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High step-up DC-DC converter with switched capacitor-coupled inductor and voltage multiplier module

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ABSTRACT

A high step-up dc-dc converter based on a switched capacitor-coupled inductor (SC-CL) with voltage multiplier cells is proposed. It is composed of a SC-CL and a voltage multiplier module stacked on the load side. SC-CL produces the maximum output voltage with maximum voltage gain. These features make the projected converter suitable for renewable energy applications such as solar photovoltaic (PV). A low turn ratio of the coupled inductor is used for realizing the higher gain. It consists of a voltage boost unit SC-CL and a voltage multiplier module. In a DC micro-grid, PV energy is one of the utmost significant sources of power. Since the PV source voltage is very low, a very high voltage gain converter is required for a DC microgrid. Here, a step-up DC-DC converter topology with a very high voltage gain characteristic is proposed. The projected converter was simulated by MATLAB/Simulink to convert 30 V to 380 V.

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1. INTRODUCTION

In recent years, there has been a considerable growth in green energy demand as well as awareness about green energy technology. This motivates researchers to investigate distributed generation systems (DGs) that generate energy from renewable sources [1]. Photovoltaic (PV) panels, fuel cells, and other renewable energy sources provide DC power [2].

DC power is also provided by energy storage devices like lithium-ion batteries and supercapacitors. As an effect, DC micro-grids are now applied in DGs to provide ideal regulation of power flow from source side to load side as well as high-quality power to consumers [3], [4]. As an example, lighting and 'gadgets' are vital considerations. Research conducted by the International Energy Agency suggests that gadgets, such as computers and consumer electronics, consume about 15% of domestic energy usage. Lights are thought to consume nearly 20% of worldwide electricity use, while lighting comprises roughly 20% of worldwide electricity usage. LEDs, which run on DC power, are becoming a popular choice for high-efficiency lighting. Similarly, because most gadgets run on DC power, these two industries together account for a considerable and growing portion of worldwide electricity consumption by DC devices [5]. However, these are currently powered by AC mains through a slew of separate transformers. High gain voltage converters are advantageous in PV systems.

For applications such as uninterruptible power supply (UPS) and compact PV inverters, the low input voltage from a PV source must be stepped up [6]-[8]. As a result, existing topologies will need to be altered to accommodate high gain converters. The PV voltage will be increased from 30 V DC to 375-400 V DC [9]-[12]. Most of the reported topologies have higher source current ripples, and they are unable to achieve very high voltage gains at a low duty ratio. In this paper, we propose a high voltage gain step-up converter using switched-capacitor-coupled inductor (SC-CL) to overcome this difficulty.

According to the literature review, when the voltage gain is great and the duty ratio is extreme, the boost converter does not attain high efficiency. Large ripple current, diode reverse-recovery difficulty, voltage strains on the power switch, and electromagnetic interference (EMI) problems are further consequences [13]. Many boost converters and switched capacitor converters have been proposed in recent years, including super-lift [14], voltage-lift [15], modified Dickson charge pump [16], and extensible switched capacitor [17]. The voltage stresses are very high in [18]-[25]. All the above-said converters have the problem of large high currents and voltage stress in the switches and diodes, which reduces the efficiency of the converters. This work proposes a SC-CL with high voltage gain and efficiency for power conversion in renewable energy systems, as shown in Figure 1. The advantages of the projected converter are as follows:

a) The projected converter provides a significant voltage gain without having to operate at an extremely high duty ratio.
b) The voltage stress on the semiconductor switches is much lesser than the load voltage, allowing for the use of low-voltage-rated MOSFETs with low on-state resistance $R_{DS(ON)}$ resistances to reduce conduction losses of switches.
c) The SC-CL design can part input current, decrease the conduction losses, and handle applications with a high input current.
d) The suggested SC-CL converter reduces input current ripple, allowing renewable energy sources to last longer.
e) Because of the leakage inductances of the connected inductors, the reverse-recovery voltage of output diodes is reduced. The coupled inductors' leakage energy is recycled, reducing voltage spikes on power transitions and increasing efficiency.

All of these characteristics indicate that the projected converter is appropriate for applications requiring high power, higher efficiency, and high voltage gain Figure 1 shows the schematic diagram of the renewable energy system. The projected converter is analyzed for one working cycle T_s and D is the duty ratio. Figure 2 shows the duty cycle.

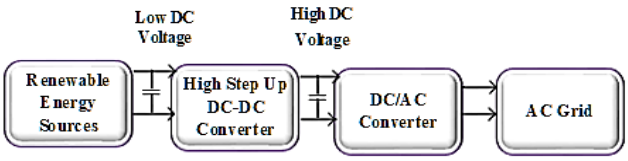

Figure 1. Schematic diagram of the renewable energy system

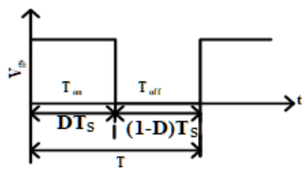

Figure 2. Duty cycle

2. PROPOSED HIGH STEP-UP DC-DC CONVERTER WITH SWITCHED CAPACITOR-COUPLED INDUCTOR AND VOLTAGE MULTIPLIER MODULE

To obtain better voltage gain, the proposed converter structure consists of a modified SC-CL with voltage multiplier cells. The secondary windings of two coupled inductors and two switching capacitors build up the voltage multiplier module. The circuit diagram of the projected converter is shown in Figure 3.

The SC-CL DC converter consists of two coupled inductors. The coupling references of the coupled inductors are symbolized by the characters "o" and "•" as given in Figure 3. The coupled inductor is demonstrated as a combination of an ideal transformer with a turn ratio, a magnetizing inductance, and a leakage inductance in this proposed paper. The voltage multiplier module consists of secondary windings of two coupled inductors, two diodes D_4 and D_5 and two switched capacitors C_4 and C_5.

The SC-CL module consists of two magnetizing inductances L_{m1} and L_{m2}, primary windings of two coupled inductors whose n is defined as the turn ratio between N_s and N_p. The SC-CL consists of a power switch S, capacitors C_1, C_2, C_3, and diodes D_1, D_2, and D_3. Where D_3 is the output diode and C_3, C_4, and C_5 are output capacitors.

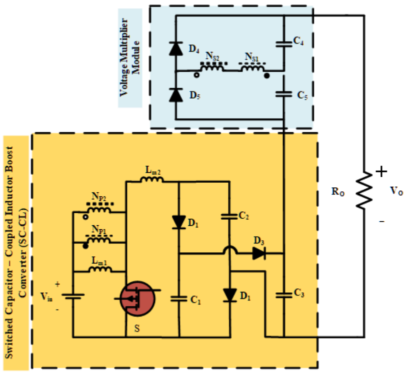

Figure 3. Circuit diagram of the proposed converter

3. OPERATING PRINCIPLE OF SWITCHED-CAPACITOR-COUPLED INDUCTOR WITH VOLTAGE MULTIPLIER CELLS

The operation of the projected converter is explained in two stages, a) stage 1 [t_0 –t_1]: This stage begins when switch S is turned ON. The diodes D_1, D_2, and D_3 are forward biased and current through D_1, D_2, and D_3 increases linearly. The inductor L_{m1} of coupled inductor is magnetized with input voltage V_i. So, the current i_{Lm1} increases linearly. But the energy stored in the inductor L_{m2} of coupled inductor is demagnetized and charges C_1 through D_1 and b) Stage 2[t_1 –t_2]**:** In this stage switch S is turned off, which makes the current through D_1, D_2, and D_5 decrease. The energy stored in L_{m1} transfers the energy to the secondary side of coupled inductor charging C_5 via D_4. The inductor L_{m2} of coupled inductor is magnetized the current i_{Lm2} increases linearly. The key waveforms of the projected converter are given for one switching period as shown in Figure 4. The parameters of the proposed converter are given as:
I_g: gate current of switch
i_{Lm1}: current through magnetizing inductor L_{m1}
i_{Lm2}: current through magnetizing inductor L_{m2}
V_s: switch voltage
I_s: switch current
V_0: output voltage
I_0: output current

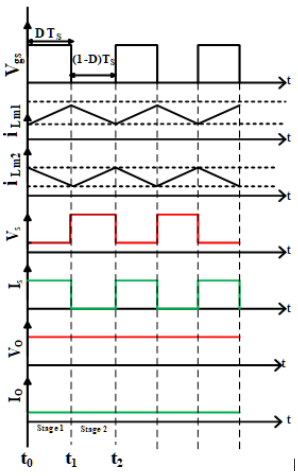

Figure 4. Key waveforms of proposed converter

4. SIMULATION RESULTS OF PROPOSED CONVERTER

The simulation model of the projected converter has been designed using MATLAB/Simulink. The circuit parameter taken for simulation is given in Table 1. The input voltage is essentially 30 V, the load resistance is 1 KΩ, and the Inductor L_{m1} and L_{m2} are 400 μH. SC-CL unit capacitors C_3, C_4 and C_5 are 620 nF, voltage multiplier unit capacitors C_1, C_2 are 1.2 μF. The switching frequency of SC-CL is 50 kHz, and the duty cycle ratio is 0.41. The simulation was carried out in order to meet the requirements and to increase the output voltage by increasing the voltage gain and efficiency. The simulated output is shown in Figures 5 to 12. Figure 5 shows the gate pulse of the switch. Figure 6 and Figure 7 show the current through inductor L_{m1} and L_{m2}. Figure 8 and Figure 9 show the voltage and current of a switch. Figure 10 and Figure 11 show output voltage and output current. Figure 11 shows the duty ratio vs voltage gain.

Table 1. Simulation parameters

SL.No	Parameters	Values
1.	Switching frequency	50 kHZ
2.	Duty ratio D	41
3.	Inductor L_{m1}, L_{m2}	400 μH
4.	Capacitor C_1, C_2	1.2 μF
5.	Capacitor C_3, C_4, C_5	620 nF
5.	Output resistor R_0	1 kΩ
6.	Supply voltage V_S	30 V
7.	Output voltage V_0	380 V

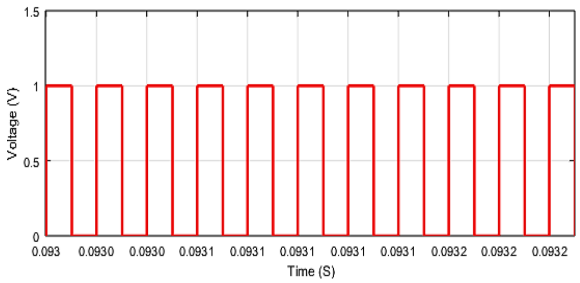

Figure 5. Gate pulse of switch

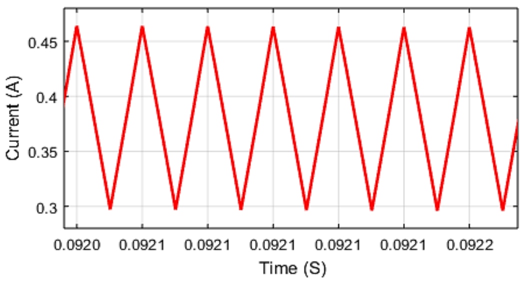

Figure 6. Current through inductor L

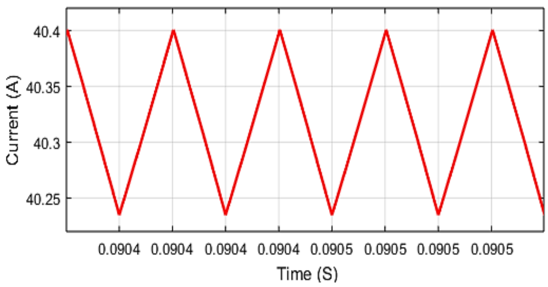

Figure 7. Current through inductor L_{m1}

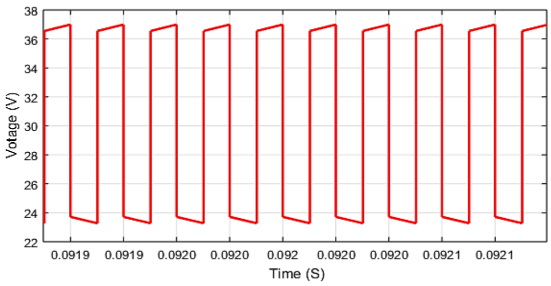

Figure 8. Voltage across switch

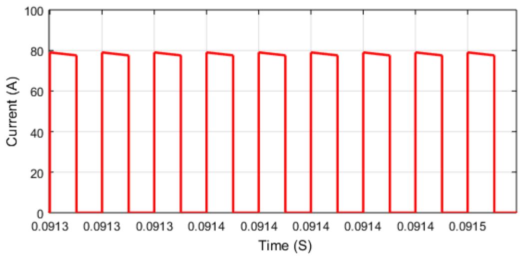

Figure 9. Current through switch

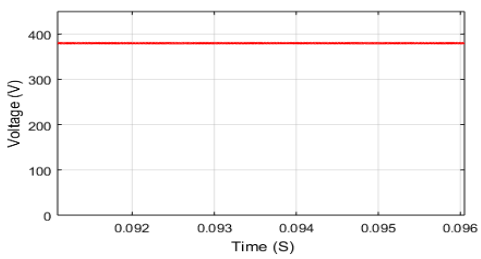

Figure 10. Output voltage

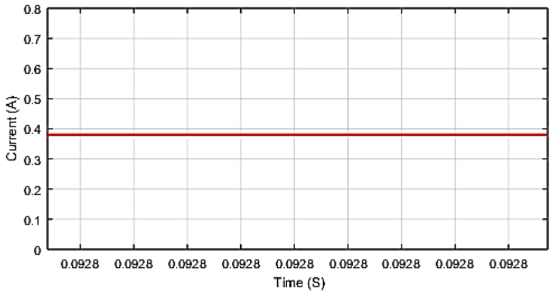

Figure 11. Output current

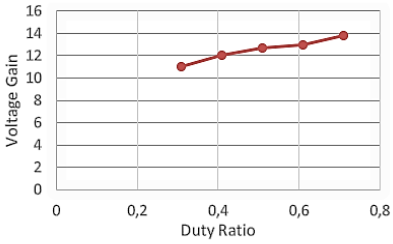

Figure 12. Duty ratio vs voltage gain

5. CONCLUSION

A high-step-up DC-DC converter with voltage multiplier cells was constructed and analyzed using a SC-CL. It was successfully demonstrated that the proposed converter could boost 30 V to 380 V. In addition, the aforementioned converter offered a high-voltage gain with a reduced duty ratio. The voltage stress across semiconductors devices was significantly reduced. The losses on the leakage inductance were minimized, and the ripples on the input current were limited and mitigated. MATLAB was used to simulate the proposed converter in order to evaluate it. The simulation results demonstrate and validate the converter's performance.

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