

DESIGN AND DEVELOPMENT OF A FUEL CELL FED DC POWER CONVERSION SYSTEM FOR LOCAL LOAD APPLICATIONS

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Abstract - Fuel cells are emerging as a reliable alternative energy source for distributed power generation due to their high efficiency and low environmental impact. However, the low output voltage characteristics of fuel cells require high-gain DC–DC conversion to meet practical load requirements. This paper presents the design and performance evaluation of a fuel cell fed high-gain DC–DC converter intended for local load applications. The proposed topology achieves enhanced voltage gain using a dual-switch configuration and operates under both open-loop and closed-loop conditions. A proportional–integral (PI) controller is implemented to regulate the output voltage against load and input disturbances. Mathematical analysis establishes the voltage gain relationship of the converter. Simulation studies are carried out under varying load resistance and input voltage conditions to evaluate dynamic and steady-state performance. Results demonstrate significant reduction in overshoot from 32.664% in open-loop operation to 0.723% under closed-loop control. Steady-state error is reduced from 7.94 to 0.6, confirming improved regulation capability. The converter achieves a voltage gain of 4 at 60% duty cycle, validating the theoretical analysis. The proposed system demonstrates suitability for fuel cell based distributed power applications requiring stable high-voltage DC output.

Keywords— Fuel cell; DC–DC converter; High-gain boost converter; PI controller; Voltage regulation; Power electronics; Closed-loop control; Distributed generation.

I. INTRODUCTION

The increasing demand for clean and sustainable energy sources has accelerated the development of distributed generation systems based on renewable technologies. Among these, fuel cells have gained significant attention due to their high efficiency, low emissions, and silent operation [1]. Proton exchange membrane (PEM) fuel cells, in particular, are widely used for low-voltage DC power generation in stationary and portable applications.

Despite their advantages, fuel cells typically produce low and variable DC voltage levels, which are insufficient for most practical load requirements. Therefore, efficient DC–DC conversion is essential to step up and regulate the fuel cell output voltage for stable operation [2]. Conventional boost converters can provide voltage amplification; however, achieving high voltage gain requires operation at high duty cycles, which increases switch stress, conduction losses, and reduces efficiency [3].

To overcome these limitations, high-gain DC–DC converter topologies have been developed, including

quadratic boost converters, cascaded structures, and switched-inductor configurations [4], [5]. These topologies aim to enhance voltage gain without excessively increasing duty cycle. However, maintaining stable output voltage under varying load and input conditions remains a critical challenge, especially when interfacing with nonlinear sources such as fuel cells.

Closed-loop control strategies are widely adopted in power electronics to regulate output voltage and improve transient response. Among various controllers, the proportional–integral (PI) controller remains popular due to its simplicity, ease of implementation, and satisfactory performance in DC–DC converter applications [6]. Proper tuning of PI parameters significantly improves line regulation, load regulation, and dynamic stability.

This work focuses on the design and analysis of a fuel cell fed high-gain DC–DC converter capable of delivering regulated high-voltage output for local load applications. The system operates under both open-loop and closed-loop conditions, and the impact of load variation and input voltage disturbance is systematically evaluated. Unlike basic boost configurations, the proposed converter achieves quadratic gain characteristics, allowing substantial voltage amplification at moderate duty cycles.

The main contributions of this paper are summarized as follows:

1. Design and mathematical analysis of a high-gain DC–DC converter suitable for fuel cell integration.
2. Implementation of closed-loop PI control for output voltage regulation.
3. Comparative evaluation of open-loop and closed-loop performance.
4. Analysis of disturbance rejection capability under input and load variations.
5. Validation of theoretical voltage gain through simulation results.

II. RELATED WORK

Fuel cell based distributed generation systems require efficient power conditioning units to interface low-voltage DC output with practical loads. Several DC–DC converter topologies have been investigated to improve voltage gain and regulation performance.

The conventional boost converter is widely used for step-up applications due to its simple structure and ease of control [3]. However, its voltage gain is limited by

$$\frac{V_o}{V_{in}} = \frac{1}{1-D}$$

where D is the duty cycle. As D approaches unity, switch stress, diode stress, and conduction losses increase

significantly, reducing system efficiency and reliability [4]. Therefore, operating at very high duty cycles is not desirable for fuel cell based systems.

To address these limitations, quadratic and high-gain boost converter topologies have been proposed. Quadratic boost converters provide voltage gain proportional to $\frac{1}{(1-D)^2}$ enabling higher output voltage at moderate duty cycles [5]. Switched-inductor and switched-capacitor based converters have also been introduced to enhance voltage amplification without extreme duty cycle operation [7].

In fuel cell applications, maintaining stable voltage under dynamic load conditions is particularly challenging due to the nonlinear and slow transient characteristics of the fuel cell stack [8]. Hence, proper closed-loop control is essential. Various control techniques including PI, PID, sliding mode control, and model predictive control have been applied to DC–DC converters [6], [9].

Among these, PI control remains the most commonly used method in industrial and academic applications due to:

- Simple implementation
- Low computational requirement
- Reliable steady-state regulation
- Ease of tuning

Several studies have demonstrated that PI-controlled boost converters achieve improved line and load regulation when compared to open-loop operation [6]. However, literature shows that limited attention has been given to evaluating open-loop versus closed-loop dynamic performance under systematic disturbance testing in fuel cell integrated systems.

Furthermore, many reported works focus primarily on theoretical analysis without presenting comparative dynamic performance metrics such as overshoot, settling time, and steady-state error reduction.

Based on the above review, the following research gap is identified:

1. Need for systematic comparison between open-loop and closed-loop performance in fuel cell fed high-gain converters.
2. Requirement for disturbance rejection analysis under both input voltage and load variation.
3. Validation of quadratic voltage gain behavior at moderate duty cycles.

The present work addresses these gaps by designing a high-gain DC–DC converter, implementing PI control, and evaluating detailed dynamic performance under varying operating conditions.

III. SYSTEM CONFIGURATION AND CONVERTER TOPOLOGY

The overall configuration of the proposed fuel cell fed DC–DC power conversion system is illustrated in Fig. 1.

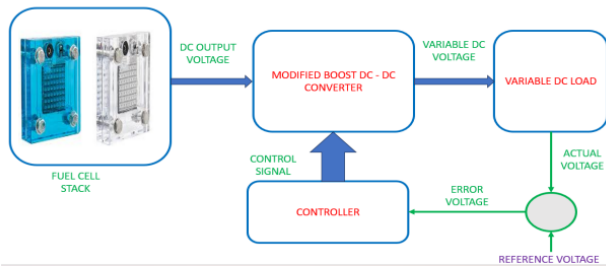


Fig. 1. Overall block diagram of the fuel cell fed DC–DC conversion system with closed-loop control.

The system consists of four major functional units:

- Fuel cell stack
- Modified high-gain DC–DC converter
- PI-based controller
- Variable DC load with feedback sensing

Fuel cells typically generate low-level DC voltage with nonlinear characteristics and slow dynamic response [1], [2]. Therefore, a suitable power conditioning stage is required to regulate and boost the voltage to the desired level for practical load applications.

As shown in Fig. 1, the DC output of the fuel cell stack is applied to the modified boost DC–DC converter. The converter output supplies the variable DC load. The actual output voltage is continuously sensed and compared with a predefined reference voltage. The resulting error signal is processed by the PI controller, which generates the appropriate control signal to adjust the duty cycle of the switching devices.

This closed-loop configuration ensures:

- Voltage regulation under load disturbances
- Line regulation under input voltage variation
- Improved steady-state accuracy
- Reduced transient overshoot

The feedback control structure is essential because fuel cells exhibit voltage fluctuation under dynamic load conditions [3]. Hence, open-loop operation cannot guarantee stable regulation.

A. Converter Circuit Topology

The detailed circuit of the modified high-gain DC–DC converter is shown in Fig. 2.

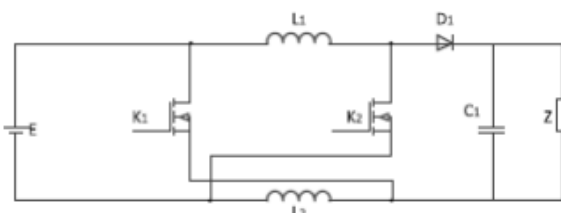


Fig. 2. Proposed dual-switch high-gain DC–DC converter topology

The topology employs dual inductors and dual switches to achieve quadratic voltage gain characteristics. Compared to a conventional boost converter, the proposed structure enhances voltage amplification without requiring extremely high duty cycles [4].

The converter consists of two inductors L_1 and L_2 , two MOSFET switches K_1 and K_2 , a diode D , and an output capacitor C . Both switches are driven simultaneously with identical duty cycle D . The symmetry of the topology ensures balanced current sharing between inductors and reduced stress on switching devices.

B. Operating Principle

The converter operates in continuous conduction mode (CCM) and has two switching intervals during one switching period T_s

Mode I: Switches ON ($0 < t < DT_s$)

- Switches K_1 and K_2 are turned ON.
- Inductors L_1 and L_2 store energy from the input source.
- Diode D_1 remains reverse biased.
- Output capacitor supplies the load.

During this interval, inductor currents increase linearly.

Mode II: Switches OFF ($DT_s < t < T_s$)

- Switches are turned OFF.
- Diode becomes forward biased.
- Inductors release stored energy to the load.
- Output capacitor gets charged.

This energy transfer mechanism results in voltage boosting.

C. Voltage Gain Derivation

Applying the volt-second balance principle to the inductors and assuming ideal components, the voltage gain of the proposed topology is obtained as:

$$\frac{V_o}{V_{in}} = \frac{1}{(1-D)^2}$$

This quadratic gain expression indicates that voltage amplification increases significantly with duty cycle compared to the conventional boost converter where gain

is $\frac{1}{(1-D)}$ [4]

For example:

- At $D = 0.5$, theoretical gain = 4
- At $D = 0.6$, theoretical gain = 6.25

However, due to practical losses and non-idealities, the simulated gain values are slightly lower as observed.

D. Design Specifications

The converter is designed based on the following parameters:

- Input voltage: 25 V
- Output voltage: 100 V
- Power rating: 1500 W
- Switching frequency: 20 kHz
- Inductance: 29.28 μ H
- Capacitance: 228.75 μ F
- Load resistance: 10 Ω

These specifications ensure proper operation in continuous conduction mode with acceptable ripple levels.

IV. CONTROL STRATEGY AND PI CONTROLLER DESIGN

To ensure stable voltage regulation under varying load and input conditions, a closed-loop control strategy is implemented. The control architecture of the proposed system is illustrated in Fig. 1.

As shown in Fig. 1, the output voltage of the converter is continuously sensed and compared with a predefined reference voltage. The difference between the reference and actual output voltage generates the error signal:

$$e(t) = V_{ref} - V_o(t)$$

This error signal is processed by a proportional–integral (PI) controller to generate the control signal that adjusts the duty cycle of the switching devices.

A. PI Controller Design

The transfer function of the PI controller is given by:

$$G_c(s) = K_p + \frac{K_i}{s}$$

where

- K_p = proportional gain
- K_i = proportional gain

From the tuning parameters obtained in simulation

- $K_p = 6.121 \times 10^{-7}$
- $K_i = 0.8121$

The proportional term improves transient response by reacting immediately to voltage deviation, while the integral term eliminates steady-state error.

B. Open-Loop vs Closed-Loop Performance

The effectiveness of the PI controller is evaluated by comparing open-loop and closed-loop performance under identical operating conditions.

From the performance data

- Overshoot reduced from 32.664% (open-loop) to 0.723% (closed-loop).
- Steady-state error reduced from 7.94 to 0.6.
- Rise time improved in regulation accuracy.
- Settling behaviour becomes more stable under disturbance.

These results confirm that closed-loop control significantly enhances voltage regulation capability.

C. Disturbance Rejection Capability

To evaluate robustness, the system is tested under:

- Load variation from 10 Ω to 12 Ω .
- Input voltage variation from 25 V to 30 V.
- Combined input and load disturbance.

Under closed-loop operation, the output voltage remains regulated around 100 V with negligible deviation. This demonstrates strong line and load regulation performance.

V. SIMULATION RESULTS AND PERFORMANCE EVALUATION

The performance of the proposed fuel cell fed high-gain DC–DC converter is evaluated through simulation under both open-loop and closed-loop operating conditions. The analysis includes voltage gain verification, load regulation, line regulation, and dynamic response comparison.

The system parameters used in simulation are listed as:

- Input voltage: 25 V
- Rated output voltage: 100 V
- Switching frequency: 20 kHz
- Inductor value: 29.28 μ H
- Capacitor value: 228.75 μ F
- Rated load: 10 Ω

A. Voltage Gain Verification

To validate the quadratic voltage gain characteristic derived in Section III, the duty cycle was varied from 10% to 90% and the corresponding output voltage was recorded.

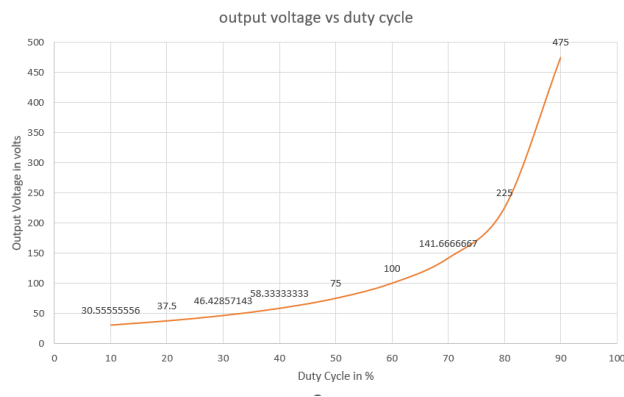


Fig. 3. Variation of output voltage with duty cycle

From the obtained results

Duty Cycle (%)	Voltage Gain	Output Voltage (V)
50	3	75
60	4	100
70	5.66	141.66

The output voltage increases nonlinearly with duty cycle, confirming the quadratic gain expression:

$$\frac{V_o}{V_{in}} = \frac{1}{(1-D)^2}$$

At 60% duty cycle, the output voltage reaches approximately 100 V for 25 V input, validating the high-gain behavior of the converter.

B. Steady-State Performance

The steady-state behavior of the converter under closed-loop operation is shown in Fig. 4.



Fig. 4. Closed-loop steady-state response of the fuel cell fed converter.

As observed in Fig. 4:

- The output voltage stabilizes at approximately 100 V.
- The output current settles according to load demand.
- The fuel cell voltage remains near its nominal operating value.
- Fuel cell current stabilizes after initial transient.

This confirms stable operation of the converter under nominal conditions.

C. Open-Loop and Closed-Loop Dynamic Comparison

To evaluate controller effectiveness, dynamic performance metrics under open-loop and closed-loop conditions are compared. The results are summarized in Table 1

Table I Dynamic Performance Comparison

Parameter	Open Loop	Closed Loop
Overshoot	32.664 %	0.723 %
Steady-State Error	7.94	0.6
Rise Time	361.15 μ s	15.23 ms
Settling Time	3.501 ms	19.99 ms

The closed-loop PI controller significantly reduces overshoot from 32.664% to 0.723%, indicating improved damping characteristics. The steady-state error is reduced from 7.94 to 0.6, confirming enhanced voltage regulation.

Although the rise time increases slightly under closed-loop control, the output voltage exhibits superior stability and reduced oscillations.

D. Line Regulation Analysis

To evaluate robustness against input disturbances, the input voltage is varied from 25 V to 30 V at 0.4 s under closed-loop operation.

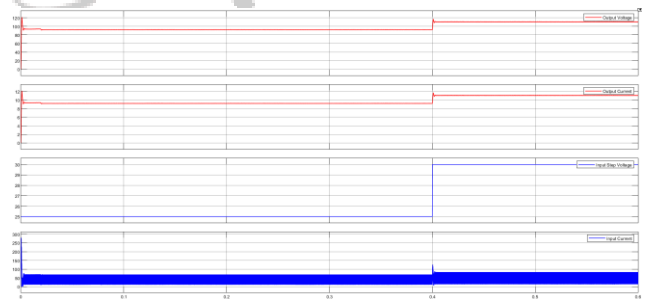


Fig. 5. Closed-loop output response under input voltage variation (25 V to 30 V).

As shown in Fig. 5:

- The input voltage increases by 20%.
- The output voltage deviation is minimal.
- The controller quickly compensates and restores output to 100 V.

From numerical results:

Input	Output
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Voltage (V)	Voltage (V)
25	100.6
30	100.5

The variation in output voltage is less than 0.2%, demonstrating excellent line regulation capability.

E. Load Regulation Analysis

The load resistance is varied from 10 Ω to 12 Ω under closed-loop operation.

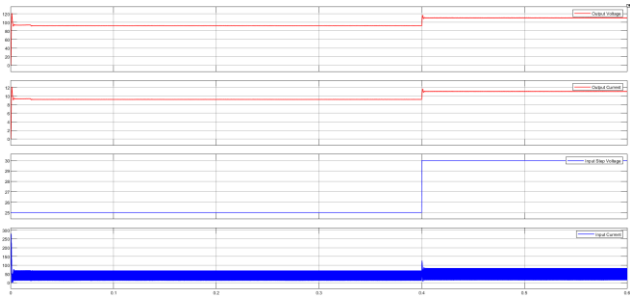


Fig. 6. Closed-loop output response under load variation (10 Ω to 12 Ω).

As observed:

- A transient disturbance appears at the instant of load change.
- The controller rapidly restores output voltage.
- Oscillations are minimal.

From the results

Load (Ω)	Output Voltage (V)
10	100.6
12	100.5

The output voltage variation is negligible, confirming strong load regulation performance.

F. Reference Tracking Performance

To evaluate tracking capability, the reference voltage is changed from 100 V to 120 V during operation.

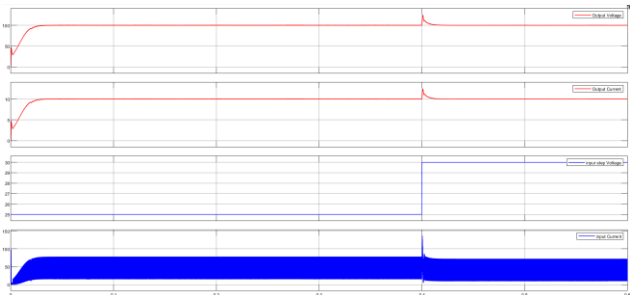


Fig. 7. Output voltage tracking under reference step change (100 V to 120 V).

The response shows:

- Smooth transition to new reference value.
- Limited overshoot.
- Stable settling without sustained oscillation.

This confirms that the PI controller effectively tracks varying reference commands, making the system suitable for adjustable DC load applications.

G. Overall Performance Discussion

The simulation results confirm:

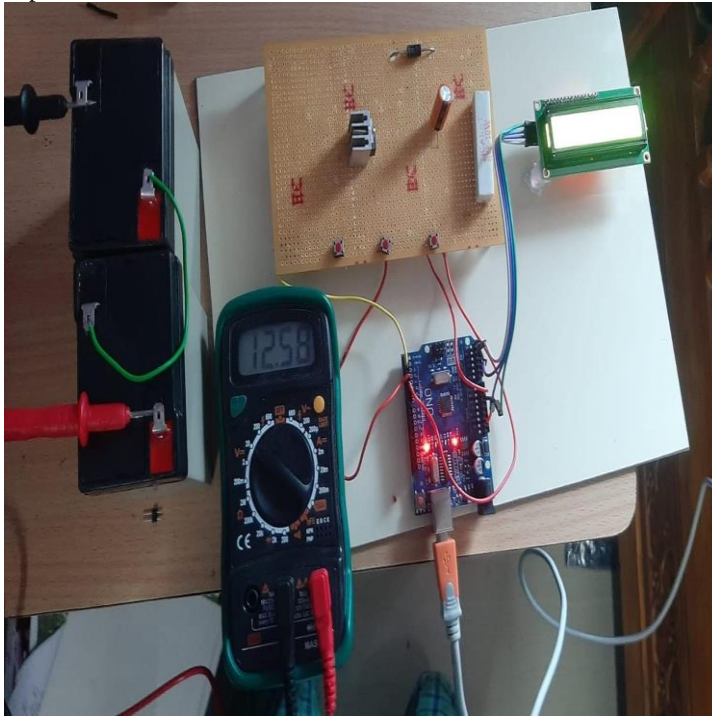
- Quadratic voltage gain behavior.
- Significant improvement in dynamic performance under closed-loop control.
- Strong disturbance rejection capability.
- Accurate reference tracking.
- Stable integration with fuel cell source characteristics.

The proposed converter demonstrates suitability for distributed generation systems requiring regulated high-voltage DC output.

Hardware Discussion
Introduction

This section presents the hardware implementation of the proposed modified boost converter system. The main objective of the hardware setup is to demonstrate the practical operation of the boost converter and to validate the theoretical analysis of the converter. The hardware model is designed using readily available electronic components and is controlled using a microcontroller-based pulse width modulation (PWM) technique. The core of the hardware system is the **Arduino Uno**, which is used to generate the switching pulse required for the operation of the boost converter. The Arduino Uno produces a PWM signal with a specific switching frequency and duty cycle, which controls the switching behavior of the power MOSFET used in the converter circuit. The modified boost converter circuit mainly consists of a power inductor, MOSFET switch, Schottky diode, output capacitor, and load resistor. In this design, an inductor of **330 μH with a current rating of 6 A** is used to store energy when the MOSFET switch is turned on. The switching element used in the circuit is the **IRLZ44N**, which is selected due to its low on-state resistance and fast switching capability. A **Schottky diode** is used in the circuit to provide a low forward voltage drop and fast recovery characteristics, which improves the overall efficiency of the converter. The output side of the converter includes a **470 μF, 50 V capacitor**, which acts as a filter to smooth the output voltage and reduce ripple. The load used for testing the converter is a **60 Ω, 15 W resistor**, which allows the converter performance to be observed under a controlled load condition. The hardware setup is designed to operate with a switching frequency generated by the Arduino and to demonstrate the boosting capability of the converter by stepping up the input voltage to a higher output voltage

level. The experimental setup helps analyze the behavior of key components such as the inductor, MOSFET, and diode during different switching modes of the converter. Figure 7.1 shows the hardware prototype of the implemented modified boost converter system. The arrangement includes the microcontroller board, power stage components, sensing elements, and the load used for experimental verification.



2. Hardware Architecture / System Overview

The hardware architecture of the proposed modified boost converter system consists of a microcontroller unit, power switching components, passive elements, and the load. The main objective of the hardware architecture is to

convert a low input voltage into a higher output voltage using controlled switching techniques.

The central control unit used in the system is the **Arduino Uno**, which generates a pulse width modulation (PWM) signal. This PWM signal determines the switching operation of the power MOSFET used in the boost converter circuit. By controlling the duty cycle of the PWM signal, the output voltage of the converter can be regulated.

The boost converter power stage mainly consists of an inductor, a MOSFET switch, a diode, and an output capacitor. When the MOSFET switch is turned on, the inductor stores energy from the input source. When the MOSFET switch is turned off, the stored energy in the inductor is transferred to the load through the diode. This process results in an output voltage that is higher than the input voltage.

In the proposed hardware system, a **330 μ H inductor with a current rating of 6 A** is used as the energy storage element. The switching device used in the circuit is the **IRLZ44N**, which is selected because it can be directly driven by the Arduino output voltage and provides efficient switching performance.

A **Schottky diode** is used in the converter to allow current to flow from the inductor to the output while preventing reverse current flow. The fast switching characteristics

and low forward voltage drop of the Schottky diode help improve converter efficiency.

To reduce output voltage ripple and stabilize the DC output voltage, a **470 μ F, 50 V capacitor** is connected at the output stage of the converter. This capacitor stores electrical energy and supplies the load during switching intervals.

For experimental testing of the converter, a **60 Ω , 15 W resistor** is used as the load. This resistive load allows the performance of the boost converter to be evaluated under controlled operating conditions.

The overall hardware system operates by generating PWM signals from the Arduino, which control the switching of the MOSFET. The switching action of the MOSFET allows the inductor to alternately store and release energy, thereby increasing the output voltage of the converter.

3. Arduino Uno Controller

The **Arduino Uno** is used as the main control unit in the proposed hardware system. It is responsible for generating the PWM switching signals required to control the boost converter circuit. The Arduino Uno is widely used in power electronics and embedded system applications because of its easy programming, flexible interfacing capability, and reliable performance.

The Arduino Uno board is based on the **ATmega328P**, which operates at a clock frequency of **16 MHz**. The board includes digital input/output pins, analog input pins, timers, communication interfaces, and voltage regulators that allow it to control various external electronic components.

In this project, the Arduino Uno generates the **PWM signal that controls the switching of the MOSFET** used in the boost converter. By adjusting the duty cycle of the PWM signal, the amount of energy transferred from the input source to the load can be controlled, which directly affects the output voltage of the converter.

Arduino Uno Pin Details

The Arduino Uno consists of several pins used for digital input/output, analog input, power supply, and communication. These pins allow the microcontroller to interact with external circuits and sensors.

Digital Input/Output Pins

The Arduino Uno has **14 digital input/output pins (D0–D13)**.

Pin	Function
D0	Serial RX
D1	Serial TX
D2–D13	General digital I/O
D3, D5, D6, D9, D10, D11	PWM output pins

In this project, a **PWM pin is used to drive the gate of the MOSFET** in the boost converter circuit.

Analog Input Pins

The Arduino Uno includes **6 analog input pins (A0–A5)**.

Pin	Function
A0–A5	Analog voltage measurement
A4	SDA (I2C communication)
A5	SCL (I2C communication)

These pins can measure analog voltages between **0 V and 5 V** using the built-in **10-bit ADC**.

Power Supply Pins

Pin	Function
Vin	External power input
5V	Regulated 5 V output
3.3V	3.3 V output
GND	Ground connection
RESET	Reset the microcontroller

These pins provide power to external components connected to the Arduino board.

Arduino Uno Features

The Arduino Uno provides several features that make it suitable for embedded control applications.

- Easy programming using Arduino IDE
- Built-in USB interface for programming and communication
- Multiple digital and analog input/output pins
- PWM output for motor control and power electronics
- Built-in analog-to-digital converter (ADC)
- Serial communication support

These features make the Arduino Uno a flexible and powerful platform for controlling power electronic circuits such as boost converters.

Arduino Uno Specifications

Parameter	Value
Microcontroller	ATmega328P
Operating Voltage	5 V
Input Voltage	7–12 V recommended
Digital I/O Pins	14
PWM Pins	6
Analog Input Pins	6
Clock Speed	16 MHz
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB

Role of Arduino in the Proposed Hardware

In the proposed modified boost converter system, the Arduino Uno performs the following functions:

1. Generates PWM switching signals for the MOSFET.
2. Controls the duty cycle of the boost converter.
3. Maintains the switching frequency required for converter operation.
4. Provides easy control and monitoring of the converter system.

Thus, the Arduino Uno acts as the **main controller responsible for the switching operation and overall control of the hardware system.**

Additional Details of Arduino Uno

1. Memory Details

The **Arduino Uno** contains different types of memory used for storing programs and data.

Memory Type	Size	Purpose
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Memory Type	Size	Purpose
Flash Memory	32 KB	Stores the program code
SRAM	2 KB	Stores temporary data during execution
EEPROM	1 KB	Stores permanent data

Flash memory is used for uploading the program, while SRAM is used during program execution.

2. Communication Interfaces

The Arduino Uno supports several communication protocols for connecting external devices.

Serial Communication (UART)

Pin Function

D0 RX (Receive)

D1 TX (Transmit)

This communication is used for **Serial Monitor debugging and data transfer.**

I²C Communication

Pin Function

A4 SDA

A5 SCL

I²C is used to connect devices such as **I²C LCD displays and sensors.**

SPI Communication

Pin Function

D10 SS

D11 MOSI

D12 MISO

D13 SCK

SPI is used for **high-speed communication with modules and sensors.**

3. PWM Generation

PWM (Pulse Width Modulation) is an important feature of Arduino used in power electronics.

The **PWM pins are:**

D3, D5, D6, D9, D10, D11

Typical PWM frequency:

~490 Hz (default)

~980 Hz on pins 5 and 6

In power electronics projects like **boost converters**, the PWM frequency can be **modified using timer registers** to achieve higher switching frequencies (such as 20 kHz).

4. Voltage Regulator

The Arduino Uno includes an **onboard voltage regulator** that converts higher input voltage into a stable **5 V supply** for the microcontroller.

Recommended input voltage:

7 V – 12 V

Maximum input voltage:

20 V (not recommended for long operation)

5. Clock Source

The **ATmega328P** on the Arduino Uno uses a **16 MHz crystal oscillator.**

This clock signal determines:

- Processing speed
- PWM timing
- Communication speed

6. Programming Method

Arduino programs are written using **Arduino IDE** and uploaded through the **USB port**.

Programming language used:

Embedded C / Arduino C++

Basic program structure:

setup()

loop()

- **setup()** runs once at startup
- **loop()** runs continuously

7. Protection Features

The Arduino Uno includes some protection circuits such as:

- Resettable **USB polyfuse**
- Reverse polarity protection
- Voltage regulation

These features help protect the board from damage.

8. Why Arduino Uno is Used in This Project

The Arduino Uno is selected for the modified boost converter because:

- Easy PWM generation
- Simple programming environment
- Availability of digital and analog pins
- Low cost and widely available
- Suitable for experimental power electronics projects

4. Inductor Selection and Energy Storage

The inductor is one of the most important components in the boost converter circuit because it acts as an energy storage element. In the proposed hardware implementation, an **inductor of 330 μH with a current rating of 6 A** is used. The main function of the inductor is to store electrical energy in the form of a magnetic field when the switching device is turned on and release the stored energy when the switch is turned off.

During the operation of the boost converter, when the MOSFET switch is turned on, current flows from the input source through the inductor. As a result, the inductor stores energy and its current gradually increases. When the MOSFET switch is turned off, the stored energy in the inductor is released and transferred to the output through the diode. This energy transfer increases the output voltage of the converter.

The selection of the inductor value plays a critical role in determining the performance of the boost converter. A properly selected inductor ensures stable operation, reduces current ripple, and improves overall efficiency. If the inductance value is too small, the current ripple will be high, which may lead to increased power losses and instability. On the other hand, if the inductance value is too large, the converter may respond slowly to changes in load conditions.

In the proposed hardware system, the selected inductor value of **330 μH** provides a suitable balance between current ripple and converter stability. The **6 A current rating** ensures that the inductor can safely handle the

current flowing through the circuit without overheating or saturation.

Therefore, the inductor serves as the primary energy storage component that enables the boost converter to step up the input voltage and deliver a higher output voltage to the load.

5. MOSFET Switching Device (IRLZ44N)

The switching device used in the proposed boost converter is the **IRLZ44N**. A MOSFET is a semiconductor device widely used in power electronic circuits because it can operate as a fast electronic switch. In the boost converter, the MOSFET controls the charging and discharging of the inductor by switching ON and OFF at a specific frequency.

The switching signal for the MOSFET is generated by the **Arduino Uno** in the form of a PWM signal. When the PWM signal is applied to the gate terminal, the MOSFET turns ON and allows current to flow through the inductor. During this period, the inductor stores energy from the input source. When the PWM signal goes low, the MOSFET turns OFF, and the stored energy in the inductor is transferred to the load through the diode, resulting in a boosted output voltage.

The IRLZ44N MOSFET is chosen for this hardware implementation because it is a logic-level device that can be directly driven by the 5 V output of the Arduino. It also has low on-state resistance, high current handling capability, and fast switching characteristics, which make it suitable for DC-DC converter applications.

The MOSFET has three terminals: **Gate (G)**, **Drain (D)**, and **Source (S)**. The gate terminal controls the switching operation, the drain is connected to the inductor and converter circuit, and the source is connected to ground. Due to its efficient switching performance and reliability, the IRLZ44N MOSFET plays a crucial role in the operation of the boost converter hardware system.

Pin Configuration of IRLZ44N

The IRLZ44N MOSFET is available in a **TO-220 package** with three terminals.

Pin Name Function

- | Pin Name | Function |
|--------------|----------------------------------|
| 1 Gate (G) | Controls the switching operation |
| 2 Drain (D) | Connected to load/inductor |
| 3 Source (S) | Connected to ground |

The **gate terminal** is connected to the PWM output of the Arduino.

The **drain terminal** is connected to the inductor. The **source terminal** is connected to ground.

Key Features of IRLZ44N

The IRLZ44N MOSFET provides several advantages that make it suitable for power converter applications.

- Logic-level gate drive (can be driven directly by Arduino)
- Low ON resistance
- High current handling capability
- Fast switching speed
- High efficiency in switching circuits
- Low power dissipation

These features allow the MOSFET to operate efficiently in high-frequency switching applications such as DC-DC converters.

Electrical Specifications

Important electrical characteristics of the IRLZ44N MOSFET are listed below.

Parameter	Value
MOSFET Type	N-Channel
Maximum Drain-Source Voltage (VDS)	55 V
Maximum Drain Current (ID)	47 A
Gate Threshold Voltage (VGS(th))	1 – 2 V
Maximum Gate-Source Voltage	±16 V
Drain-Source ON Resistance	≈ 0.022 Ω
Power Dissipation	94 W

These parameters make the IRLZ44N suitable for switching applications involving moderate voltage and high current.

Advantages of Using IRLZ44N in the Boost Converter

The IRLZ44N MOSFET is selected in the hardware design for the following reasons:

1. It can be directly driven by the **5 V output of the Arduino**.
2. It has **low conduction loss** due to low ON resistance.
3. It can handle **high current levels** safely.
4. It supports **high-frequency switching**, which is required for boost converter operation.
5. It improves the **overall efficiency of the converter**.

Role of MOSFET in the Proposed Hardware

In the modified boost converter hardware system, the MOSFET performs the following functions:

- Acts as the **main switching device**
- Controls **inductor charging and discharging**
- Determines the **energy transfer process**
- Helps regulate the **output voltage through PWM control**

Schottky Diode (1N5822)

The **1N5822** is a commonly used power diode in switching power supplies and DC-DC converters. It belongs to the Schottky diode family, which is known for its **low forward voltage drop and fast switching speed**. These characteristics make the 1N5822 suitable for high-frequency applications such as boost converters, where efficient energy transfer and low power loss are required.

Working Principle

A Schottky diode operates based on a **metal-semiconductor junction**, unlike a conventional PN junction diode. Because of this structure, the diode exhibits very fast switching behavior and minimal reverse recovery time. When the diode is forward biased, current flows easily from the anode to the cathode. When it is reverse biased, the diode blocks current flow.

In the boost converter circuit, the diode provides a path for the inductor current when the MOSFET switch is turned OFF. During this period, the energy stored in the inductor flows through the diode to the output capacitor and the load, resulting in a higher output voltage.

Electrical Specifications of 1N5822

Parameter	Value
Diode Type	Schottky Rectifier
Maximum Repetitive Reverse Voltage	40 V
Maximum Forward Current	3 A
Forward Voltage Drop	≈ 0.3 – 0.5 V
Operating Temperature	–65°C to 125°C
Package Type	DO-201 axial

These specifications indicate that the 1N5822 diode can handle moderate current levels while maintaining low power loss.

Pin Configuration

The **1N5822** diode has two terminals:

Terminal Function

Anode Connected to the inductor side

Cathode Connected to the output capacitor and load

The cathode side is usually marked with a **silver or white band** on the diode body.

Role of 1N5822 in the Boost Converter

In the modified boost converter hardware, the 1N5822 Schottky diode performs the following functions:

1. Provides a current path from the inductor to the output when the MOSFET switch is OFF.
2. Prevents reverse current from flowing back to the source.
3. Transfers stored energy from the inductor to the load and capacitor.
4. Improves converter efficiency due to its low forward voltage drop.
5. Supports fast switching operation required for high-frequency converters.

Advantages of Using 1N5822

- Low forward voltage drop, reducing conduction losses
- High switching speed suitable for switching converters
- Good efficiency in power electronics circuits
- Simple and reliable operation

7. Output Capacitor (470 µF, 50 V)

The output capacitor is an important component in the boost converter circuit because it helps maintain a stable DC output voltage. In the proposed hardware implementation, a **470 µF, 50 V electrolytic capacitor** is used at the output stage of the converter. The main purpose of this capacitor is to store electrical energy and reduce voltage ripple in the output.

During the operation of the boost converter, the MOSFET switch repeatedly turns ON and OFF. When the MOSFET

is ON, the diode becomes reverse biased and the load is temporarily supplied by the output capacitor. When the MOSFET turns OFF, the energy stored in the inductor flows through the diode and charges the capacitor. This charging and discharging process helps maintain a continuous supply of voltage to the load.

The **470 μF capacitance value** is selected to provide sufficient energy storage and to reduce fluctuations in the output voltage. A larger capacitance value helps reduce output voltage ripple and improves the stability of the converter output. The **50 V voltage rating** ensures that the capacitor can safely handle the boosted output voltage without damage.

Electrolytic capacitors are commonly used in power electronic circuits because they offer high capacitance values in a compact size. However, they are polarized components, meaning that the positive and negative terminals must be connected correctly in the circuit to avoid damage.

Functions of the Output Capacitor

1. Stores electrical energy at the output stage.
2. Supplies power to the load when the diode is OFF.
3. Reduces ripple in the DC output voltage.
4. Improves the stability of the boost converter output.

Thus, the output capacitor plays a significant role in smoothing the output voltage and ensuring reliable operation of the boost converter circuit.

8. Load Resistor (60 Ω , 15 W)

The load resistor is used in the boost converter circuit to represent the electrical load connected to the output of the converter. In the proposed hardware setup, a **60 Ω , 15 W power resistor** is used as the load. The purpose of this resistor is to consume the output power produced by the converter and allow the performance of the circuit to be analyzed under a controlled load condition.

When the boost converter operates, the output voltage generated across the converter is applied across the load resistor. According to Ohm's law, the current flowing through the load depends on the value of the resistance and the output voltage of the converter. This allows the output current and power delivered by the converter to be measured and evaluated during experimental testing.

The **60 Ω resistance value** is selected to limit the current flowing through the circuit and maintain safe operation of the components. The **15 W power rating** ensures that the resistor can safely dissipate the heat generated due to power consumption without being damaged.

In power electronic circuits, high-power resistors such as wire-wound resistors are commonly used because they can handle larger currents and dissipate more heat compared to ordinary resistors.

Functions of the Load Resistor

1. Acts as the output load for the boost converter.
2. Allows measurement of output voltage and current.
3. Helps evaluate the performance and efficiency of the converter.
4. Dissipates electrical power as heat during operation.

Thus, the load resistor provides a practical way to test and analyze the performance of the boost converter under real operating conditions.

9. Battery Source (Two 6 V, 5 Ah Batteries in Series)

The input power source for the hardware setup is provided by **two 6 V, 5 Ah rechargeable batteries** connected in series. Batteries are used to supply a stable DC voltage to the boost converter circuit during experimental testing. The series connection of the batteries increases the total output voltage while keeping the current capacity the same.

Each battery has a nominal voltage of **6 V** and a capacity of **5 Ah**. When two such batteries are connected in series, the total voltage becomes **12 V**, while the current capacity remains **5 Ah**. This 12 V DC supply acts as the input voltage for the boost converter.

In a series connection, the **positive terminal of one battery is connected to the negative terminal of the other battery**. The remaining free terminals provide the combined output voltage for the circuit.

Series Connection Formula

Total Voltage:

$$V_{total} = V_1 + V_2$$

For two batteries:

$$V_{total} = 6V + 6V = 12V$$

Battery capacity remains:

5 Ah

Advantages of Using Battery Supply

1. Provides a **stable DC input voltage** for the converter.
2. Allows the hardware system to operate **independently without external power supply**.
3. Suitable for **portable and experimental setups**.
4. Provides sufficient energy storage for continuous operation.

Thus, the two **6 V, 5 Ah batteries connected in series provide a 12 V input source**, which is used to power the modified boost converter hardware system.

VI. CONCLUSION

This paper presented the design and performance evaluation of a fuel cell fed high-gain DC-DC converter for local load applications. A modified dual-switch boost topology was employed to achieve quadratic voltage gain characteristics, enabling substantial voltage amplification at moderate duty cycles. The theoretical voltage gain relationship was derived and validated through simulation results. Closed-loop control using a PI controller was implemented to regulate the output voltage under varying load and input conditions. Comparative analysis between open-loop and closed-loop operation demonstrated significant improvement in dynamic performance. The overshoot was reduced from 32.664% to 0.723%, and the steady-state error decreased from 7.94 to 0.6.

Furthermore, the system exhibited strong line and load regulation capability, maintaining output voltage stability under input voltage variation and load disturbance. The disturbance rejection analysis confirmed that the proposed controller effectively compensates for source and load fluctuations commonly associated with fuel cell systems. Additionally, reference tracking performance validated the suitability of the converter for adjustable DC load applications.

Overall, the proposed fuel cell fed high-gain DC–DC converter demonstrates reliable regulation performance, improved dynamic characteristics, and suitability for distributed generation systems. Future work may focus on hardware implementation, efficiency analysis, and advanced control strategies such as adaptive or intelligent control methods to further enhance system robustness.

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