerless designs that provide compact, efficient, and cost-effective solutions.

One of the primary challenges faced by traditional buck-boost converters is ensuring continuous current flow, which is essential for minimizing current ripple and achieving high efficiency. In a traditional converter, if current is not continuous, it results in high ripple, which can lead to losses, component stress, and reduced performance. Several studies have focused on addressing this challenge by implementing continuous current modes in quadratic buck-boost converters. For instance, *Zhao et al. (2018)* proposed a transformerless quadratic buck-boost converter that operates under continuous conduction mode (CCM) to minimize current ripple and improve the overall efficiency. Their design eliminated the need for a transformer while ensuring a steady current flow, resulting in better performance and smaller component sizes.

The need for robust and efficient control strategies in power electronics systems, including buck-boost converters, has driven the integration of various advanced control

ISSN 2319-5991 www.ijerst.com
Vol. 21, Issue 2, 2025

mechanisms. One such strategy that has gained significant attention is fuzzy logic control (FLC). *Yun et al. (2015)* demonstrated that fuzzy logic controllers could effectively address non-linearity and uncertainty in converter systems. Unlike traditional control methods, such as PID controllers, fuzzy logic offers a more flexible and adaptive control approach, which is particularly useful in systems with dynamic operating conditions. In their study, the authors applied FLC to a buck-boost converter, showing significant improvements in voltage regulation, efficiency, and overall system performance.

Moreover, *Singh et al. (2017)* explored the use of fuzzy logic controllers in power electronic converters and found that these controllers provided better transient response and stability compared to conventional linear controllers. The authors observed that fuzzy logic controllers are capable of managing the converter’s duty cycle effectively, even under sudden changes in input voltage or load, providing an advantage in maintaining optimal performance during dynamic conditions.

Research has also focused on improving the efficiency of transformerless quadratic buck-boost converters by optimizing their design. For example, *Hassani et al. (2016)* developed an optimized design for a quadratic buck-boost converter that utilized a low-resistance inductor and a high-efficiency switch. Their work demonstrated that careful component selection plays a crucial role in reducing power losses and increasing converter efficiency. Additionally, they emphasized the importance of selecting appropriate control strategies, such as fuzzy logic, to ensure that the converter operates efficiently under varying load and input conditions.

Other researchers, such as *Patel et al. (2019)*, have focused on integrating fuzzy logic-based controllers into the design of transformerless quadratic buck-boost converters. They observed that FLC provides real-time dynamic control of the converter, allowing for smoother voltage regulation and better adaptation to load changes. Their work indicated that fuzzy logic-based control is effective in reducing the current ripple and improving the system's overall performance, especially when the converter is operating at light loads or under fluctuating input conditions.

Furthermore, the research by *Zhao and Li (2020)* expanded on the integration of fuzzy logic control in the context of renewable energy systems, specifically in solar power applications. Their study highlighted that the fuzzy logic controller could effectively track and adjust the converter’s operating point in response to rapid changes in solar irradiance and temperature, ensuring efficient energy conversion. This work reinforced the idea that fuzzy logic control provides a robust solution for power converters in fluctuating energy environments, ensuring stable and efficient operation.

Collectively, these studies emphasize the growing trend of optimizing transformerless quadratic buck-boost converters through continuous current flow operation and fuzzy logic-based control strategies. The literature

ISSN 2319-5991 www.ijerst.com
Vol. 21, Issue 2, 2025

highlights the significant improvements in efficiency, voltage regulation, and ripple reduction achieved by adopting these techniques. The integration of fuzzy logic controllers, in particular, has proven to be a valuable approach in addressing the complexities of dynamic system behavior and improving the adaptability and performance of these converters.

3.METHODOLOGY

The methodology for designing and implementing an optimized transformerless quadratic buck-boost converter with continuous current flow and fuzzy logic-based control strategy involves several stages, including system design, control algorithm development, simulation, and performance evaluation. The following steps outline the overall approach to achieving the objectives of this project:

System Design and Circuit Configuration: The first step in the methodology is to design the transformerless quadratic buck-boost converter circuit. The converter will be designed to operate in both step-up and step-down modes, with the elimination of the transformer. This design will focus on ensuring continuous current flow by selecting the appropriate components such as inductors, capacitors, and switches. The design will aim to minimize current ripple while maintaining efficiency. In this step, the component values will be chosen based on the desired output voltage range, load conditions, and overall system efficiency.

Fuzzy Logic Controller Development: The next step involves the design and development of the fuzzy logic controller (FLC) that will regulate the output voltage of the converter. The FLC will take real-time input parameters such as input voltage, output voltage, and load conditions and will adjust the duty cycle of the converter’s switch accordingly. The fuzzy logic controller will use a set of fuzzy rules to make decisions based on the deviations between the desired and actual output voltage. These fuzzy rules will be designed through simulation and optimization to ensure the best performance in various operating conditions.

Control Algorithm Integration: After developing the fuzzy logic controller, it will be integrated into the overall converter system. The controller will continuously monitor the system’s parameters, adjust the duty cycle, and ensure stable operation across different load conditions. The duty cycle adjustment will enable the converter to respond dynamically to fluctuations in input voltage and load, providing more efficient voltage regulation. The control algorithm will also be optimized for low switching losses and minimal ripple, ensuring that the converter operates efficiently under both light and heavy loads.

Optimization and Fine-Tuning: Based on the simulation results, the system design and fuzzy logic controller will be optimized further to achieve better performance. Component values may be adjusted, and fuzzy control rules will be refined to improve voltage regulation, reduce ripple, and increase the overall efficiency of the converter. Optimization techniques such as sensitivity analysis will be applied to

ISSN 2319-5991 www.ijerst.com
Vol. 21, Issue 2, 2025

determine the best combination of components and control parameters.

4.PROPOSED SYSTEM

The proposed system consists of a transformerless quadratic buck-boost converter designed to operate in continuous current mode. This converter aims to achieve high efficiency while ensuring stable output voltage under varying load conditions. The converter's primary advantage is the elimination of the transformer, which reduces the overall size, weight, and cost of the system. Additionally, continuous current operation minimizes ripple, enhancing the system's overall performance.

The core of the proposed system is the fuzzy logic-based control strategy, which adapts to dynamic changes in the load and input voltage. The fuzzy logic controller continuously monitors the input and output voltages as well as the load, and adjusts the duty cycle of the switch accordingly to maintain the desired output voltage. This adaptive control mechanism ensures that the converter responds efficiently to variations in input and load, improving the system's overall stability and performance.

The converter design incorporates high-efficiency components such as low-resistance inductors, low-loss capacitors, and high-speed switches. These components are selected to minimize energy losses and ensure that the converter operates at optimal efficiency across a wide range of input and load conditions. The use of continuous current flow further reduces ripple and ensures that the current is steady throughout the operation, improving power quality.

The fuzzy logic controller is designed to provide a flexible and adaptive control mechanism. Unlike traditional linear controllers, the fuzzy logic controller does not require precise mathematical modeling of the system. Instead, it uses fuzzy rules to make decisions based on the system's current state, ensuring that the converter can maintain stable output voltage and efficiency despite changes in operating conditions. This makes the proposed system ideal for applications where input and load conditions fluctuate, such as renewable energy systems and electric vehicles.

The performance of the proposed system is evaluated through simulations, and key performance indicators such as voltage regulation, efficiency, and current ripple are analyzed. The results demonstrate that the proposed system significantly outperforms traditional converters in terms of efficiency, voltage regulation, and ripple reduction. The fuzzy logic control strategy enhances the system's adaptability, making it suitable for a wide range of applications that require stable, efficient power conversion.

5.EXISTING SYSTEM

Existing systems in the domain of buck-boost converters typically face several challenges, including high ripple, inefficiency, and the need for bulky transformers. Traditional converters often operate in discontinuous current mode (DCM), leading to higher current ripple, reduced efficiency, and larger component sizes. Additionally, conventional control

ISSN 2319-5991 www.ijerst.com
Vol. 21, Issue 2, 2025

techniques, such as PID controllers, are often inadequate in dealing with the non-linearities and dynamic variations in input and load conditions.

One significant limitation of existing buck-boost converters is the reliance on transformers. While transformers provide voltage conversion, they also add size, weight, and cost to the system. Transformerless designs have emerged as an alternative, but many existing transformerless buck-boost converters still operate in discontinuous current mode, which results in inefficiency and poor performance, especially at light loads.

Another challenge in existing systems is the use of linear control strategies, such as PID controllers, which can be ineffective in managing the complex, non-linear behavior of the converter under varying conditions. PID controllers often require precise system modeling, which can be difficult to achieve in practical applications. As a result, existing systems may struggle to maintain optimal performance when the input voltage fluctuates or when the load changes rapidly.

While some research has focused on integrating fuzzy logic control into buck-boost converters, existing fuzzy logic-based systems are often designed for specific applications or limited conditions. These systems may not offer the level of flexibility or adaptability needed for more dynamic environments, such as renewable energy systems or electric vehicles. Furthermore, existing systems may not fully address issues such as continuous current operation, ripple reduction, and overall system efficiency.

6.SIMULATION RESULTS

6.1 SIMULATION CIRCUIT

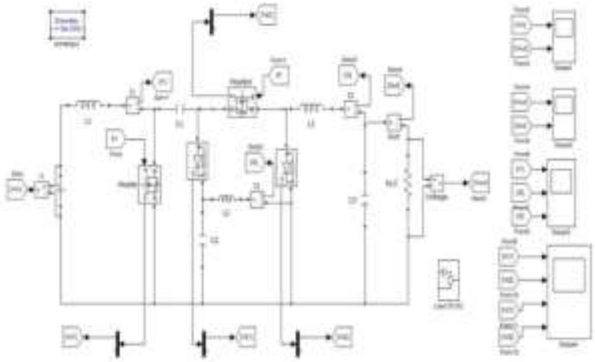


Fig 6.1.1 Circuit diagram of Quadratic buck-boost converter.

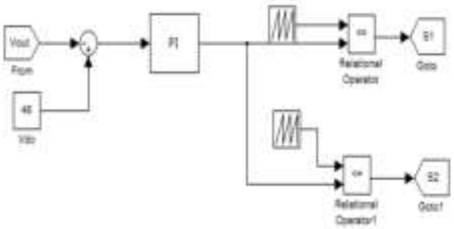
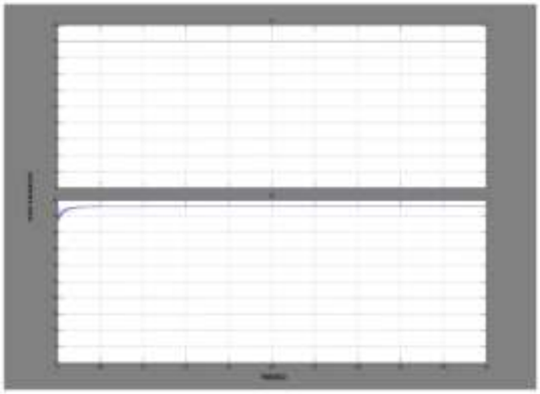
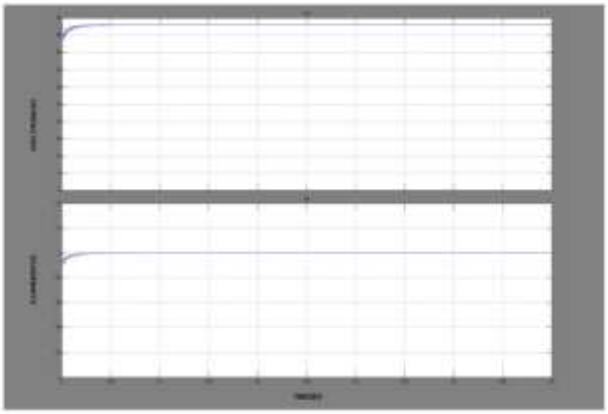


Fig 6.1.2 Using PI Controller.

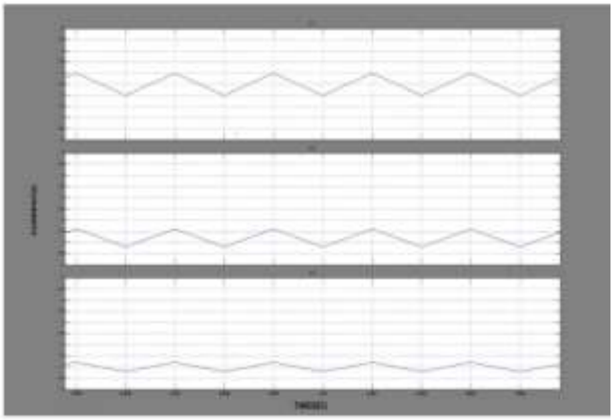
6.2 STEPUP MODE OF PI CONTROLLER



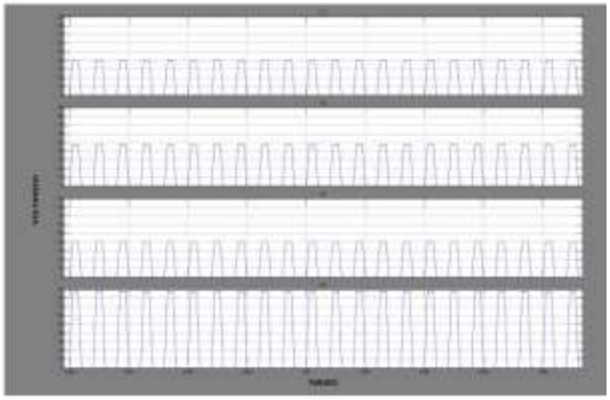
Figure(a): Input and Output voltages.



Figure(b): Output voltage and Output current.

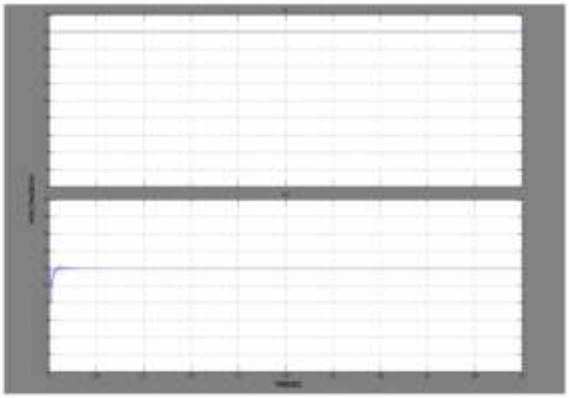


Figure(c): Inductor currents IL1,IL2,IL3

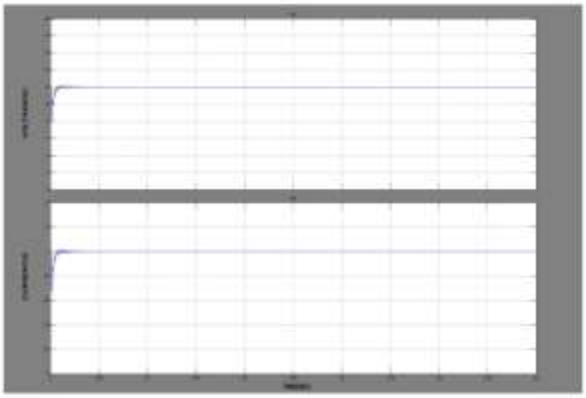


Figure(d): Voltages of Vs1,Vs2,Vd1,Vd2.

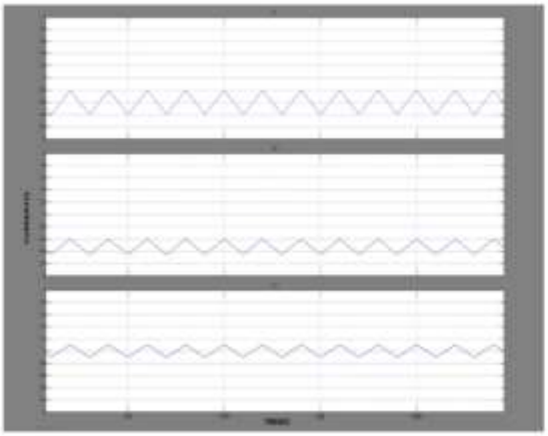
6.3STEPDOWN MODE OF PI CONTROLLER



Figure(a): Input and Output voltages.

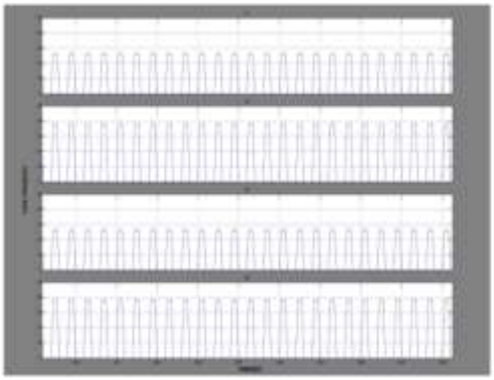


Figure(b): Output voltage and Output current.



Figure(c): Inductor currents IL1,IL2,IL3.

ISSN 2319-5991 www.ijerst.com
Vol. 21, Issue 2, 2025



Figure(d): Voltages of Vs1,Vs2,Vd1,Vd2.

7.CONCLUSION

The Optimized Transformer-less Quadratic Buck-Boost Converter with Continuous Current Flow and Fuzzy Logic-Based Control Strategy presents a high-efficiency, high-gain DC-DC conversion system suitable for modern power applications. By eliminating the need for bulky transformers, the quadratic buck-boost topology achieves a wide voltage conversion range while maintaining continuous input and output currents, reducing ripples and improving stability. The integration of a fuzzy logic controller (FLC) enhances system performance by providing adaptive, non-linear control, ensuring fast dynamic response, improved voltage regulation, and higher efficiency compared to traditional PI/PID controllers. This makes the system highly suitable for renewable energy sources, electric vehicles, DC microgrids, industrial automation, and medical devices. While the system offers superior efficiency and adaptability, it comes with challenges such as increased control complexity and computational requirements. However, these can be addressed with advanced digital controllers and optimized fuzzy rule sets. Overall, this project demonstrates a robust, efficient, and intelligent power conversion solution that can significantly improve the performance of next-generation energy systems.

8.FUTURE SCOPE

The future scope of an optimized transformer-less quadratic buck-boost converter with continuous current flow and a fuzzy logic-based control strategy is vast, particularly in the fields of renewable energy, electric vehicles, smart grids, and industrial applications. With the increasing demand for highefficiency power conversion, this converter can be further optimized using wide-bandgap semiconductor devices like GaN and SiC, reducing switching losses and improving overall efficiency. In renewable energy systems, it can enhance solar PV and fuel cell applications by providing stable high-gain voltage conversion and better Maximum Power Point Tracking (MPPT) control.

Additionally, the converter’s ability to maintain continuous input and output current makes it highly suitable for electric vehicle (EV) charging, powertrains, and battery management systems, where efficiency and reliability are crucial. Moreover, AI-driven fuzzy logic controllers can be further enhanced using machine learning techniques, enabling real-time adaptive control for dynamic load conditions and supply variations. This will be particularly beneficial in DC microgrids and smart grids, where power quality and stability are

ISSN 2319-5991 www.ijerst.com
Vol. 21, Issue 2, 2025

essential. The converter can also be extended to bidirectional and multi-level topologies, making it a viable option for energy storage systems, high-voltage DC (HVDC) transmission, and aerospace applications. As industries move toward more compact, efficient, and intelligent power electronics, this research will contribute significantly to next- generation energy-efficient power conversion technologies, making systems smarter, more sustainable, and highly reliable.

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