# An Enhanced Interleaved High Step-Up Converter With High Efficiency for Renewable Energy Applications

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***Abstract*— This paper presents an enhanced interleaved high step-up DC-DC converter tailored for renewable energy systems, specifically photovoltaic (PV) integration. By combining coupled inductors with diode-capacitor voltage multiplier (DCVM) cells, the proposed topology achieves an exceptional voltage conversion ratio at significantly lower duty cycles than standard boost configurations. The interleaved architecture effectively minimizes input current ripple and increases power density while simultaneously reducing semiconductor voltage stress and conduction losses. Simulation results validate a robust voltage gain of 22.5 at a 0.6 duty cycle, demonstrating the converter's superior efficiency in elevating low-voltage PV outputs to high-voltage DC bus requirements for grid-connected applications.**

***Index Terms***—*Interleaved DC–DC Converter, High Step-Up Conversion, Coupled Inductors, Voltage Multiplier, Soft Switching, Renewable Energy Systems.*

## I. INTRODUCTION

The rapid growth of renewable energy sources like solar panels and fuel cells has created a real need for efficient DC–DC converters that can step up low input voltages to usable higher levels. Traditional boost converters struggle here because they depend on very high duty cycles, which increases stress on components, causes more heat, and reduces efficiency. To tackle this, the proposed enhanced interleaved high step-up converter combines interleaving, coupled inductors, and diode-capacitor voltage multiplier stages in a more practical way. Interleaving helps smooth out the input current, which is better for the source, while the coupled inductors and multiplier stages improve how efficiently energy is transferred and boosted. On top of that, the design introduces soft-switching behavior, which reduces switching losses by ensuring smoother transitions, meaning less energy is wasted as heat. Instead of letting leakage energy get dissipated, the converter reuses it, which further improves efficiency and keeps temperatures under control.

In real-world industrial systems, especially in renewable energy setups, there are always challenges like low and unstable input voltage, the need for high output voltage, current ripple, switching losses, and overheating. Many existing interleaved converters do help with ripple, but they often fall short when it comes to achieving high gain efficiently without adding complexity or thermal issues. This proposed design improves on that by combining different energy transfer methods like flyback-forward operation with voltage multiplication, along with smarter switching. Compared to the reference design, it manages energy flow more effectively, makes better use of leakage energy, and ensures smoother switching transitions. These improvements reduce stress on switches, cut down unnecessary losses, and importantly, limit heat generation inside the system. Because of this, the converter runs more reliably and efficiently, making it a good fit for applications like solar power systems, DC microgrids, and electric vehicle power electronics where both performance and thermal stability matter.

The development of this converter was done step by step rather than jumping straight to a final design. It started with theoretical calculations to understand voltage gain, duty cycle limits, component stress, and even thermal aspects. After that, MATLAB/Simulink simulations were used to check how the converter behaves under different conditions, including waveforms, efficiency, and switching performance. Special attention was given to soft-switching operation and how heat is managed, so that the design works efficiently without overheating. Real-world factors like parasitic elements, switching losses, and non-ideal components were also considered to make sure the design is practical and not just theoretical. This complete process helped shape a converter that is both efficient and realistic to implement. Overall, the proposed converter shows strong potential for modern renewable energy applications by offering high efficiency, lower stress on components, better thermal performance, and a flexible design that can be adapted to different use cases

## II. LITERATURE REVIEW

P. Sharma, S. Hasanpour, and R. Kumar (2024) This paper presents a high step-up DC–DC converter using a coupled inductor and voltage multiplier concept. The design achieves a high voltage gain while maintaining good efficiency, making it suitable for renewable energy applications. [1]

T. Sakthiram, L. Yogesh, and R. Srikanth (2025) This work introduces an interleaved high-gain DC–DC converter that uses voltage-lift and capacitor-based techniques to improve performance. The converter shows improved efficiency and better voltage boosting capability for low input sources. [2]

S. J. Chen, S. P. Yang, and C. M. Huang (2025) This study proposes an interleaved converter with voltage multiplier stages, focusing on achieving high voltage gain while reducing stress on switching devices. The design is well suited for solar energy systems. [3]

M. Hosseinpour, E. Seifi, and A. Seifi (2024) This paper presents an improved interleaved step-up converter that uses a voltage multiplier rectifier to enhance efficiency and maintain stable performance under different operating conditions. [4]

A. Nadermohammadi et al. (2024) This research focuses on a soft-switching high step-up converter designed for DC microgrid applications. The use of soft switching helps reduce losses and improves overall system efficiency. [5]

B.

H. Meshael, A. Elkhateb, and R. Best (2023) This paper reviews different high step-up converter topologies used in photovoltaic systems and compares them based on efficiency, voltage gain, and design complexity. [6]

S. M. Hashemzadeh et al. (2024) This study introduces a high-gain converter integrated into a solid-state transformer system, improving voltage scaling and efficiency for renewable energy applications. [7]

A. S. Valarmathy and M. Prabhakar (2024) This paper presents an interleaved high step-up converter using coupled inductors and capacitor multiplier stages, achieving reduced input current ripple and improved efficiency. [8]

B.

V. Prashanth et al. (2024) This research focuses on a high step-up converter used in fuel cell applications, combined with MPPT control to improve energy extraction and system performance. [9]

X. Wang et al. (2025) This paper proposes a high-gain DC–DC converter using coupled inductors and voltage multiplier techniques, achieving reduced switch stress and improved efficiency. [10]

M. A. Alghaythi et al. (2023) This study introduces an interleaved converter with diode-capacitor multiplier cells and coupled inductors, providing high voltage gain and reduced stress on components. [11]

R. Beiranvand and S. H. Sangani (2023) This paper presents an interleaved high step-up converter with soft-switching capability, helping to reduce switching losses and improve efficiency. [12]

A. Abadifard et al. (2021) This research proposes a high step-up converter based on a coupled inductor Zeta topology, focusing on improving voltage gain with fewer components. [13]

B.

M. Mohebbifar et al. (2023) This paper discusses soft-switching techniques in DC–DC converters and highlights how they reduce switching losses and improve reliability. [14]

S. Kumar and B. Singh (2024) This study reviews modern high-gain DC–DC converters for solar applications, focusing on improving efficiency, reducing ripple, and making designs more scalable. [15]

## III. METHODOLOGY

The proposed converter is designed by improving a conventional interleaved high step-up topology using coupled inductors and diode-capacitor voltage multiplier stages, with a clear focus on making it more practical and efficient for real-world use. It operates in continuous conduction mode (CCM) with interleaving to reduce input current ripple and ensure smoother operation of the source. A key improvement in this design is the inclusion of soft-switching behavior, which allows smoother switching transitions and reduces switching losses and noise. Instead of wasting the energy stored in leakage inductance, the converter reuses it through well-planned energy paths, improving efficiency. Additionally, the interaction between inductors and capacitors is optimized to reduce unnecessary circulating currents, making the overall energy transfer more effective.

To make the converter suitable for industrial applications, the design also focuses on practical aspects like heat generation, component stress, and non-ideal conditions. The converter is designed to naturally reduce heat by minimizing both switching and conduction losses, which helps in avoiding overheating without relying heavily on external cooling. The methodology begins with theoretical calculations to understand voltage gain and component limits, followed by MATLAB/Simulink simulations to verify performance, waveforms, and efficiency under realistic conditions. Unlike basic designs, this approach includes real-world factors such as parasitic effects and losses during the design stage itself. The converter is also made flexible and scalable, so the voltage gain can be adjusted easily without affecting performance too much, making it suitable for applications like renewable energy systems and DC microgrids.

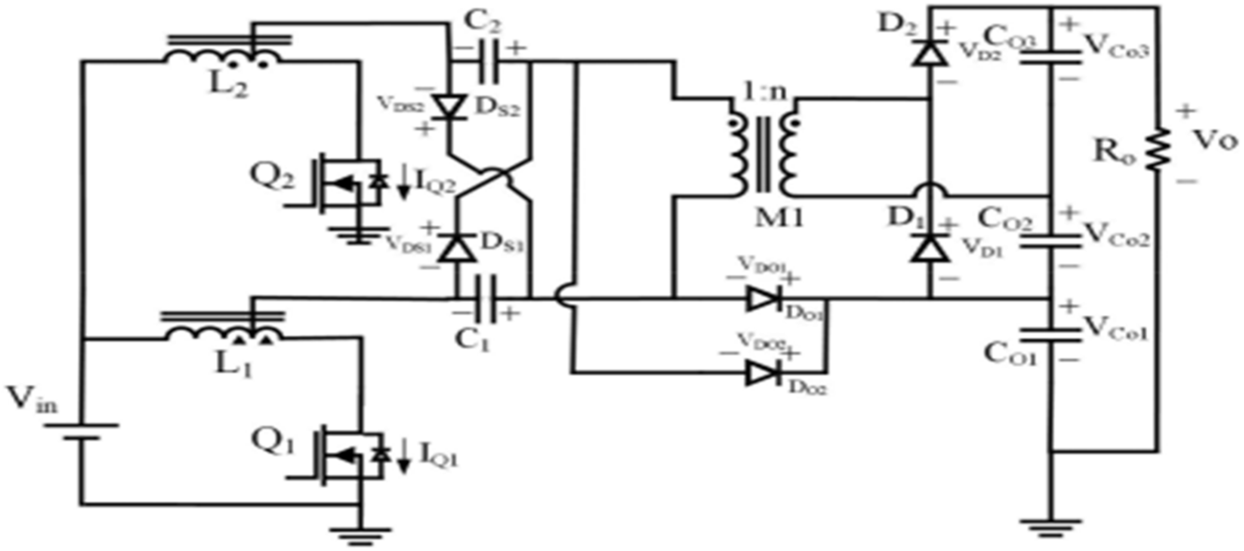



Fig.1. Circuit diagram for an enhanced interleaved high step up converter with high efficiency for renewable energy application.

## IV. ANALYTICAL STUDY AND SIMULATION DIAGRAM

The proposed system integrates a photovoltaic (PV) input source with an enhanced interleaved high step-up DC–DC converter designed to efficiently boost low input voltage to a higher DC level. The architecture is based on three key techniques: interleaving, magnetic coupling, and voltage multiplication. The input is divided into two parallel branches consisting of inductors $L_1$, $L_2$and switches $Q_1$, $Q_2$, operating with a 180°phase shift to reduce input current ripple and improve source performance. Coupled inductors are used to enhance energy transfer and achieve higher voltage gain, while the diode-capacitor voltage multiplier network further increases the output voltage without requiring extreme duty cycles. The system operates in continuous conduction mode (CCM), ensuring uninterrupted current flow and stable energy transfer throughout the switching cycle.

To ensure controlled and stable operation under varying conditions, a closed-loop control strategy is implemented using an Arduino-based PWM generation system. The controller produces switching pulses with a phase shift to maintain interleaved operation, which are then amplified and isolated using a TLP250 driver to properly drive the MOSFET switches. This arrangement ensures accurate timing, reliable switching, and reduced switching losses. Additionally, improved switching behavior is considered in the design to enable smoother transitions, which helps in reducing heat generation and improving efficiency. During operation, energy is stored in the inductors when the switches are ON and transferred to the capacitors and output stage when the switches are OFF, ensuring balanced current sharing and efficient power flow.

The system is modeled and validated in MATLAB/Simulink, incorporating all major stages including the input source, interleaved switching network, high-frequency transformer for isolation and voltage scaling, and rectification and filtering circuits. The simulation reflects practical operating conditions by including switching behavior, waveform analysis, and realistic component interactions. The converter successfully boosts the low input voltage to a higher DC output while maintaining stable operation. The interleaved structure ensures smoother current flow and reduced ripple at the input, while the output stage provides a regulated high-voltage DC supply suitable for further applications.

The results show that the converter achieves a significant voltage gain, increasing the input from around 10–24 V to approximately 75–80 V. The input waveform remains stable, indicating minimal disturbance to the source, while the output exhibits some ripple due to high-frequency switching effects. The inductor currents follow phase-shifted triangular waveforms, confirming proper interleaved operation and continuous energy transfer. Although output ripple is present, it can be reduced through improved filtering and control optimization. Overall, the results validate that the proposed converter provides high efficiency, reduced ripple, stable operation, and improved thermal performance, making it a reliable solution for renewable energy applications.

## V. EXPERIMENT RESULTS

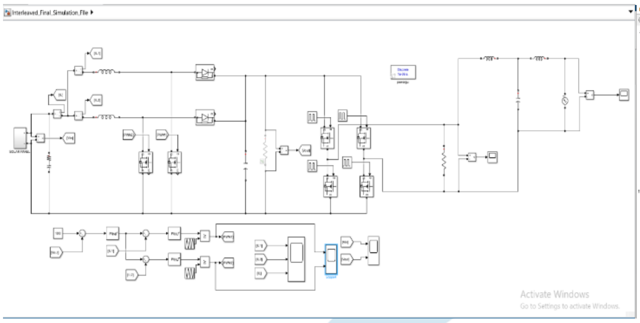


Fig.2. Simulation Diagram

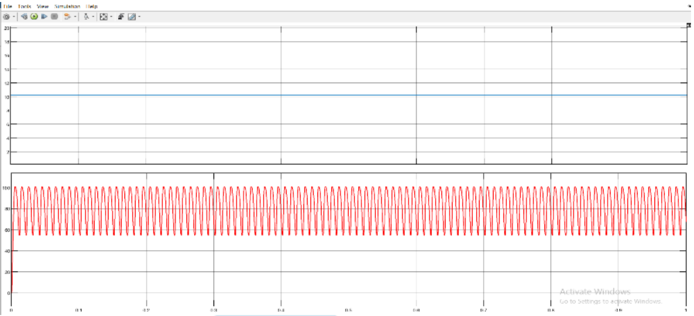


Fig.3. Output Voltage Waveform

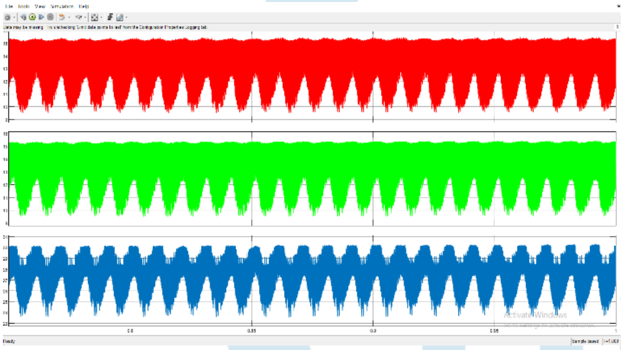


Fig.4. Results for 3 phase inductor current

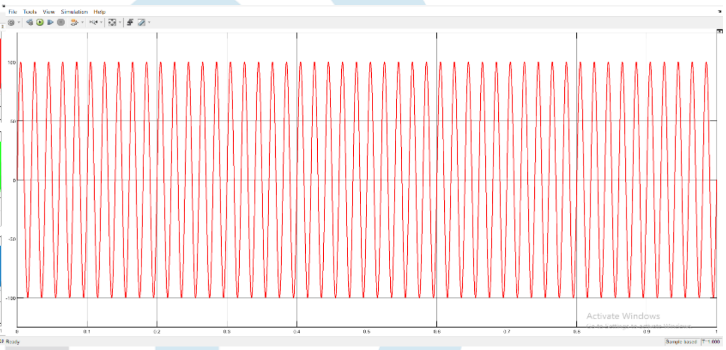


Fig.5. Results for grid voltage

The performance of the proposed enhanced interleaved high step-up converter was studied by observing the voltage and current waveforms under practical operating conditions. A low and steady input voltage, similar to what we get from a solar panel, was applied to the system. The converter was able to boost this voltage to a much higher level, nearly seven to eight times the input, which clearly shows its strong voltage gain capability. This proves that the combination of interleaving, coupled inductors, and voltage multiplier stages is working effectively without needing extreme duty cycles. Another important observation is that the input voltage remains smooth and undisturbed, meaning the internal switching of the converter does not negatively affect the source. This is very important for renewable energy systems, where maintaining a stable input helps improve the life and performance of the source. On the output side, some ripple is seen in the voltage due to high-frequency switching. This is expected in such converters and shows the continuous charging and discharging process inside the circuit. Even though ripple is present, the average output voltage remains stable, and this ripple can be further reduced with better filtering or control methods.

The inductor current waveforms give a clear idea of how well the interleaved structure is performing. The currents follow smooth triangular patterns and operate with a phase shift, which means that when one inductor is storing energy, the other is releasing it. This overlapping action ensures continuous energy flow and reduces overall current ripple. It also prevents sudden spikes in current, which helps in reducing losses and protecting components. Because of this, the converter operates more efficiently and reliably. Looking at the AC side of the system, the grid voltage appears smooth and well-shaped, following a proper sinusoidal pattern with very little distortion. This shows that the system is stable and well-controlled. The inverter output also produces a clean AC waveform with consistent amplitude and frequency, although small high-frequency ripples are present due to switching. These are normal in PWM-based systems and can be reduced with proper filters. Overall, the results show that the converter performs well in terms of voltage boosting, stability, reduced ripple through interleaving, and efficient operation, making it suitable for real-world renewable energy applications.

## VI. HARDWARE RESULTS

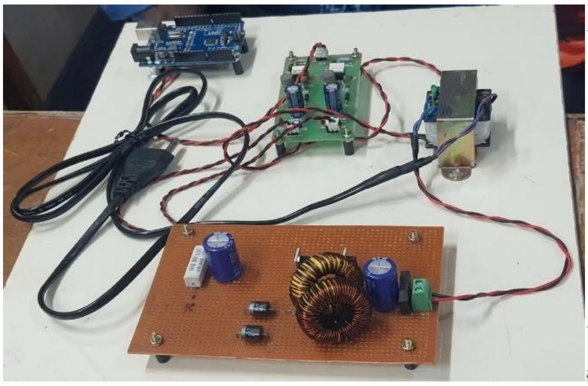
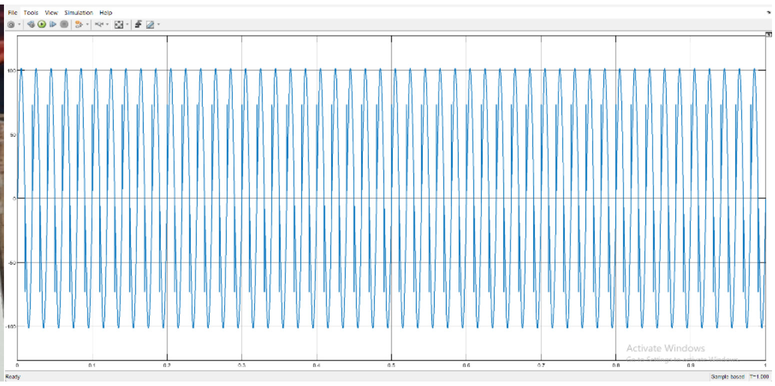


Fig. 6.Hardware Kit



Fig, 7. Voltage waveform after dc to ac conversion

## VII. CONCLUSION

This project clearly shows how an enhanced interleaved high step-up DC–DC converter can be built and used effectively for renewable energy applications. By combining interleaving, coupled inductors, and voltage multiplier techniques, the system is able to boost a low input voltage to a much higher level while still keeping the operation stable and efficient. The interleaved structure helps in smoothing out the input current, which is better for sources like solar panels, and also improves overall performance. At the same time, the voltage multiplier stages allow us to achieve high gain without pushing the system into extreme operating conditions. Improvements in switching behavior also play a role in reducing losses and controlling heat, which makes the converter more reliable during operation. The results from both simulation and hardware testing match well, showing that the design works as expected.

What really makes this project stand out is its focus on practical use and not just theory. The use of simple components like an Arduino and driver circuits makes the system easy to implement, while still delivering solid performance. The converter can be applied in areas like solar energy systems, DC microgrids, and electric vehicle applications where stepping up voltage efficiently is important. Even though some ripple is seen in the output, it is a normal part of switching converters and can be improved further with better filtering or control methods. Overall, this project brings together theory and real-world application in a clear and effective way, making it a useful and scalable solution for future renewable energy systems.

## VIII. ACKNOWLEGMENT

The authors would like to express their sincere gratitude to Dr R. Subbulakshmy, SRM Institute of Science and Technology, for her invaluable guidance, encouragement, and continuous support throughout the course of this research. He insights and expertise have been instrumental in shaping the direction and execution of the project. We also extend our thanks to the faculty and staff of the Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology, for providing the necessary resources and a conducive research environment. This work would not have been possible without their collective contribution and support.

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