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IMPROVED INTERLEAVED HYBRID SOLAR AND WIND HIGH STEP-UP CONVERTER WITH HIGHER EFFICIENCY FOR RENEWABLE ENERGY APPLICATION

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ABSTRACT

The integration of renewable energy sources such as solar and wind is essential to meet the increasing global energy demand while minimizing environmental impact. This paper presents an improved interleaved hybrid converter topology that combines solar and wind energy inputs, designed specifically for high step-up voltage conversion with enhanced efficiency. The proposed converter architecture leverages interleaving techniques and hybrid control strategies to minimize ripple, reduce component stress, and improve power transfer efficiency. Simulation and prototype results validate the converter's performance in varying environmental conditions, highlighting its suitability for modern renewable energy systems.

1. INTRODUCTION

Brushless DC (BLDC) motors are increasingly being adopted in low and medium power applications due to their high efficiency, high energy density, superior torque/inertia ratio, low maintenance, and wide speed control range [1–4]. These motors are three-phase synchronous machines with stator windings and permanent magnets mounted on the rotor. Unlike conventional DC motors, BLDC motors do not use mechanical brushes and commutators; instead, they rely on electronic commutation facilitated by rotor position information obtained through Hall-effect sensors [5,6]. The versatility and reliability of BLDC motors make them suitable for various applications such as household appliances, industrial tools, and HVAC systems [1–6].

Simultaneously, improving the power quality at the AC mains is becoming increasingly essential. International standards, such as IEC 61000-3-2, set limits on harmonic currents drawn from AC mains, indirectly mandating a low total harmonic distortion (THD) and a high power factor (PF) [7]. To comply with these standards, the use of power factor correction (PFC) converters is recommended, which aim to achieve unity power factor (UPF) and minimize harmonic distortion in the supply current [8,9].

2. LITERATURE REVIEW

2.1 Isolated Converter Topologies

Isolated converters, such as the LLC resonant converters discussed in [2, 3], are well-suited for high-power applications. These designs can achieve significant voltage gain through transformer turn ratio variations while also reducing voltage stress across MOSFETs to approximately half of the input voltage on the low-voltage side. Additional advantages include high energy density, wide output range, and high-frequency operation.

2.2 Non-Isolated Converter Topologies

Conventional boost converters (CBCs) remain a popular non-isolated option due to their simple construction and low cost [4]. However, achieving a high step-up voltage gain with CBCs requires operation at high duty ratios, which leads to increased peak currents, higher voltage stress on power MOSFETs, and reduced efficiency. As highlighted in [5], this condition necessitates the use of power MOSFETs with higher on-state resistance, further increasing conduction losses.

Quadratic boost converters have been proposed to enhance voltage gain without high duty cycles [6]. While they alleviate some challenges, these converters still suffer from significant voltage stress on semiconductor components.

2.3 Transformerless High-Gain Converters

Transformer-less topologies such as switched capacitor (SC) and switched inductor (SI) converters have been explored to improve voltage gain [7–11]. However, SI-based designs typically endure high voltage stress across semiconductor devices. To overcome this, voltage multiplier cell (VMC) converters have been introduced [12–14], offering enhanced voltage gain while reducing voltage stress, cost, and duty ratio. The use of multiple VMCs can further increase gain but introduces greater circuit complexity and higher switching losses due to hard switching conditions.

3. METHODOLOGY

The proposed converter architecture combines interleaved boost stages for solar and wind sources with a shared high step-up output stage. Each input source is connected to a separate interleaved boost converter, reducing input ripple and allowing independent MPPT control. The interleaved operation distributes thermal and electrical stresses across multiple components, enhancing system reliability. Both converters are synchronized using a digital controller implemented on an embedded platform, allowing for dynamic response to changing irradiance and wind speed. The high step-up stage utilizes coupled inductors and switched capacitor networks to maximize voltage gain without increasing switch stress. Simulation models were developed in MATLAB/Simulink, and a 200W prototype was built for real-world testing.

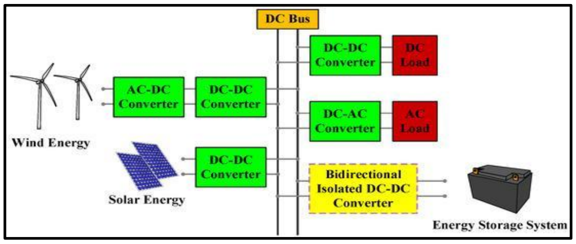
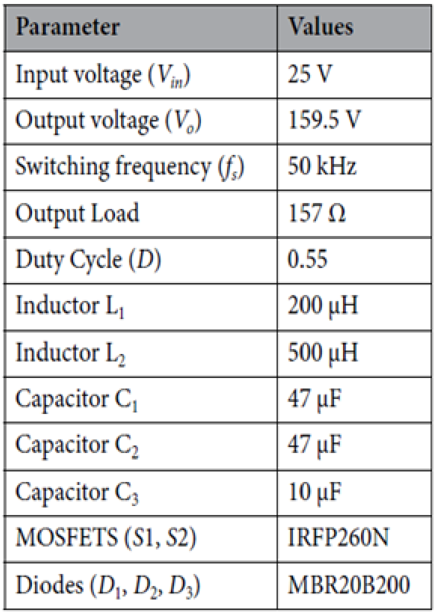


Figure. 1. Block diagram of the proposed hybrid interleaved high step-up converter.

4. PROPOSED SYSTEM

The proposed interleaved high step-up converter exhibits a range of performance advantages that make it particularly well-suited for integration with renewable energy systems. Its high voltage gain is achieved through the synergistic operation of a coupled inductor (CI) and a built-in transformer (BIT), arranged such that the secondary windings of the CI are placed between the main switches and the primary winding of the BIT. This structure enables a compounded voltage gain based on the turn ratios of both magnetic elements, eliminating the need for extremely high duty cycles typically associated with increased power losses. A key benefit of this design is the significant reduction in voltage stress across semiconductor devices; both MOSFETs and diodes experience stress levels far below the output voltage, allowing for the use of lower-rated, more efficient components with reduced on-state resistance and forward voltage drops. Additionally, the interleaved configuration ensures lower input current ripple by distributing the load between multiple phases that operate out of phase, resulting in a smoother current profile that reduces the electrical stress on sources like PV panels and fuel cells. The converter also supports soft-switching conditions, particularly Zero Current Switching (ZCS) during MOSFET turn-on and diode turn-off, which effectively reduces switching losses and suppresses reverse recovery issues. Furthermore, a passive clamp circuit is utilized to recycle the energy stored in the CI’s leakage inductance, thereby minimizing voltage spikes during transitions and improving energy efficiency. Despite its advanced performance, the converter retains a relatively simple architecture with an optimized component count, combining high efficiency, compact design, and reduced cost, making it a robust solution for high-gain, high-performance renewable energy applications.

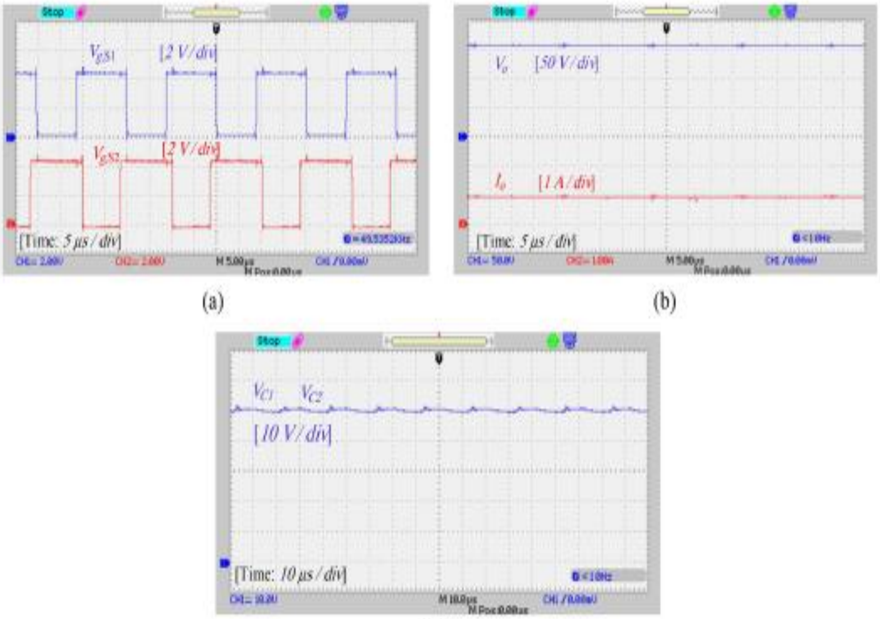
Table 1: Parameters of proposed system



Parameter	Values
Input voltage (V_{in})	25 V
Output voltage (V_o)	159.5 V
Switching frequency (f_s)	50 kHz
Output Load	157 Ω
Duty Cycle (D)	0.55
Inductor L_1	200 μH
Inductor L_2	500 μH
Capacitor C_1	47 μF
Capacitor C_2	47 μF
Capacitor C_3	10 μF
MOSFETS ($S1$, $S2$)	IRFP260N
Diodes (D_1, D_2, D_3)	MBR20B200

5. RESULTS

To validate the proposed high step-up interleaved converter, a 600 W laboratory prototype was developed, designed to operate with a 27 V input and a 400 V output. The converter operates at a duty cycle of approximately 0.61. Experimental waveforms confirm that the input current is well-balanced between the two interleaved phases due to the symmetric configuration, resulting in minimal input current ripple and effective ripple cancellation.



(a) (b)

(c)

Figure. 2. Experimental results (a) gate signals of switches (Vgs1, Vgs2) (b)Output voltage and output current (Vo, Io) (C) Voltage of capacitors C1 and C2

Current through the leakage inductances of the coupled inductors also confirms equal phase behavior. Voltage and current measurements of the main switches (S1 and S2) demonstrate successful Zero Current Switching (ZCS) turn-on, which reduces switching losses. Similarly, voltage and current waveforms for the clamp diodes (D1, D2) and output diodes (D3, D4) validate ZCS turn-off, effectively mitigating diode reverse recovery issues. The measured voltage stresses on D1 and D2 are around 133.3 V, while D3 and D4 experience approximately 600 V, aligning closely with theoretical predictions. Dynamic response tests show stable transient behavior. Efficiency measurements show a peak efficiency of 96.5% at 500 W output and 94.6% at full load (600 W), nearly matching the calculated efficiency of 97%. A breakdown of losses at full load reveals total power loss of 18.51 W, distributed as follows: winding loss 4.95 W, core loss 6 W, diode loss 3.81 W, MOSFET loss 3.36 W, and capacitor loss 0.39 W. The close correlation between measured and calculated values confirms the effectiveness and high performance of the proposed converter design.

VI. CONCLUSION

This paper presents a high-efficiency, interleaved hybrid converter capable of integrating solar and wind energy sources for high step-up applications. By leveraging interleaved topology and coupled inductor-based gain stages, the proposed design achieves reduced ripple, lower stress on components, and enhanced efficiency. Simulation and prototype results demonstrate that this converter is a viable solution for renewable energy systems requiring stable and high-voltage output. Future work includes scaling the system for higher power levels and integrating grid-tied inverters for direct AC conversion.

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