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Modeling of High efficiency high step-up DC/DC converter with voltage multiplier module

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Abstract: The utilization of Renewable energy becomes an important source of electrical energy with the advancement in power electronic technology. Renewable energy systems generate low voltage output and thus, high step-up dc/dc converters are widely employed in many renewable energy applications Low voltage is converted into high voltage by using step-up converter The review of various topologies of high step up converter and their performance with voltage multiplier circuits are discussed in this paper. The merits and demerits of these converters are discussed. This paper shows the comparison of efficiency and voltage gain for various boost converter topologies integration with voltage multiplier.

1. INTRODUCTION

The conventional boost converter provides step up conversion without high gain due to the limitation of conduction losses in the circuit parameters. The gain reaches infinite, when the duty cycle tends to unity. The gain depends on the *I*2*R* losses in the inductors and the power electronic devices connected. The voltage gain is difficult to obtain with conventional boost topologies because of the parasitic components, which limits the frequency and the system size. A voltage multiplier is a device which converts the low voltage input to a higher voltage by means of capacitors and diodes combined circuit. The voltage multiplier helps in reducing the turn's ratio of transformer for better performance.Fig.1. shows a typical photovoltaic system that consists of a solar module and a high step up converter.

The conventional boost converters are provided with voltage multipliers to increase the voltage gain without having high duty cycle and reduce the voltage stress across the switches. The voltage multiplier reduces the peak current flowing through the switch and enhances the dynamic response with the increase of turn OFF period. The

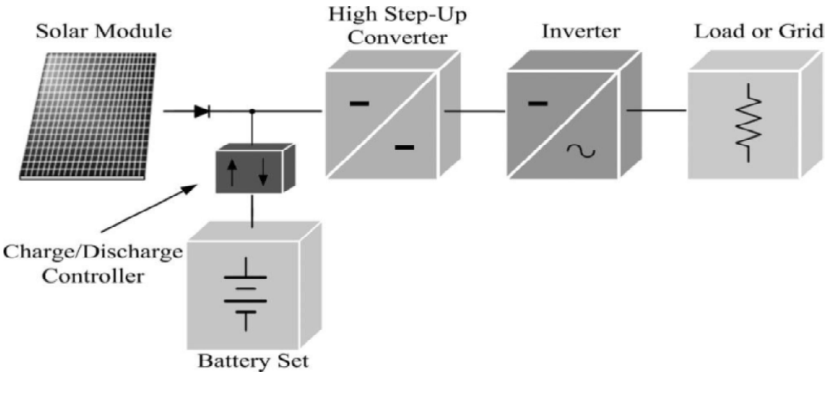

Figure 1: Typical Photovoltaic system

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integration of voltage multiplier with high step up converter increases the voltage conversion ratio and gain. The voltage multipliers are provided with capacitors and diodes in the circuit for converting the input voltage to another high level output. The converter with the voltage multiplier determines the efficiency and performance of the photovoltaic system connected to the system. This Isolated boost converter with coupled inductors topology satisfies high efficiency.

2. PROPOSED SYSTEM

2.1. Step-up DC/DC Converter with Voltage Multiplier Module

The proposed high efficiency high step-up converter with voltage multiplier module is shown in Fig.2. A conventional boost converter and two coupled inductors are located in the voltage multiplier module, which is stacked on a boost converter to form an asymmetrical interleaved structure. Primary windings of the coupled inductors with N_p turns are employed to decrease input current ripple, and secondary windings of the coupled inductors with Ns turns are connected in series to extend voltage gain. The turn's ratios of the coupled inductors are the same.

The equivalent circuit of the proposed converter is shown in Fig.3. Where L_{m1} and L_{m2} are the magnetizing inductors, L_{k1} and L_{k2} represent the leakage inductors, S_1 and S_2 denote the power switches, C_b is the voltage-lift capacitor, and n is defined as a turns ratio N_s/N_p.

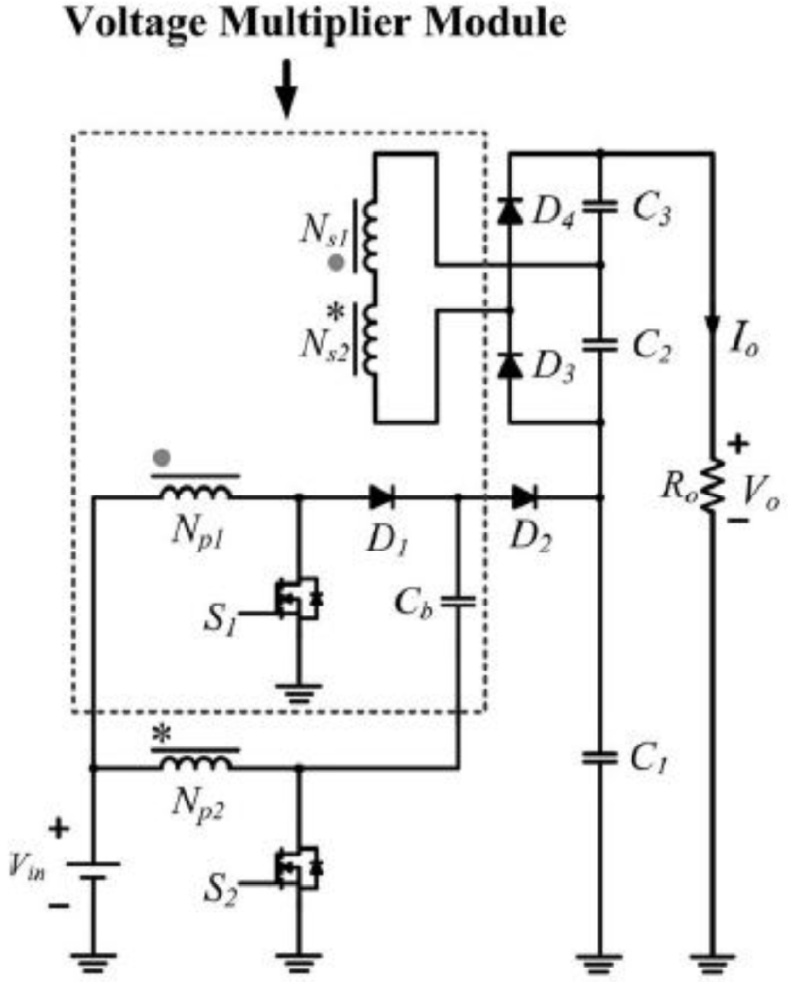

Figure 2: Proposed high step-up converter with a voltage multiplier module

2.2. Multilevel switched capacitor DC/DC Converter

Avoiding the transformers bring obvious benefits of size, cost and weight reduction and thus the reduction of overall complexity of the converter. The other advantage is the possibility to work at higher temperatures than inductor based counterparts. Recently there has been a new converter developed which meets the requirements of high

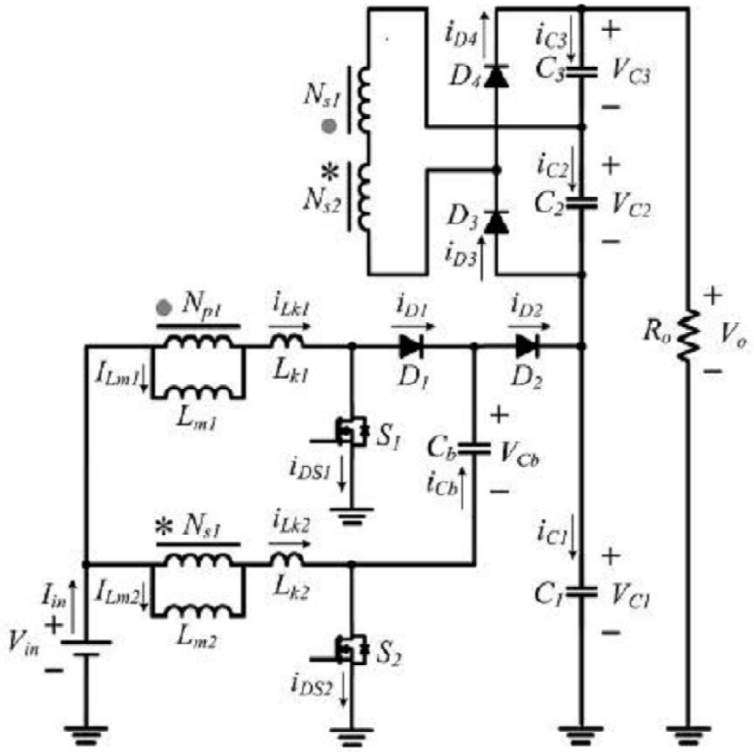

Figure 3: Equivalent Circuit

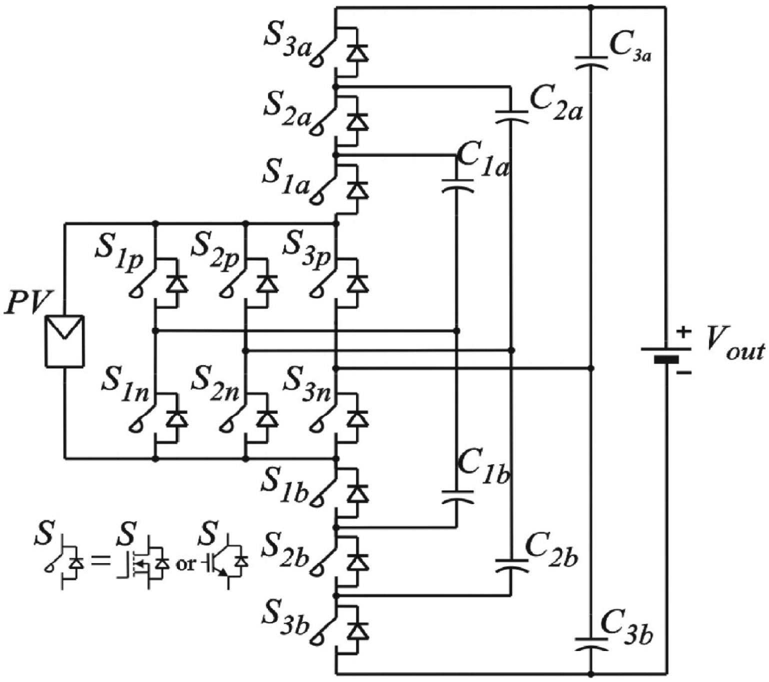

Figure 4: Multilevel switched capacitor DC/DC Converter

efficiency and ability to work in high temperatures. The voltage gain is accomplished by voltage multiplier cells that operate based on switching capacitor principle. The penalty is a relatively big number of switches, which is in this case 12. Moreover, due to capacitive load the switches are exposed to high current stress.

The possibility to use low voltage rated switches and the lack of inductors make it possible to achieve the compact and cost effective solution.

2.3. Comparison of Step-up DC/DC Converter with Voltage Multiplier Module and Multilevel switched capacitor DC/DC Converter

Topology	*[%]*	P_{max} *[kw]*	*Gain [V/V]*	F_s *[kHz]*	V_I *[VDC]*	V_{BUS}	*Voltage gain formula*	*No of switches*	*No of diodes*
Step-up DC/DC Converter with Voltage Multiplier Module	97.4	0.22	10.0	85	20 to 70	200	(2 + n.D)/(1–D)	1	3
Multilevel switched capacitor DC/DC Converter	94.7	1.00	9.5	100	40 to 56	380	(2n + 1)/(1–D)	4	2

3. MODES OF OPERATION

The proposed converter operates in continuous conduction mode (CCM), and the duty cycles of the power switches during steady operation are interleaved with 180æ% phase shift. The key steady waveforms in one switching period of the proposed converter contains six modes.

3.1. Mode 1

Mode 1 [t_0, t_1]: At $t = t_0$, the power switches S_1 and S_2 are both turned ON. All of the diodes are reversed-biased. Magnetizing inductors L_{m1} and L_{m2} as well as leakage inductors L_{k1} and L_{k2} are linearly charged by the input voltage source V_{in}.

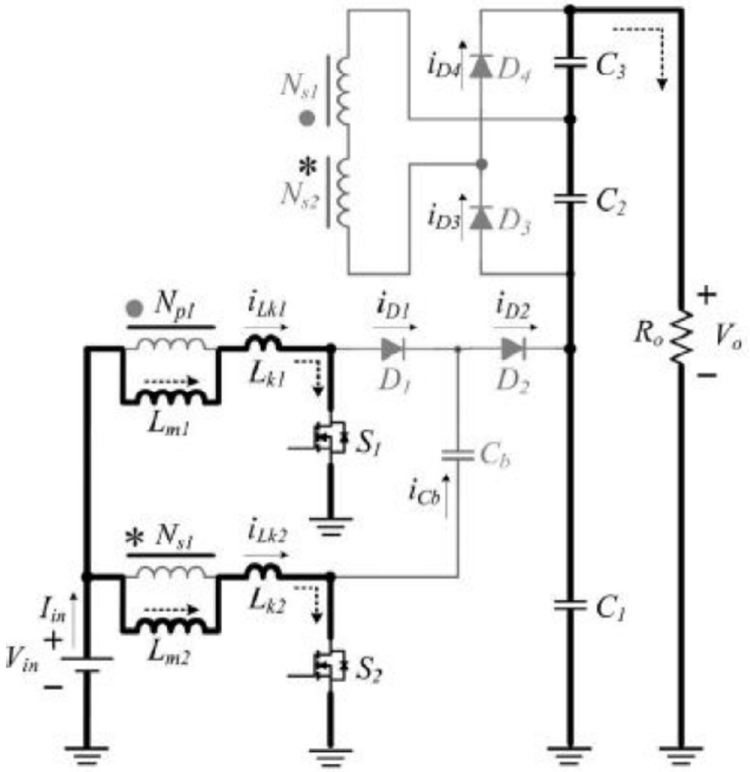

Figure 5: Mode 1

3.2. Mode 2

Mode 2 [t_1, t_2]: At $t = t_1$, the power switch S_2 is switched OFF, thereby turning ON diodes D_2 and D_4. The energy that magnetizing inductor L_{m2} has stored is transferred to the secondary side charging the output filter capacitor C_3. The input voltage source, magnetizing inductor L_{m2}, leakage inductor L_{k2}, and voltage-lift capacitor C_b release energy to the output filter capacitor C_1 via diode D_2, therefore extends the voltage on C_1.

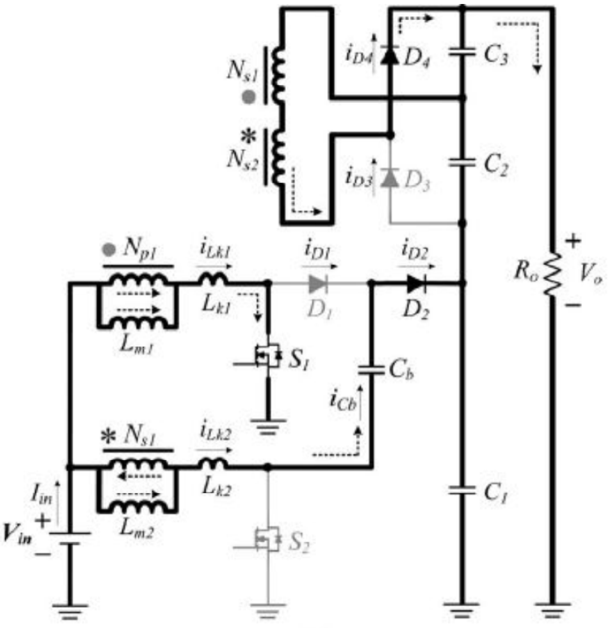

Figure 6: Mode 2

3.3. Mode 3

Mode 3 [t_2, t_3]: At $t = t_2$, diode D_2 automatically switches OFF because the total energy of leakage inductor L_{k2} has been completely released to the output filter capacitor C_1. Magnetizing inductor L_{m2} transfers energy to the secondary side charging the output filter capacitor C_3 via diode D_4 until t_3.

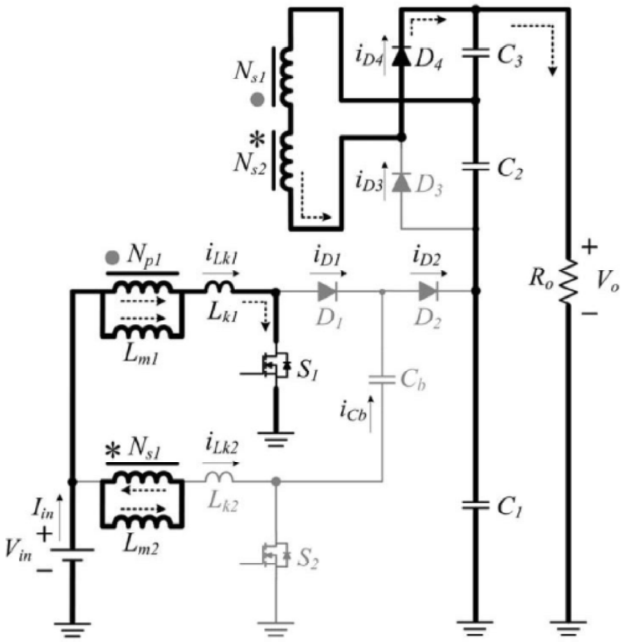

Figure 7: Mode 3

3.4. Mode 4

Mode 4 [t_3, t_4]: At $t = t_3$, the power switch S_2 is switched ON and all the diodes are turned OFF. The operating states of modes 1 and 4 are similar.

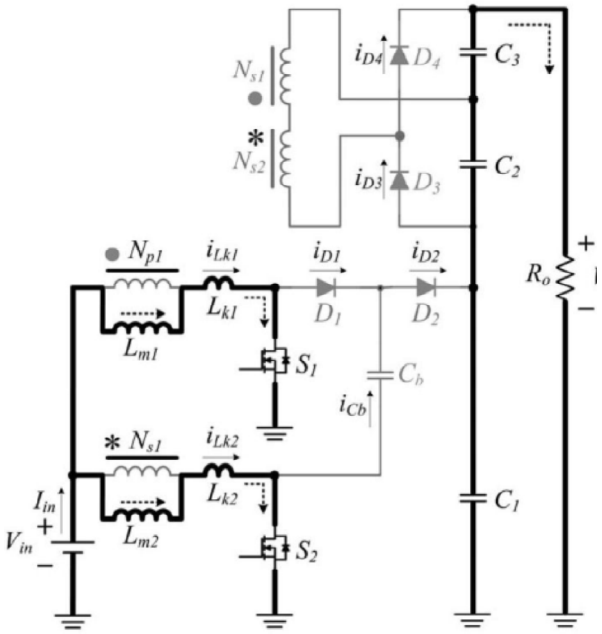

Figure 8: Mode 4

3.5. Mode 5

Mode 5: Mode 5 [t_4, t_5]: At $t = t_4$, the power switch S_1 is switched OFF, which turns ON diodes D_1 and D_3. The energy stored in magnetizing inductor Lm1 is transferred to the secondary side charging the output filter capacitor C_2. The input voltage source and magnetizing inductor Lm1 release energy to voltage-lift capacitor C_b via diode D_1, which stores extra energy in C_b.

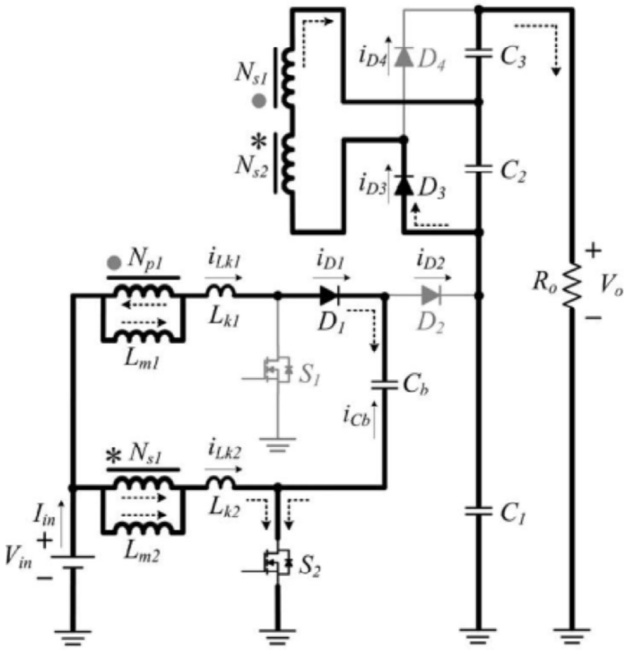

Figure 9: Mode 5

3.6. Mode 6

Mode 6 [t_5, t_0]: At $t = t_5$, diode D_1 is automatically turned OFF because the total energy of leakage inductor L_{k1} has been completely released to voltage-lift capacitor C_b. Magnetizing inductor L_{m1} transfers energy to the secondary side charging the output filter capacitor C_2 via diode D_3 until t_0.

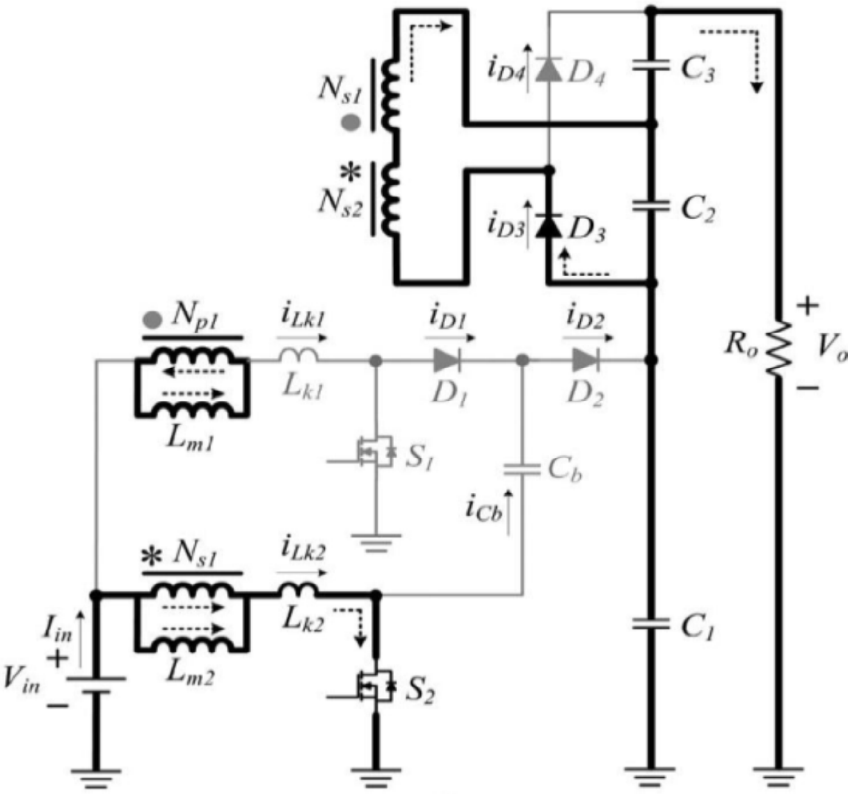

Figure 10: Mode 6

4. SIMULATION AND RESULT DISCUSSIONS

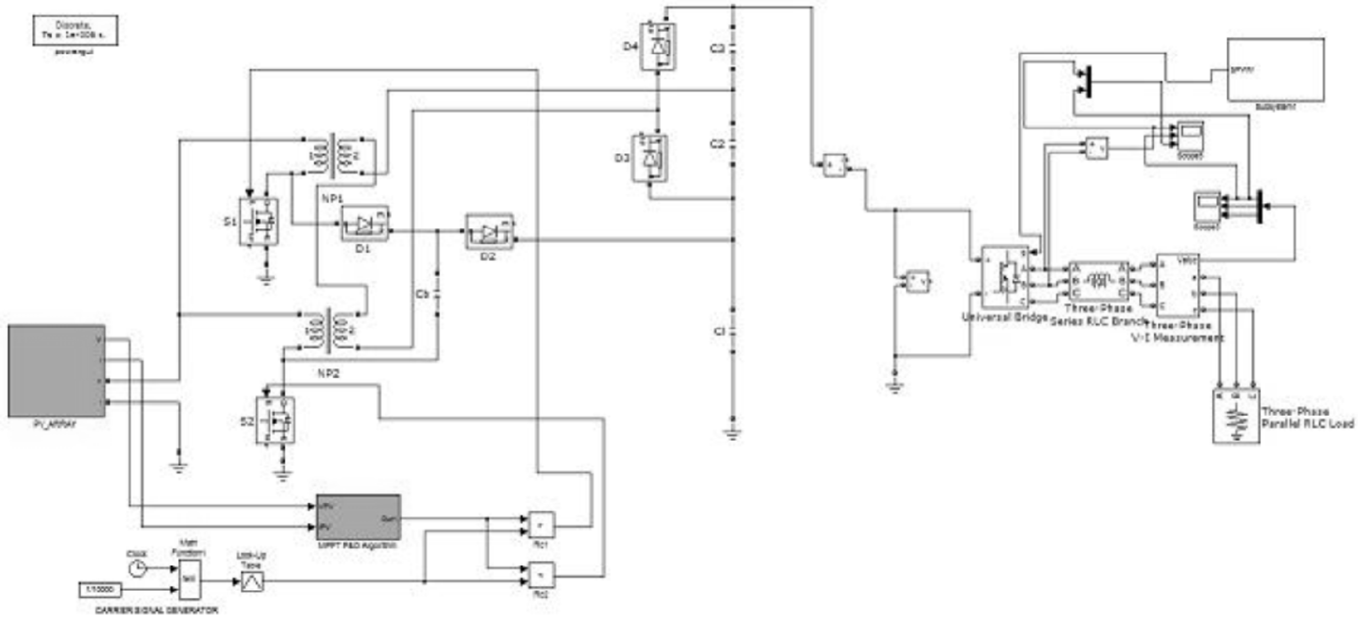

Figure 11: Simulink Block Diagram

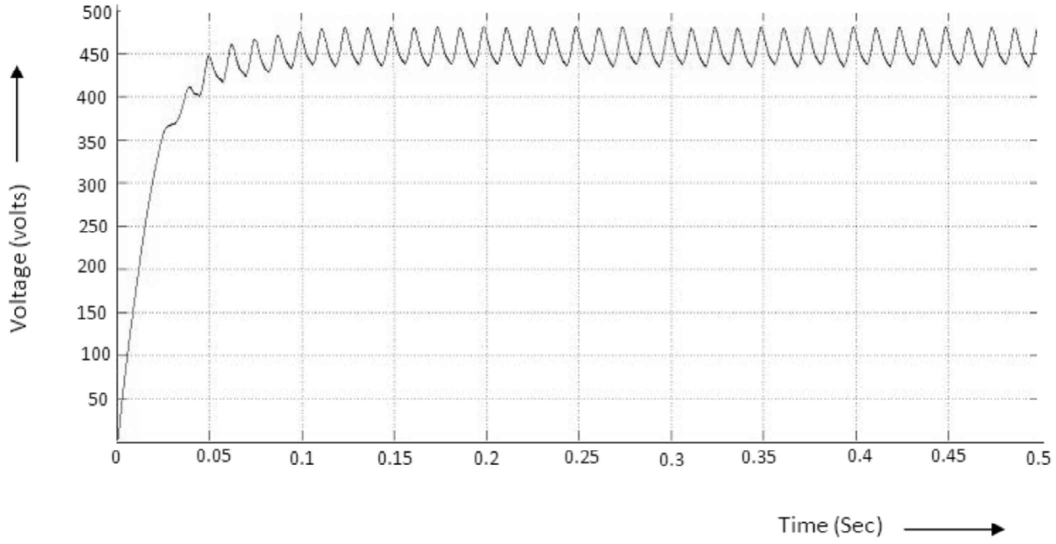

Figure 12: Output voltage

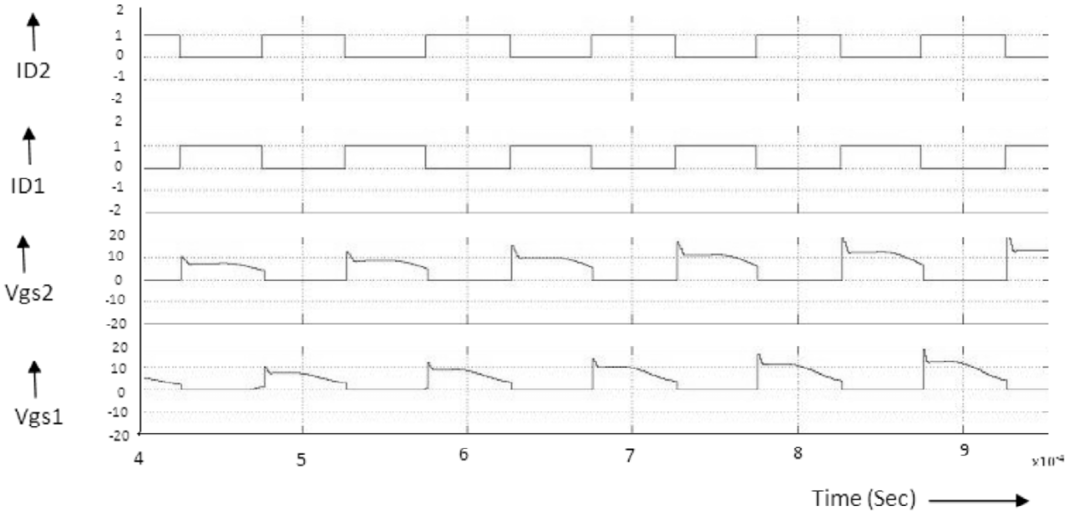

Figure 13: V_{gs1}, V_{gs2}, I_{D1} & I_{D2}

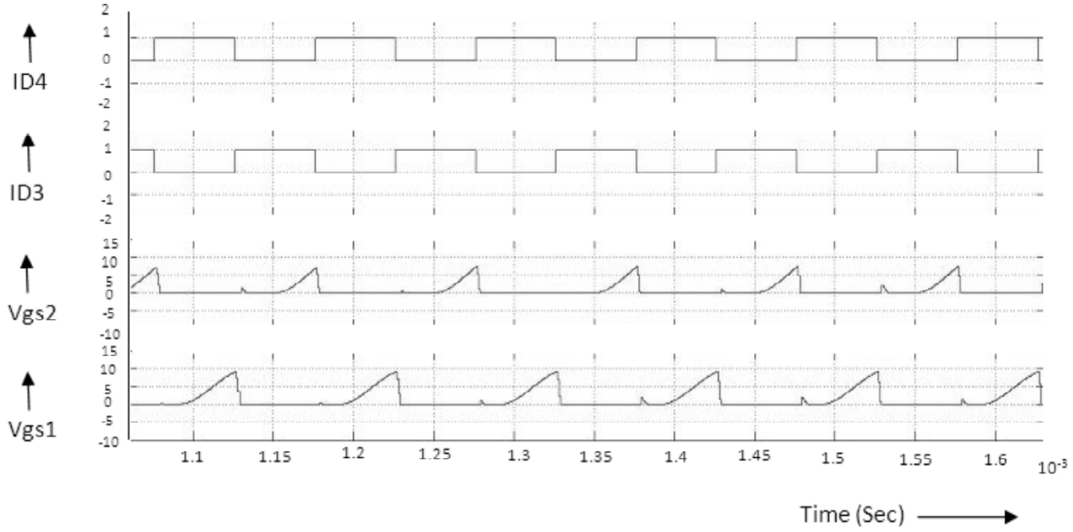

Figure 14: V_{gs1}, V_{gs2}, I_{D3} & I_{D4}

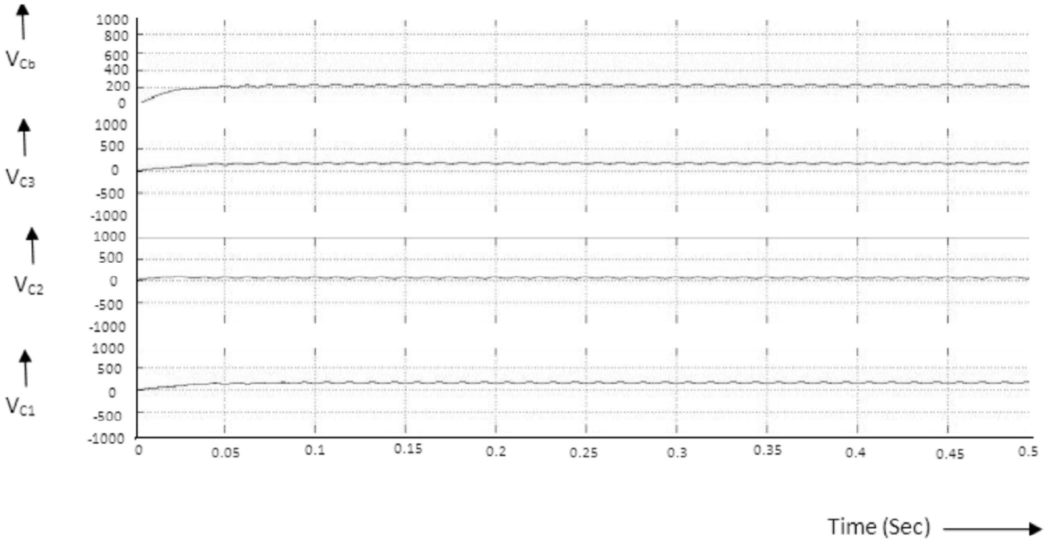

Figure 15: $\mathbf{V_{c1}, V_{c2}, V_{c3}}$ **&** $\mathbf{V_{cb}}$

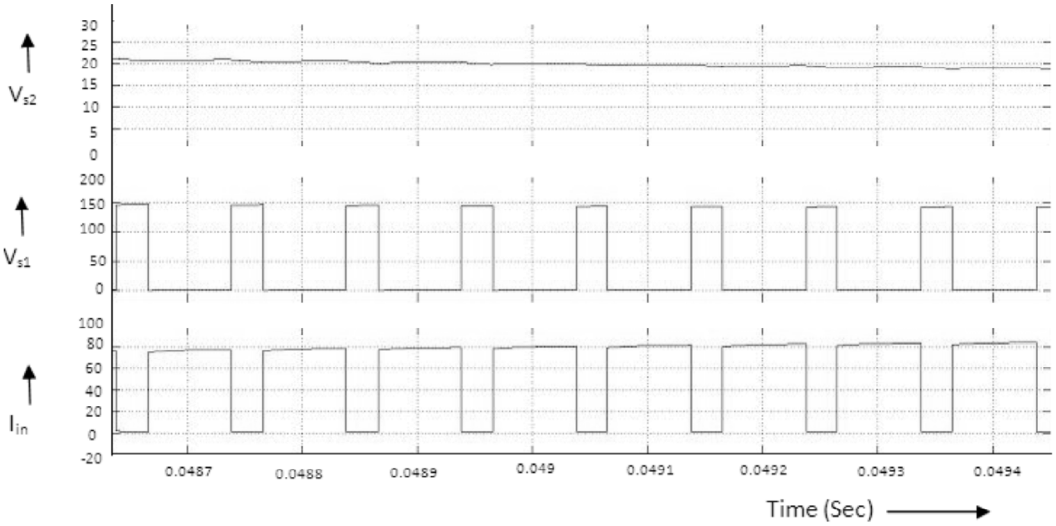

Figure 16: $\mathbf{I_{in}. V_{s1}, V_{s2}}$

The voltage obtained in the output side (V_o) is 450 V shown in figure 12. The switch voltage is clamped at 80 V which is indicated in figure 16, which is much smaller than the output voltage. Figure 15 shows the voltage on all capacitors to illustrate the high voltage storage and theoretical analysis. V_{C1} is equal to V_{Cb} plus output voltage of boost converter, and V_{Cb} is equal to the output voltage of the boost converter. Thus, V_{C1} is twice of V_{Cb}. V_{C2} is equal to V_{C3} and both are nearly V_{Cb} because turns ratio is fixed as 1. Figure 16 shows the input current ripple (I_{in}) and the peak – peak current ripple which is very low.

5. CONCLUSION

The topological principles and simulation results of the proposed converter is presented in this paper. It has been successfully implemented in an efficiently high step up conversion without an extreme duty ratio and a number of turn's ratio through the voltage multiplier module. Here, the voltage stress over the power switches is restricted and is much lower than the output voltage. So the proposed system is suitable for renewable energy applications that need high step- up conversion with high efficiency.

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