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NON - ISOLATED HIGH GAIN DC-DC CONVERTER

A Fuzzy Logic-Regulated Boost System for Microgrid Applications

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Abstract: DC-DC converters are becoming increasingly popular in renewable energy applications and solar PV systems. This report introduces a non-isolated, non-coupled inductor-based high-gain DC-DC boost converter with the desirable features of low voltage stress on controlled power switches and high voltage gain at lower duty ratios. The proposed converter is well suited for boosting the low-input DC voltage obtained from distributed generation units like photovoltaic (PV) or fuel cells to substantially higher DC voltage. The converter comprises only two switches, and a single PWM signal governs its operation. These characteristics result in a topology that is more compact, less costly, lighter weight, and easier to control. A Fuzzy Logic Controller based voltage control loop is introduced for load voltage regulation under varying input conditions. The proposed converter is compared with conventional controllers across various performance parameters. The simulation is carried out in MATLAB/Simulink software, and a hardware prototype is developed to validate the results experimentally.

***Index Terms* -** DC-DC Converter, Fuzzy Logic Controller, High-Gain, Microgrid, PWM, Renewable Energy.

I. Introduction

High-gain DC-DC boost converters are essential electronic circuits that convert a low DC voltage input into a significantly higher DC voltage output. They are a cornerstone technology for many modern applications, especially in the field of renewable energy. Sources such as photovoltaic (PV) solar panels and fuel cells typically produce a low, variable DC voltage (e.g., 24-30V), which is insufficient for direct connection to a grid-tied inverter or for powering many standard appliances that require a higher voltage (e.g., 400V). High-gain converters bridge this gap, enabling the efficient utilization of these green energy sources.

The conventional boost converter, while simple, faces significant limitations when a very high voltage gain is required. To achieve a high gain, the converter must operate at an extremely high duty ratio. This leads to high voltage and current stress on the switching components, increased conduction and switching losses, and severe electromagnetic interference (EMI).

To overcome these challenges, researchers have developed numerous advanced converter topologies. Lin et al. introduced a novel high-gain boost converter designed for renewable energy systems, providing high efficiency with low voltage stress. Q. Zhao et al. presented a family of high-efficiency converters that avoid extreme duty ratios by utilizing diodes and coupled windings to recycle leakage energy. Similarly, works by Gules et al. and Zaoskoufis et al. explored modified SEPIC and coupled-inductor converters to achieve high static gain.

This project focuses on a novel non-isolated, non-coupled inductor-based high-gain DC-DC converter capable of achieving a high voltage conversion ratio of approximately 16.67 at a moderate duty ratio. The primary objectives are to design and simulate the converter, develop an intelligent Fuzzy Logic Controller (FLC) to precisely regulate the output voltage, and ensure the system maintains a constant 400V output under dynamic operating conditions. Furthermore, a comparative analysis is conducted against an open-loop system and a conventional Proportional-Integral (PI) controller.

II. RESEARCH METHODOLOGY

The methodology encompasses the design, control, and analysis of a high-gain DC-DC converter. The system is engineered to take a variable low-voltage DC input (24V to 30V) and convert it into a stable, high-voltage 400V DC output.

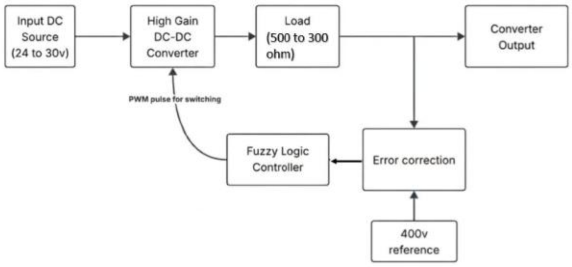

Figure 1. Block diagram of the proposed system.

Figure 1 illustrates the overall architecture of the closed-loop control system. The process begins with the low-voltage DC source, which powers the high-gain converter. The converter's output is connected to a variable load. The feedback loop consists of a voltage sensor, an error correction block, and the controller that generates the PWM signal.

2.1 Proposed Converter Topology

The circuit topology chosen is a non-isolated, non-coupled inductor-based converter. The circuit is composed of two inductors, three capacitors, three diodes, and two power MOSFET switches. Both switches are driven synchronously by a single PWM signal, reducing the need for complex gate drivers.

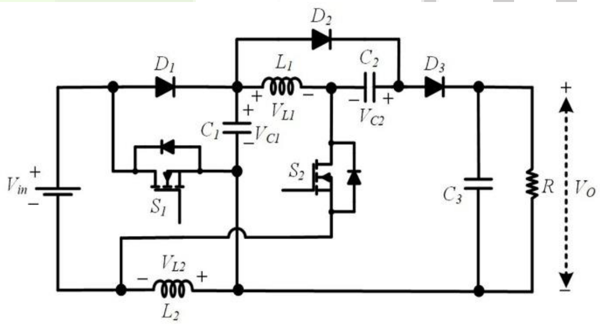

Figure 2. Proposed high-gain boost converter circuit.

The schematic details the interconnection of the components. The arrangement of the switched-inductor and switched-capacitor cells allows the converter to multiply the input voltage multiple times within a single switching cycle.

2.2 Modes of Operation

The converter's operation is broken down into two distinct modes:

- ON Mode (Switches Closed): When the PWM signal is high, both MOSFETs are turned ON. The primary diodes are reverse-biased. The input voltage source charges the second inductor, and the first capacitor charges the first inductor.

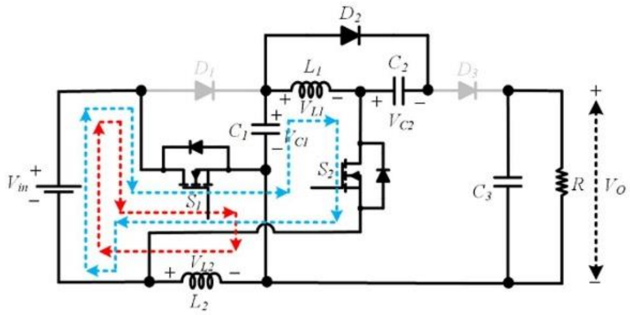

Figure 3. Equivalent circuit for switch-on mode.

This shows the current paths during the ON mode where the inductors store energy from the source and capacitors.

- OFF Mode (Switches Open): When the PWM signal goes low, both switches turn OFF. The energy stored in the inductors is released, forward-biasing the active diodes. This energy is transferred to the output, charging the capacitors and supplying power to the load.

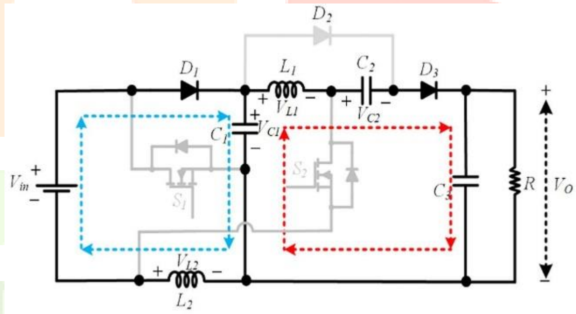

Figure 4. Equivalent circuit for switch-off mode.

This illustrates the current paths when the switches are open. The energy from the inductors is released, delivering a high-voltage output to the load.

2.3 Steady-State Analysis and Voltage Gain

Applying Kirchhoff's Voltage Law (KVL) during the ON state, the voltage across the first inductor equals the input voltage plus the voltage across the first capacitor, which also equals the voltage across the second capacitor. The voltage across the second inductor simply equals the input voltage.

During the OFF state, the energy stored in the inductors is released towards the load, and the respective voltage equations shift to account for the output voltage and capacitor voltages.

By applying the volt-second balance principle to both inductors, the ideal voltage gain is derived. This gain depends heavily on the output voltage, input voltage, and the duty ratio. For the given parameters of a 24V input and a 400V output, the required duty cycle is calculated to be 0.69. To maintain Continuous Conduction Mode (CCM) and minimize ripple, the selected passive component values are 9.3 microhenries and 1 microhenry for the inductors, alongside 33 microfarads, 220 microfarads, and 220 microfarads for the capacitors.

2.4 Controller Design

To ensure the high-gain converter maintains a stable 400V output, a Fuzzy Logic Controller (FLC) was implemented over a traditional Proportional-Integral (PI) controller. The FLC operates based on linguistic "IF-THEN" rules that mimic human decision-making, making it highly effective for non-linear systems.

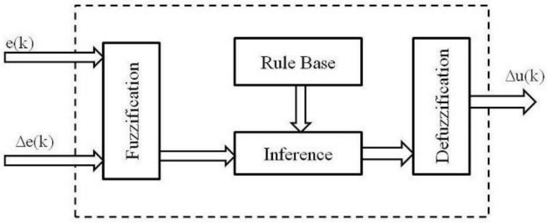

Figure 5. Block diagram of the Fuzzy Logic Controller.

The three main components of the FLC: Fuzzification, Rule Base/Inference Engine, and Defuzzification, which converts the fuzzy output into a crisp control signal to adjust the duty cycle.

Triangular membership functions are predominantly used for the inputs—error and change in error—ensuring smooth transitions across the entire input domain.

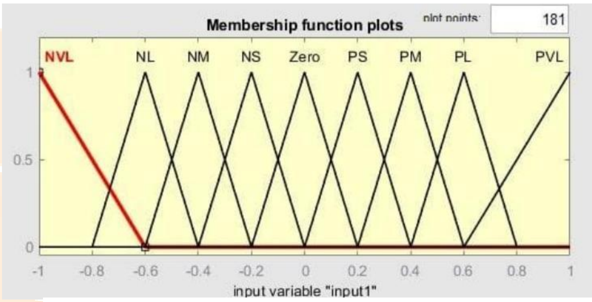

Figure 6. Membership functions for the FLC.

Nine linguistic variables spanning a normalized input range from -1 to 1 are utilized for precise control logic.

Ve	NVL	NL	NM	NS	Zero	PS	PM	PL	PVL
D	Zero	Zero	Zero	Zero	Zero	PS	PM	PM	PL

Table 1. Fuzzy Logic Controller rules.

The rule base matrix showing the corresponding output for the duty cycle adjustment based on voltage error and change in error.

III. Hardware Implementation

The hardware implementation of the converter integrates high-speed power electronic switching with intelligent digital control.

3.1 Control and Software Environment

The control unit of the converter utilizes a Raspberry Pi 5 to generate the PWM switching signals required to control the MOSFET switches. The controller continuously monitors the output voltage and dynamically adjusts the duty cycle to maintain a stable output voltage.

3.2 Power Supply and Input Regulation

The input stage utilizes two 230V/24V step-down transformers connected to produce a combined 48V AC output. This is converted to DC using a bridge rectifier circuit. A single-channel relay acts as a voltage selection switch, enabling the system to supply different input voltage levels (e.g., 36V and 72V) to test the converter's robustness.

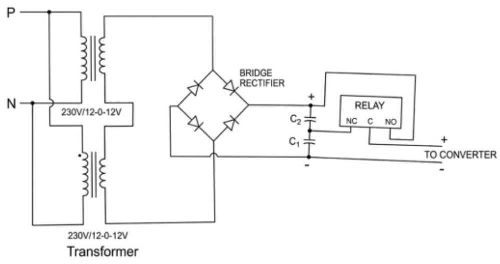

Figure 7. Circuit diagram from the supply

The input regulation stage effectively steps down, rectifies, and routes the variable power supply to the main converter circuit.

3.3 Switching and Driver Circuitry

The switching stage uses IRF840 MOSFETs. A CD4050 non-inverting buffer IC acts as an initial signal conditioning stage, which is fed to a TLP250 opto-isolated gate driver to provide galvanic isolation and rapid gate charging/discharging.

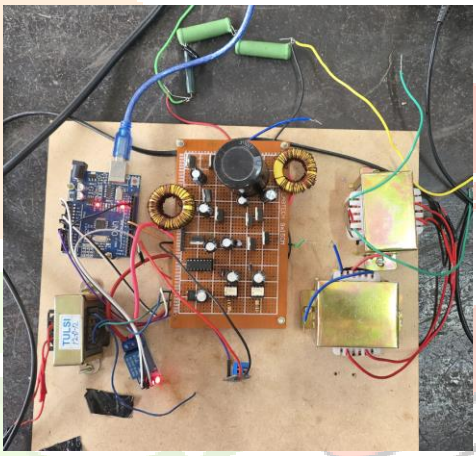

Figure 8. Hardware circuit of the proposed

The complete hardware setup highlighting the integration of the control unit, driver circuitry, and the high-voltage power conversion stage.

IV. Results And Performance Analysis

The entire system was simulated in MATLAB/Simulink. The input voltage was varied from 24V to 30V, and the load resistance was varied from 500 ohms to 300 ohms at t=0.1s.

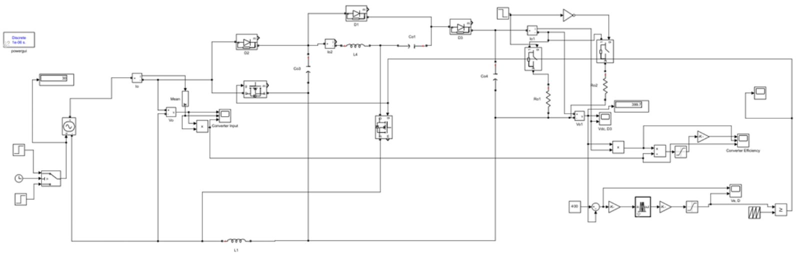

Figure 9. Simulation diagram of the high-gain DC-DC converter in Simulink.

The Simulink model representing the DC input source, the power stage, and the closed-loop fuzzy logic control system.

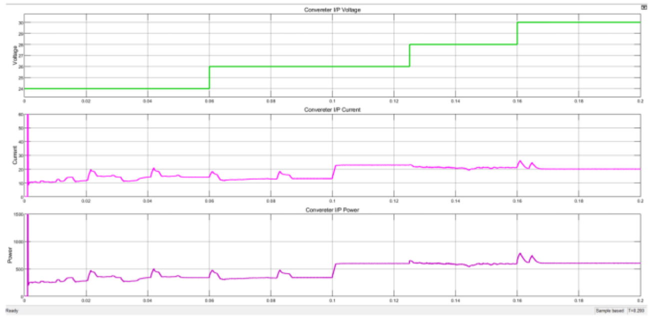

Figure 10. Converter input voltage, current, and power results.

Waveforms showing the input voltage stepping from 24V up to 30V, and the input current increasing from 11A to 25A when the load varies.

4.1 Controller Performance Comparison

The FLC's performance was benchmarked against an open-loop system and a traditional PI controller. As detailed in Table 3, the FLC achieved a much faster response (0.2ms rise time) and a significantly lower steady-state error (3V).

Parameters	Open Loop	PI Control	Fuzzy Logic Control
Rise time, Tr	2ms	0.6ms	0.2ms
Settling time, Ts	10ms	1.75ms	0.32ms
Steady state error	16V	8V	3V
Efficiency	84%	85%	92%

Table 3. Comparison of Open Loop, PI, and Fuzzy Logic Controllers.

Summary metrics highlighting the superiority of the FLC with a 92% efficiency compared to the PI controller's 85%.

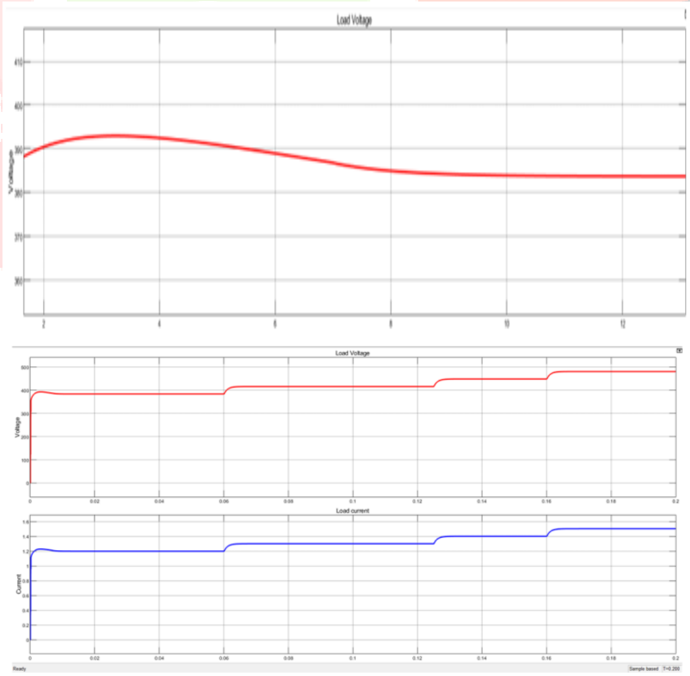

Figure 11 & 12. Simulation results of the Open-loop control system.

Transient and full views showing the load voltage settling at t=10ms with a steady-state error of 16V.

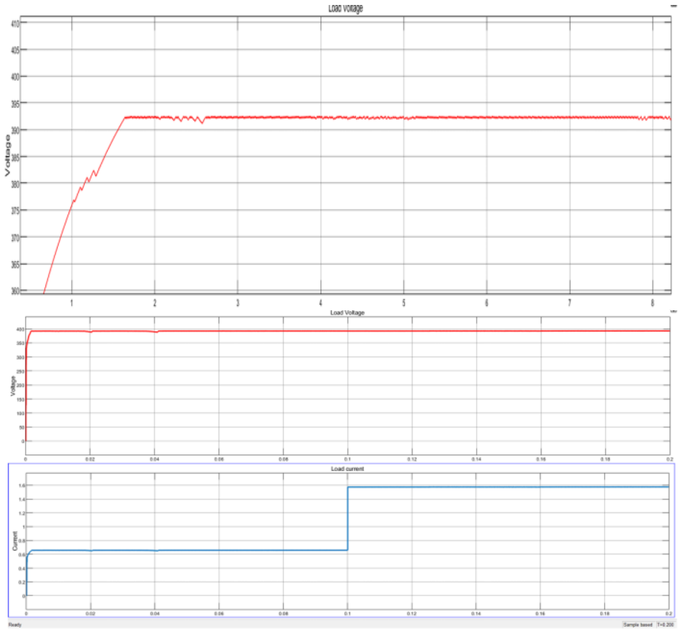

Figure 13 & 14. Simulation results of the PI control system.

The PI controller settles at t=1.75ms with a steady-state error of 8V, improving upon the open-loop setup.

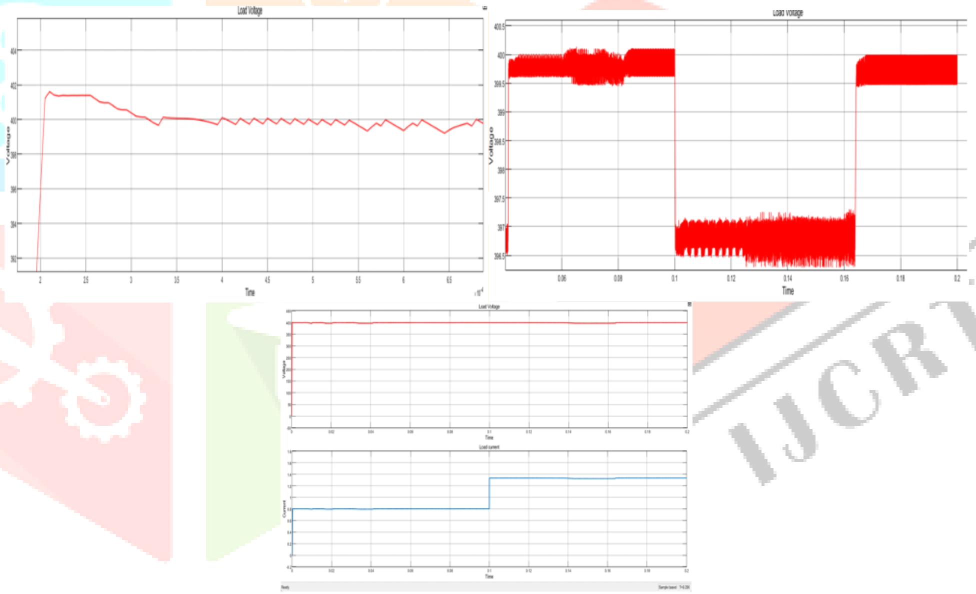

Figure 15, 16 & 17. FLC initial rise time, steady-state error, and output voltage.

The FLC output rapidly rises and stabilizes around 399.5V - 400V. It experiences a brief, controlled dip to 397V when the load is suddenly applied at t=0.1s, demonstrating excellent disturbance rejection.

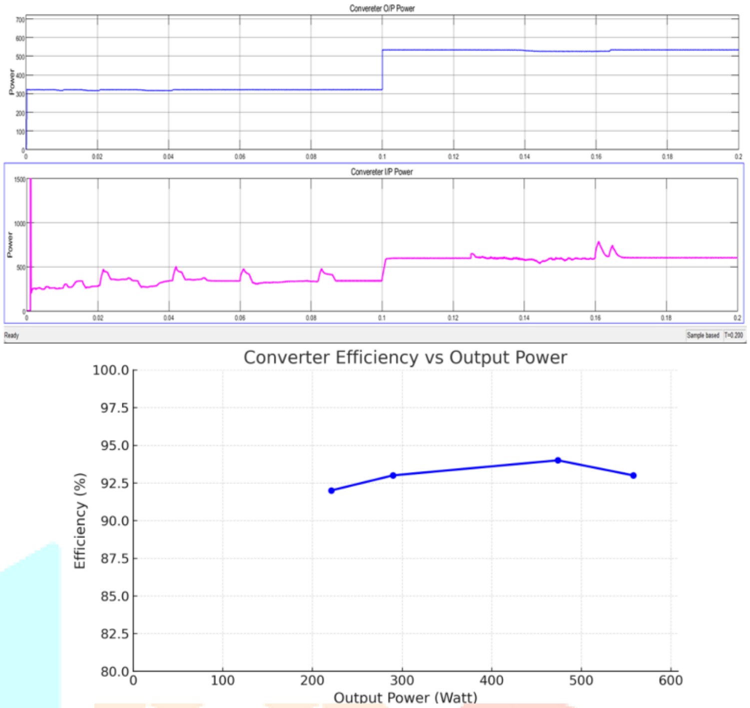

Figure 18 & 19. Converter Output Power and Efficiency with FLC.

The power rapidly steps up to approximately 555W. The efficiency remains consistently high in the 92% to 94% range across varying loads

4.2 Experimental Results

The hardware prototype was thoroughly tested to validate the real-world robustness of the FLC.

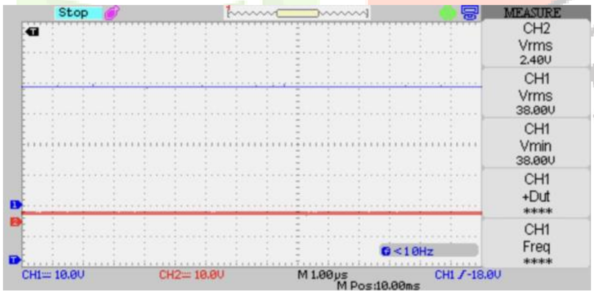

Figure 20. Output waveform of the hardware prototype.

When a variable input voltage of 36V to 72V is provided, a highly stable and constant output voltage of 380V is successfully obtained, demonstrating robust physical regulation.

V. Conclusion

This project successfully designed, simulated, and physically implemented a non-isolated, high-gain DC-DC converter. A high voltage gain of around 16.67 was achieved at a relatively low duty ratio. Simulation results conclusively demonstrated that the Fuzzy Logic Controller significantly outperforms open-loop and conventional PI control schemes in response time, steady-state accuracy, and overall efficiency. The physical prototype confirmed these findings, actively adjusting the switching pulses to maintain a stable 380V DC output despite significant input variations. Combining high voltage gain, a reduced component count, and advanced control performance, the proposed converter stands as an excellent candidate for demanding applications like renewable energy systems and DC microgrids.

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