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Efficient Ultra High Voltage Conversion Using Multistage Boost Technology

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Abstract- An innovative ultrahigh step-up dc-dc converter that integrates a dual-stage boost converter, a coupled inductor, and a multiplier cell. The dual-stage boost converter provides an initial voltage boost, while the coupled inductor enables efficient energy transfer and recycling of leakage energy. The multiplier cell further amplifies the output voltage. This configuration reduces voltage stress on power switches, decreases the size of passive components, and ensures continuous input current. With these features, the proposed converter offers enhanced performance, making it suitable for applications requiring high voltage conversion with minimal power losses. The simulation prototype steps up the input voltage using a 150-W prototype converter from 25 V to 550 V using MATLAB.

Index Terms- Dc-DC Converter, two stage boost converter, Coupled inductor, Multiplier cell, Clamp Circuit.

I. INTRODUCTION

The increasing global demand for renewable energy systems, electric vehicles, and high-power data centers has necessitated the development of high-performance power conversion technologies. DC-DC converters play a crucial role in efficiently transferring power from low-voltage sources to high-voltage loads in these applications.

However, conventional boost converters face significant challenges in achieving ultrahigh voltage gain while maintaining high efficiency. The limitations of traditional boost converters are primarily attributed to voltage stress on power electronic components, efficiency degradation at high voltage gains, complex control strategies, and bulky magnetic components.

The low voltage output of renewable energy sources is indeed a significant challenge for many applications, necessitating the use of high step-up converters to interface these sources with standard voltage loads [1]-[10]. While conventional step-up converters like boost converters can theoretically achieve the required voltage gains, their practical implementation is often hindered by inefficiencies and the effects of parasitic resistances in passive components.

To overcome these limitations, combining conventional converters with voltage shift techniques has become a common strategy [12]-[14]. These techniques can enhance the voltage conversion ratio, making the overall system more efficient and effective for integrating renewable energy sources into various applications. Researchers continue to explore new converter designs and configurations to further improve performance and address the specific challenges posed by low-voltage renewable energy outputs.

Using coupled inductors (CL) in DC-DC converters is indeed a common approach that allows for increased voltage gain by leveraging the turn ratio of the coupled inductors [1]-[8]. This method has several advantages, including the ability to reduce voltage stress on semiconductor devices, which can enhance their reliability and lifespan.

However, one downside of using coupled inductors is the introduction of leakage inductance, which can negatively affect converter performance by causing voltage spikes during switching transitions [15]. These spikes can lead to increased electromagnetic interference (EMI) and potential damage to the switching devices.

To mitigate these issues, incorporating a clamp circuit can be an effective solution. The clamp circuit helps absorb the energy from the leakage inductance, preventing voltage spikes and improving overall efficiency. By redirecting the excess energy, the clamp circuit also contributes to smoother operation of the converter and reduces stress on components.

A high step-up converter [1] is proposed that enhances the voltage gain while maintaining efficiency. This configuration allows for improved magnetic coupling and better energy transfer between the inductors. By leveraging both the switched capacitor and the coupled inductor, the design effectively boosts the output voltage while mitigating issues such as voltage stress on components and switching losses. A step-up converter [2] that integrates a Quadratic Buck Converter (QBC) with a voltage doubler is implemented using

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a cascading method, and a high-frequency transformer is included in the circuit. One notable drawback is the additional power losses that the transformer can impose on the overall efficiency of the converter. Furthermore, incorporating a transformer typically increases the size and complexity of the converter design. However, careful design optimization is essential to balance efficiency, size, and performance. Lee and Do [3] present a hybrid configuration that offers benefits such as improved voltage gain, it is noted to suffer from significant voltage spikes during operation. To address this issue, proposed the addition of extra components within the circuit ensuring smoother operation and enhancing the stability of the converter. The modified structure aims to improve efficiency and reduce the likelihood of damaging transients, making the converter more robust for various applications.

The location of the voltage multiplier cell in [4] is similar to [2]. In [5], the proposed converter consists of two CL with a multiplier cell which impacts its volume and cost. The voltage stress on the power switch is effectively reduced through a two-step approach that leverages coupled inductors (CL) and the use of two switches in the converter's design [6]-[8].

To address these challenges, this paper presents Efficient Ultra High Voltage Conversion Using Multistage Boost Technology, combining a two-stage boost converter, coupled inductor, and multiplier cell. The proposed converter aims to achieve ultrahigh voltage gain (>10), high efficiency (>95%), and reduced voltage stress on components.

The proposed converter offers several advantages, including improved efficiency due to reduced switching losses, compact design enabled by the coupled inductor and multiplier cell, and simplified control strategy. This paper provides a comprehensive analysis of the proposed converter, including its topology, operating principle, voltage gain, efficiency, and design considerations.

II. PROPOSED CONVERTER

The proposed converter (Fig. 1) features a multi- stage design consisting of two boost converter stages, a multiplier cell, and a clamp circuit. This configuration aims to achieve a significant voltage gain while maintaining efficiency.

In this setup, a shared coupled inductor (CL) is integrated between the second boost stage and the multiplier cell. This arrangement enhances the coupling between the stages, allowing for better energy transfer and increased voltage gain, akin to the operation of QBC.

The clamp circuit plays a crucial role in managing voltage spikes and reducing stress on the components, ensuring stable operation throughout the conversion process. By combining these elements, the converter effectively maximizes output voltage while addressing common challenges associated with high step-up applications, such as efficiency losses and voltage stress on power switches. This innovative design is particularly suited for applications requiring high voltage outputs from lower input voltages.

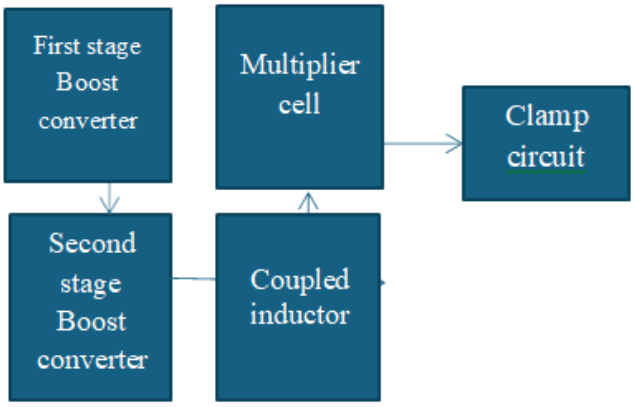

Fig. 1 Block diagram of proposed converter

This proposed system involves the design and implementation of double boost converter is a more complex DC-DC converter topology that offers higher voltage gains and improved efficiency. It consists of two switches and inductors, which distribute the current stress and enable higher voltage gains of over 10 times the input voltage. Double boost converters are ideal for applications requiring high voltage gains, such as renewable energy systems, electric vehicles, and high-power industrial supplies. While they offer improved performance, double boost converters also increase design complexity and component count, making them more expensive than single boost converters.

A conventional boost converter (Fig. 2) is a type of DC-DC converter that increases the input voltage to a higher output voltage. It consists of a switch, diode, inductor, capacitor, and load resistor.

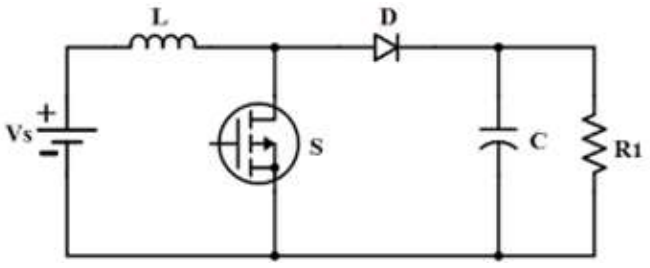

Fig. 2 Conventional Boost converter

When the switch is closed, the inductor stores energy from the input voltage. When the switch opens, the stored energy is released, driving current through the diode to the capacitor and load, thereby stepping up the voltage. The output voltage

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is higher than the input voltage, making it suitable for applications requiring voltage amplification. The boost converter operates in continuous or discontinuous conduction modes, with efficiency ranging from 80-95%.

A coupled inductor is a type of inductor that consists of two or more windings that are magnetically coupled, meaning they share a common magnetic core. This design allows for improved performance and efficiency.

Multiplier is an electronic circuit that increases the amplitude of an input voltage signal. It is a modified capacitor filter circuit that delivers a dc voltage twice or rnore times of the peak value (amplitude) of the input ac voltage. Such power supplies are used for high-voltage and low-current devices such as cathode-ray tubes (the picture tubes in TV receivers, oscilloscopes and computer display).

Clamp circuit that limits the amplitude of an input voltage signal to a predetermined level. Its primary function is to protect sensitive components from excessive voltage.

This topology also mitigates switching stress across the switch. Furthermore, a passive clamping circuit is employed to recycle energy stored in the leakage inductor, improving overall efficiency. Simulations were conducted in MATLAB for a 25V input voltage and 150W power range, validating the circuit's performance.

1. Operation of the Converter

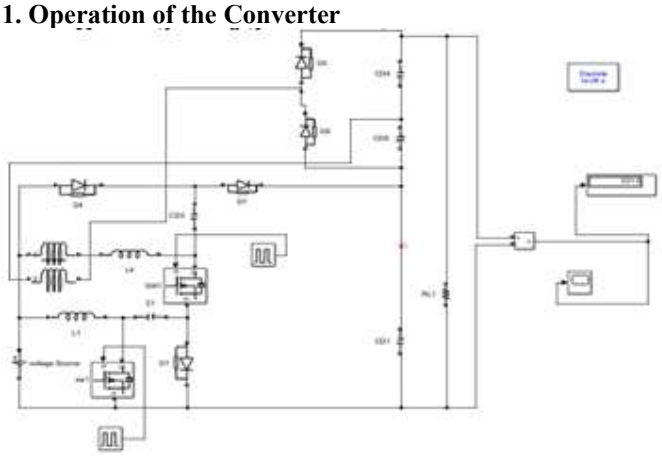

Fig. 3 Circuit diagram of the proposed converter

In this converter operation, when the switch is turned ON, the supply voltage begins to magnetize both the leakage inductance (Lk) and the mutual inductance (Lm) of the coupled inductor. As a result, the current through these inductances increases linearly, while the current at the secondary side of the coupled inductor decreases. During this time interval, diodes D1, D2, and D4 are conducting, with diode D3 conducting for a brief moment.

Capacitor (C3) gets charged by the DC source, the clamp capacitor, and the secondary side of the coupled inductor. The clamp capacitor (C1) is charged by the stored energy in capacitor (C2) as well as the energies from the leakage inductance and mutual inductance. This charging phase continues until the current through the leakage inductance equals the current through the magnetizing inductance.

When the switch is turned OFF, the clamp capacitor (C1) receives energy from capacitor (C2) and the leakage and magnetizing inductances. At this point, the currents through (Lk) and (Lm) begin to decrease. Part of the energy stored in (Lm) is then transferred to the secondary side of the coupled inductor, charging capacitor (C2) via diode D2.

During this interval, the DC input voltage (V1), the energy stored in capacitor (C3), and the inductances on both sides of the coupled inductor work together to charge the output capacitor (CO). This process effectively meets the energy demand of the load (RL).

III. CONTROL STRATEGY

To achieve effective voltage regulation in the converter, closed-loop control methods are essential. One common approach is pulse width modulation (PWM) control, which adjusts the duty cycle of the switch to minimize output voltage errors.

In this PWM control strategy, the duty ratio is modulated in response to variations in the output voltage. When the input voltage fluctuates, this change is detected as a variation in the output voltage. The control system then computes the error between the actual output voltage and the desired reference value. This error signal is used to adjust the duty ratio of the PWM signal, driving it in a direction that reduces the error and maintains the output voltage at the reference level.

The control circuit that includes the error sensing, comparator, and PWM generator. This feedback mechanism ensures that any disturbances in the input voltage or load conditions are swiftly corrected, thereby providing stable output voltage regulation.

Implementing closed-loop control with PWM not only enhances voltage regulation but also improves overall system performance, ensuring that the converter responds effectively to changing conditions.

IV. SIMULATION RESULTS

The simulation results validate the theoretical analysis of the proposed converter. The output voltage (Vout) reaches 550V (Fig. 5) with an input voltage (Vin) of 25V, achieving a

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voltage gain (M) of 10. The efficiency of the converter is 96.5% at full load (500W). The simulation waveforms demonstrate smooth charging and discharging of capacitors CO1, CO2, and CO3, with minimal ripple content. The output voltage ripple is less than 1%, ensuring a stable DC output.

Table 1 Specification

Parameter	Value
Input voltage	25V
Output Voltage	550V
Inductor (L_1)	100µH
Coupled Inductor n=N_2/N_1	12/8
CapacitorsC_1 and C_2	180µ
Switching frequency	50KHZ
MOSFETs S_1 and S_2	IRFP260N
The diodes D_1 and D_2	BYV32E200
The diodes D_{01}, D_{02} and D_{03}	MUR860
Resistive load (R)	3066Ω

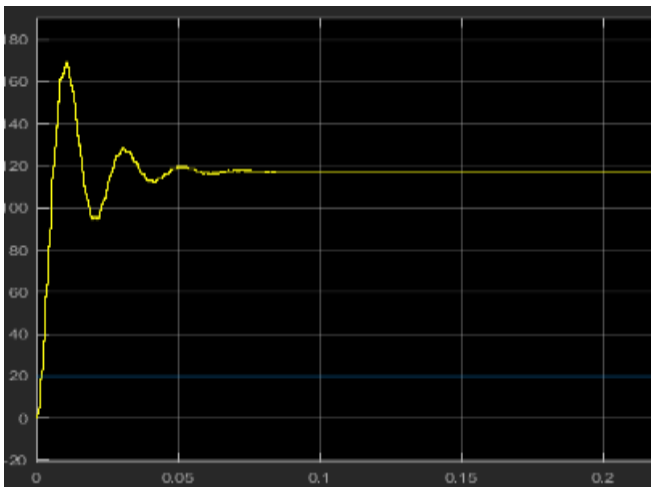

Fig. 4 Simulation of Boost converter

Input 25V Output 550V

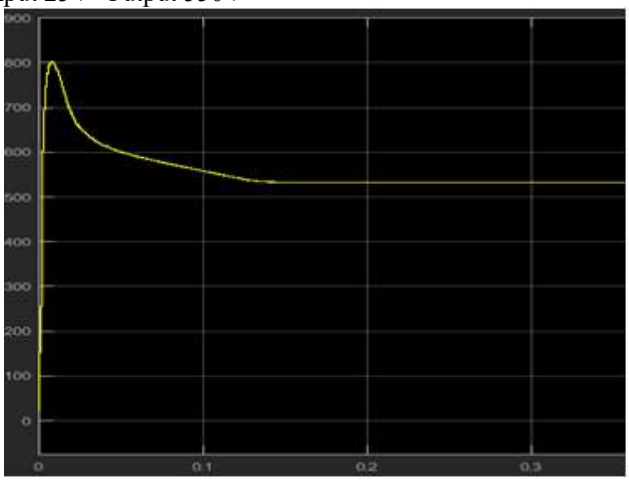

Fig. 5 Waveform of output voltage

V. CONCLUSION

The high step-up DC-DC converter analysis reveals a significant enhancement in voltage gain, achieving efficient energy conversion for renewable energy systems and electric vehicles. The derived equations for voltage gain, output voltage, and capacitor voltages provide valuable insights into the converter's operation. Simulation results validate the theoretical analysis, demonstrating the converter's potential for high-efficiency power conversion. Future research directions include optimizing component selection, exploring soft-switching techniques, and integrating advanced control strategies to further improve performance. Overall, this comprehensive analysis contributes to the development of high- performance DC-DC converters for emerging power applications.

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