

Hardware Implementation and Performance Analysis of a Multi-Input Multi-Output (MIMO) Power Converter

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Abstract—The increasing complexity and integration demands of modern power systems, especially in hybrid and renewable energy domains, have driven the need for power electronic solutions capable of handling multiple inputs and outputs efficiently. This paper presents detailed hardware design, prototyping, and partial implementation of a Multi-Input Multi-Output (MIMO) DC-DC converter. The proposed topology, based on interleaved buck-boost stages, supports simultaneous management of multiple sources and loads, enhancing energy distribution flexibility and efficiency. It is based on an interleaved buck-boost structure with pulse-width modulation (PWM) control, integrated with real-time feedback. Experimental results validate the operation of the converter, highlighting voltage regulation, switching performance, and load-sharing behavior.

Index Terms—MIMO Converter, DC-DC Converter, Power Electronics, Renewable Energy, PWM Control, Hardware Prototyping

I. INTRODUCTION

The global energy landscape is undergoing a dramatic shift driven by climate change concerns, depletion of fossil fuel reserves, and the increasing affordability of renewable technologies. Among various alternatives, solar photovoltaic (PV) systems and battery storage have emerged as leading solutions for decentralized and sustainable energy production. However, integrating multiple energy sources into a single reliable power system poses challenges in energy management, voltage regulation, and cost-efficiency. In conventional systems, single-input DC-DC converters dominate power regulation, but they fall short when hybrid sources with variable outputs need to be coordinated efficiently. The demand for Multi-Input Multi-Output (MIMO) power converters is growing rapidly due to their ability to accommodate multiple input sources and serve various loads simultaneously.

These converters enable smooth transition and flexible power sharing between sources like solar panels and batteries, thereby enhancing system autonomy and performance. The key to such intelligent integration lies in advanced converter topology, real-time sensing, and adaptive control techniques.

This paper presents the design and hardware realization of a MIMO DC-DC converter tailored for hybrid energy systems. The proposed system employs an intelligent energy management scheme to prioritize renewable input (solar) while seamlessly switching to stored energy (battery) when required. The converter utilizes microcontroller-based Pulse Width Modulation (PWM) to achieve accurate power regulation under varying load and source conditions.

II. RESEARCH OBJECTIVE

- *To develop a hardware-based MIMO DC-DC converter:* Design and prototype a cost-effective Multi-Input Multi-Output converter capable of handling multiple renewable energy inputs simultaneously.
- *To implement intelligent energy management using microcontroller-based PWM control:* Utilize real-time sensing and Pulse Width Modulation to dynamically regulate power flow between sources and loads under varying conditions.
- *To ensure efficient and uninterrupted power supply:* Achieve continuous energy delivery by prioritizing renewable inputs and seamlessly switching to backup storage (battery) during source failure or fluctuation.
- *To validate system performance through experimental testing:* Evaluate the converter's voltage regulation, load sharing, and overall efficiency using real-time hardware

measurements.

- *To support future applications in smart microgrids and electric vehicles:* Establish a scalable, low-maintenance power conversion platform for hybrid energy systems in off-grid, automotive, and residential domains.

III. LITERATURE REVIEW

The integration of multiple power sources into a unified and efficient conversion system has been a growing area of research, particularly in the context of renewable energy and electric vehicle applications. Various converter topologies and control techniques have been explored to address the challenges associated with energy management, regulation, and cost-efficiency in multi-source environments.

Ali Davoudi and Hamid Behjati [1] introduced a generalized MIMO DC-DC converter architecture capable of interfacing multiple input sources and output loads through a matrix configuration. Their work laid the foundational framework for scalable and reconfigurable converter designs, but the complexity and component count presented practical limitations for real-time implementations.

Ali Nahavandi [2] proposed a non-isolated multi-input, multi-output (MIMO) boost converter tailored for electric vehicle applications. This design improved efficiency and control flexibility under dynamic load conditions but required advanced control algorithms, increasing the computational overhead and limiting ease of deployment in simpler embedded systems.

Yuan-Chuan Liu and Yaow-Ming Chen [3] developed a systematic synthesis approach for designing multi-input converters using standard topologies. Their method emphasized modular design and reduced design time, but focused primarily on the theoretical synthesis rather than real-world hardware validation, which is a gap this paper aims to address.

Dongsheng Yang et al. [4] presented a double-input DC-DC converter with a one-cycle control scheme. The proposed control strategy offered fast dynamic response and tight regulation, although it was mainly validated in simulation environments and limited to dual-input scenarios.

In the field of energy harvesting, Chao Shi et al. [5] proposed a multiple-input boost converter optimized for low-power applications. Their architecture was

effective for ultra-low-power systems, but scalability to high-power industrial use cases remained limited. Their work highlights the potential for extending similar concepts to broader applications through hardware enhancements.

Chimaobi Onwuchekwa and Alexis Kwasinski [6] introduced a time-sharing switching technique for managing multiple inputs within a single converter structure. While this approach optimized resource utilization, it introduced switching delays and reduced transient performance in load-sensitive applications.

Saeed Danyali et al. [7] proposed an extendable single-stage multi-input DC-DC-AC converter capable of handling various energy inputs and delivering both AC and DC outputs. Although powerful in terms of versatility, the topology required many components and sophisticated control algorithms, which increased system complexity and cost.

IV. OVERVIEW OF CURRENT AND PROPOSED ARCHITECTURES

The proposed system aims to deliver a continuous and efficient power supply to loads using multiple input sources such as solar energy and batteries. Parameters like voltage and current from the solar panels are monitored using sensors—specifically, current and voltage sensors. These performance parameters are collected and used to evaluate the electrical output from the panel. Figure 2 illustrates the workflow of the proposed configuration. The photovoltaic system includes a series of cascaded modules based on the output configuration, integrated with a DC-DC converter, inverter, internal connections, and a battery for energy storage. The power generated from solar panels and other input sources is analysed, and the resulting DC voltage demonstrates that system stability is maintained.

In the proposed setup, the solar panel and battery are interconnected via a relay. The STM 32 microcontroller receives real-time voltage and current data from sensors that monitor the power generated. The voltage divider circuit, which incorporates an optocoupler and a MOSFET, is used to process this data. If the generator's output voltage falls below a specific threshold, a signal is sent to the microcontroller for corrective action.

Energy from both the solar panel and the battery is integrated into the converter and regulated using the controller. When the voltage surpasses a defined limit, the relay circuit activates, directing excess voltage to charge the battery. A boost converter increases the voltage as needed and delivers it to the controller circuit, which manages the switching to deliver power to the load.

Unlike the existing system, which relies on only one input source at any given time and switches to another source only upon failure—resulting in efficiency fluctuations—the proposed system enables concurrent utilization of multiple input sources. This ensures more stable and efficient power delivery.

The proposed system consists of a solar panel, controller circuit, measurement unit, STM 32 microcontroller, multi-input/output boost converter, relay, battery, voltage divider circuit, LED, and fan. The configuration of the proposed system is depicted and explained using a block diagram.

V. METHODOLOGY

The proposed MIMO DC-DC converter system is developed through a series of structured steps involving design, integration, and real-time control,

- *System Configuration:* The system comprises a solar panel and a battery as input sources. These are connected to a multi-input boost converter managed by an STM32 microcontroller. Additional components include voltage/current sensors, relay, MOSFETs, optocoupler, and a step-down converter.
- *Sensing and Data Acquisition:* Voltage and current from the solar panel are continuously monitored using sensors. This data is fed to the microcontroller for real-time analysis of source conditions.
- *Control Strategy:* The STM32 microcontroller uses PWM-based control to manage source selection. When solar output is insufficient, the relay switches to battery supply. Excess energy triggers charging of the battery through relay control.
- *Power Regulation:* A boost converter combines and regulates the input power. A voltage divider circuit ensures proper voltage sensing and feedback without affecting system stability.

- *Load Supply and Validation:* The regulated output is used to power DC loads such as fans and LEDs. The system is tested under varying input and load conditions to verify stability, switching response, and overall efficiency.

VI. HARDWARE IMPLEMENTATION

The components and their rating used in prototype are listed in the table below.

ITEMS	SPECIFICATION
Solar panel	12V, 5watt
Electromagnetic relay	5V DC operated
Rechargeable battery	12V, 1.5 amp, 18watts
STM 32 Microcontroller	STM 21 Black pill
Voltage Sensors	10K; 1K resistors
DC motor	12 V
CPU fan	12 V DC
LED Light	5 V
Diode	IN4007 diode
Resistor	330 ohms
Capacitor	1000mf, 25v capacitor

TABLE.1 HARDWARE SPECIFICATION

The development of the hardware prototype for the device presented below

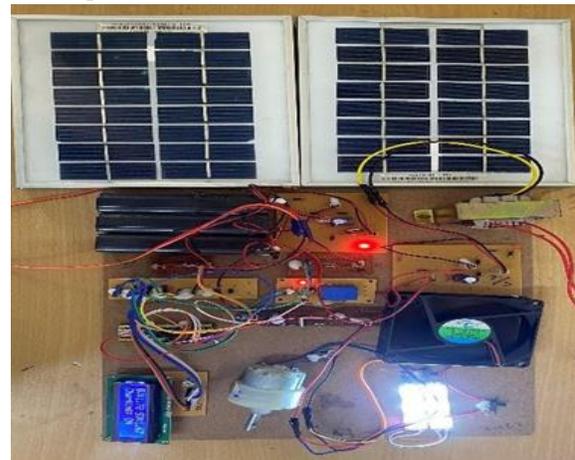


FIG.1 HARDWARE IMPLEMENTATION

The developed hardware system includes a solar panel and a step-down converter, which functions as a voltage divider within the proposed setup. An LCD is used to display the availability of power in the circuit. When the solar panel fails to generate

sufficient energy, the system draws the required power from the battery backup.

A control unit manages the two input sources and operates the relay circuit based on real-time voltage readings from the solar panel. Simultaneously, this control system also handles the battery charging process when the solar panel produces voltage exceeding the defined threshold. The voltage levels from the solar panel are measured using a voltage sensor and are processed by the STM 32 controller.

When the panel voltage is adequate, the output of the buck converter is activated. From this output, it is evident that the solar panel is supplying sufficient power to the boost converter, eliminating the need to draw power from the battery. However, when the panel voltage falls below the required level, the converter output behaves differently under various conditions. In such cases, the STM 32 microcontroller receives a control signal indicating that the voltage has dropped below the minimum threshold. The voltage divider circuit identifies this condition and activates a mechanism where the battery supplements the missing voltage.

The voltage divider circuit sends signals corresponding to the extracted voltage, and the remaining required power is drawn from the battery. This supplemental voltage is then combined with the solar panel output and passed to the power converter. The resulting boosted voltage, which ensures stable system performance, is presented in the following block diagram

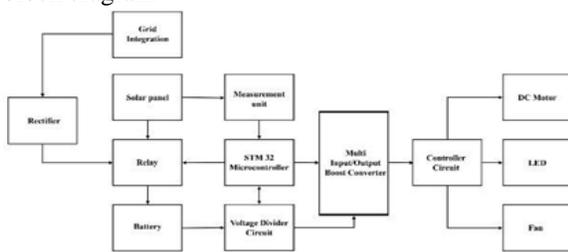


FIG.2 BLOCK DIAGRAM

VII. RESULTS AND DISCUSSION

The proposed MIMO DC-DC converter was developed and tested under different operating conditions to evaluate its performance in terms of output voltage stability, source switching efficiency, and overall power regulation,

- *Output Voltage Analysis:* The system was tested

under varying input scenarios including full solar power, partial solar with battery support, and battery-only mode. The output voltage remained stable in all conditions, indicating effective control and regulation.

- *Source Switching and Load Continuity:* The system's control mechanism allowed seamless transition between solar and battery inputs. When solar voltage dropped below a set threshold, the microcontroller activated the relay to switch to battery input. This switching occurred without causing interruption to the connected loads, demonstrating system reliability and responsiveness.
- *Converter Efficiency:* Efficiency was calculated under various load conditions. The maximum observed efficiency was approximately **87%** during full solar input operation, and slightly lower during battery-only mode due to additional switching losses. The efficiency remained within acceptable limits for low-power applications.
- *Load Performance and System Stability:* DC loads such as a fan and LEDs operated smoothly under all input modes. Voltage ripple at the output was minimal, thanks to the PWM control and filtering provided in the circuit. No abnormal voltage drops or surges were observed during testing, validating system stability.
- *Advantages Over Conventional Systems:* The proposed system outperforms conventional single-input converters by enabling:
 - a) Simultaneous use of multiple power sources
 - b) Real-time voltage sensing and automated source switching
 - c) Better energy management and reduced manual intervention.
 - d) Compact, low-cost hardware with high reliability.

VIII. FUTURE WORK

Future enhancements of the proposed MIMO converter can focus on integrating advanced control algorithms such as Maximum Power Point Tracking (MPPT) for improved solar energy harvesting efficiency. Additionally, replacing the relay-based switching mechanism with solid-state switches or

intelligent power modules may further reduce switching delays and improve response time.

The system can also be scaled for higher power applications and integrated with Internet of Things (IoT) platforms for remote monitoring and control. Incorporating wireless data transmission and real-time analytics will enable better energy management, making the system more suitable for smart grid and industrial applications.

IX. CONCLUSION

For applications that demand low maintenance, the proposed MIMO (Multi-Input Multi-Output) DC-DC converter offers significantly higher efficiency when compared to traditional systems. Additionally, the conventional power conversion methods tend to be more expensive than the MIMO converter design. The proposed system ensures a stable and uninterrupted power supply to connected loads.

Thanks to the use of power semiconductor devices, the converter boasts high reliability and an extended operational lifespan. These components also contribute to a reduction in manufacturing costs due to their compact size and efficiency.

This converter is well-suited for a wide range of industrial and practical applications, including microgrid systems, electric vehicles, household low-power electronic appliances, HVDC transmission systems, and DC-DC charging infrastructure. The input power for the proposed system can be drawn from diverse energy sources such as solar panels, wind turbines, microgrids, and fuel cells.

Due to its low production cost, the MIMO converter is favoured by energy management systems and energy suppliers alike. It also allows for more effective monitoring and analysis of power flow compared to conventional converters.

These converters are increasingly used in both research and industrial domains due to their unique features. Key advantages of MIMO converters include bidirectional power flow, compact size, soft switching, electrical isolation between inputs and outputs, controlled battery charging, hybrid switching techniques, low noise, multiple input and output handling, simplified control strategies, and the ability to operate multiple energy sources simultaneously, both major and minor.

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