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A High Voltage Gain DC-DC converter with VMC Technique for PV Applications

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Abstract: A DC-DC converter is designed to produce a DC output voltage from a DC input. When a required output voltage is higher than input voltage, a boost converter is typically used. Due to its low conduction loss, simple design, and affordability, a conventional boost converter is suitable for step-up applications. However, it is not ideal for achieving high step-up ratios. Operating conventional boost converters at high ratios can result in significant voltage and current stress on the switches. To address this, an interleaving technique in boost converters is introduced, offering higher voltage gains suitable for high-power applications. Traditional DC-DC boost converters face limitations in achieving high voltage gains due to factors such as more stress on power switches, diode reverse recovery problems and the series resistance of inductors and capacitors. This document proposes a novel DC-DC converter that achieves high voltage gains without requiring an extremely high duty cycle. The design uses two inductors with identical inductance levels, charging them in parallel during the switch-on phase and discharging them in series during the switch-off phase, enhancing voltage conversion efficiency. Specifically designed for photovoltaic systems, the proposed converter family offers high-voltage-gain capabilities. It can function as a multiport converter drawing power from two independent sources or a single source in an interleaved fashion, maintaining continuous input current withlow ripple-ideal for applications like solar energy. By cascading multiple diode-capacitor stages, the design effectively boosts voltage while minimizing stresses on switches, diodes, and capacitors.

Index Terms: VMC - voltage multiplier cell, PEC - power electronic converter, IB - Interleaved boost, ZCS – Zero current switching, PV- Photo Voltaic

I. INTRODUCTION

Nowadays, in the world, due to the growing need for electricity production, reducing the use of fossil energy sources, the importance of protecting the environment, electricity restrictions, and fuel supply, the use of new energies is taken into consideration [1]. Since the output voltage of renewable energy sources as solar energy systems is affected by weather and environmental conditions, these sources usually have low output voltage, so the need for a power electronic converter (PEC) to convert the voltage level is inevitable. DC-DC converters are widely used in renewable energy generation systems such as solar photovoltaic (PV) system, wind power system and fuel cell for correct energy conversions [2],[3].

A combination of PV cells will form a PV module and a combination of PV modules will form a PV array to supply the specified loads. Normally, these solar PV modules will be connected in series to increase the PV output voltage due to the nature of solar PV energy thatcan only generate low DC output voltage in the range between 12V to 75V [4].To increase the input voltage from these renewable sources a boost converter is commonly used. A classic boost converterhas only one input and offers limited gain.

It is possible to achieve improved static voltage gain withreduced duty cycles, component losses and stress with somerecenttopologies.TheseincludeSwitchedCapacitors,SwitchedInductors, Magnetic Coupling, Voltage Multiplier Cell, Voltage Lift, Cascaded, Multi-level and interleaved techniques [5].

By using the VMC [6],[7] the duty cycle required to achievethe required voltagecan be reduced and this topology offersa reduction in the maximum switch voltage and zero current switching. In [8],[9]a VMC is proposed showing the inherent ZCS feature and high static gain of this topology. This circuit however is limited to a single input,[10] also shows the benefits of the topology but still only a single input. A multi-input converter [11], shown in Fig. 1, can accept n-inputs and a VMC can be added to each branch to offer highstaticgain,continuousinput/outputcurrentandlowvoltage/currentstressoncomponents.Thistopologycanaccepti nputsfromdifferentDCsourcesintoasingleconverter to give aregulated DCoutput.topology.

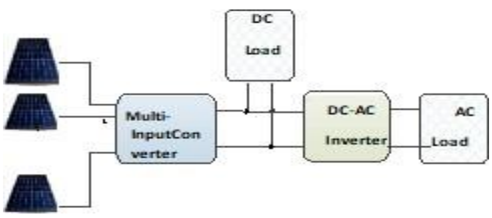

Fig.1. Application of multi-input dc-dc converter in renewable energy

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This paper will propose and model a two-phase interleaved boost converter with the inclusion of VMCs to show an improvement in the static gain. Component values will be calculated, and from these,calculated and simulated values for the efficiency of the converter will be presented. The paper is organized as follows. In section II, the proposed topology and switching strategy are presented. The calculated and simulation results are presented in section III, and finally section IV concludes the paper.

II. PROPOSED TOPOLOGY

The energy provided by solar, and wind is variable and dependent on the climatic conditions, this makes the energy that can be delivered to the load also variable. To achieve a constant voltage from these sources a boost converter can be used which will control the duty cycle of the switch to provide the required and constant output voltage. A typical boost converter is shown in Fig. 2.

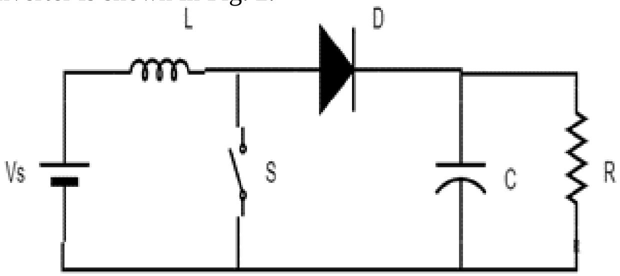

Fig. 2. Conventional Boost Converter

To achieve a topology with dual inputs one option is to combine two independent boost converters and feed them to a common DC bus, as in Fig. 3, then supply the load. This though increases the cost, complexity, and efficiency of the system. Another approach is to design a dual-input converter that can control the dc bus voltage in a single step, as in Fig. 4, to feed the load [11].

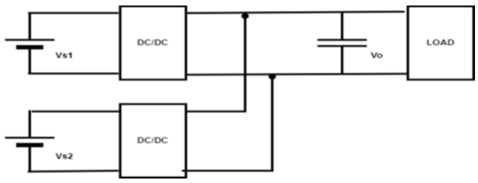

Fig.3. Common DC

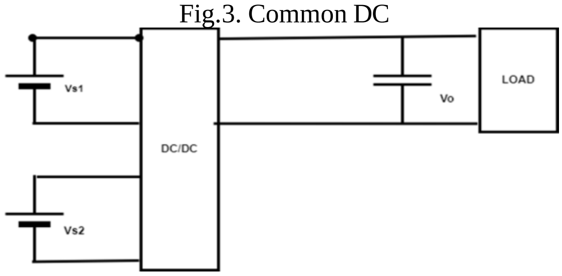

Fig.4. Dual Input Converter

To extend the capability of the dual input converter a topology that can accept n-sources is required. A dc-dc boost converter described in [11] has the ability of n-inputs, as shown in Fig.5

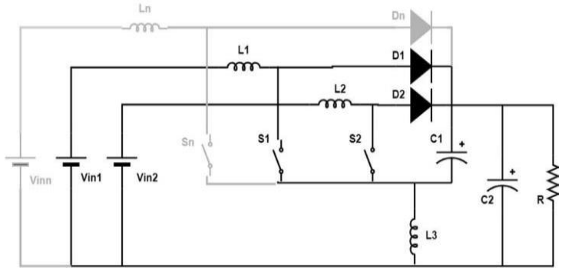

Fig. 5. n-input converter

This circuit is derived from a boost converter with the inputs being pulsating current sources. The output of this circuit is limited by the boost available for a typical boost converter (1), being

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$$q = \frac{Vo}{Vi} = \frac{1}{1-D} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

The capacitor C1 and the inductor L3 are to ensure the continuity of the output current regardless of the switching scheme.

A VMC added to a classic boost converter is shown in Fig. 6. This VMC, from [6], adds a resonant inductor L_r, diodes D_{M1} and D_{M2} plus capacitors C_{M1} and C_{M2}. The position of the VMC is between the switch and the existing output capacitor, C_o.

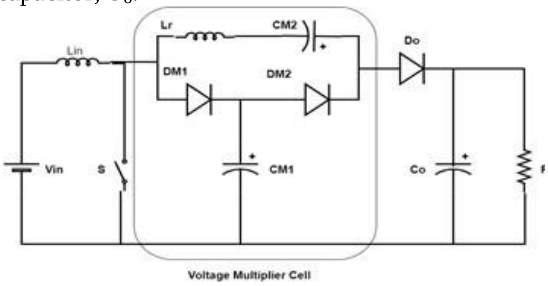


Fig. 6. VMC added to Boost Converter

When the switch is turned on the energy in C_{M1} is partially transferred to C_{M2} then the voltage in this capacitor is nearly equal to C_{M1}. When the switch is turned off C_{M1} charges to a voltage level equal to that of the classic boost converter. With this scheme, the VMC offers a gain of twice the classic boost converter, with switchvoltages equal for both the classic boost and VMC boost converters. To reduce switch conduction losses a MOSFET with low R_{DS0N} and drain to source voltage can be used.The resonant inductor, L_r, is introduced to achieve zero- current switching which also minimizes the negative effects of the reverse recovery currents of the diodes. This promotes the current transitions in all components that occur in a resonant way, with low *di/dt.* To maintain high efficiency this reduces the converter commutation losses which is further improved when operating at a higher frequency.

A boost converter with a VMC cell is presented in [2] with the gain being (2),

$$q = \frac{Vo}{Vi} = \frac{(M+1)}{(1-D)} \ldots\ldots\ldots\ldots\ldots (2)$$

M= no. of VMC cells,
D=Duty Cycle of Switch

This equation shows that the gain achieved by the VMC converter is twice that of the classic boost converter. This VMC cell can be inserted into a Two-phase interleaved boost converter based on Fig. 5, giving the topology in Fig. 7, which is the proposed topology for this paper. In the proposed topology even though there are 2 VMC cells they are in parallel, not series, so each of the two boost branches has a value of M=1

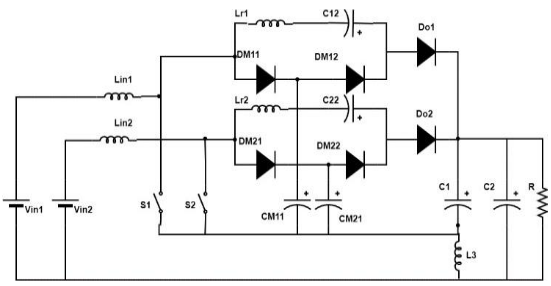
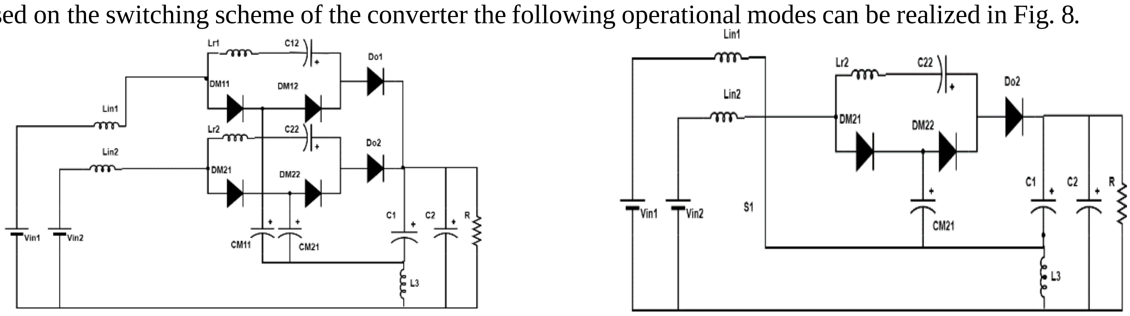


Fig. 7. Proposed Topology

Based on the switching scheme of the converter the following operational modes can be realized in Fig. 8.



(a) (b)

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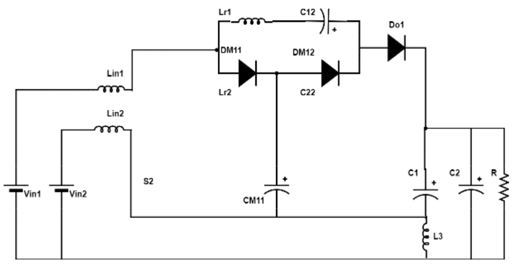
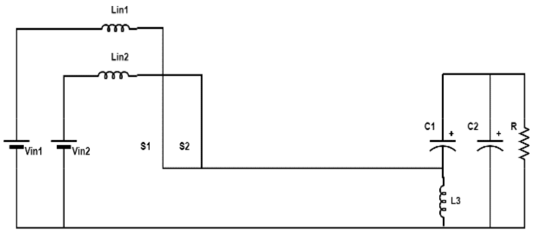


(c)



(d)

Fig. 8. operating modes based on the switching schemes (a) S1 on, S2 off (b) S1 and S2 off (c) S2 on, S1 off (d) S1 on, S2 on

Theswitching scheme used for the two switches was to have them both on at the same time. This results in only half of the current flowing through each half of the circuit thereby reducing the I²R losses in the components.

III. RESULTS

The output from the circuit is required to be from 23 volts up to 120 volts, with a nominal voltage of 60 volts and 36 Watts. The switching frequency is 32kHz and the two input voltagesV_1 = 12 volts and V_2 = 12 voltsfrom [3] component values for the simulation can be calculated as seen in Table I. These values are also used for the calculated gain.

Table I: Component Values

Vin	12v
Vout	23-120v
Pout	5-144W
NominalVoltage	60v
NominalPower	36W
f	32kHz
Rout	100ohm
C1,C2	220uF
DutyD1,DutyD2	10-80%
C12, C22	50uF
Lin1, Lin2	250uH
Lr1,Lr2	2uH
Cm11,Cm21	2uF

Fig. 9 shows the switching scheme at 40% duty cycle and the waveforms for the converter.

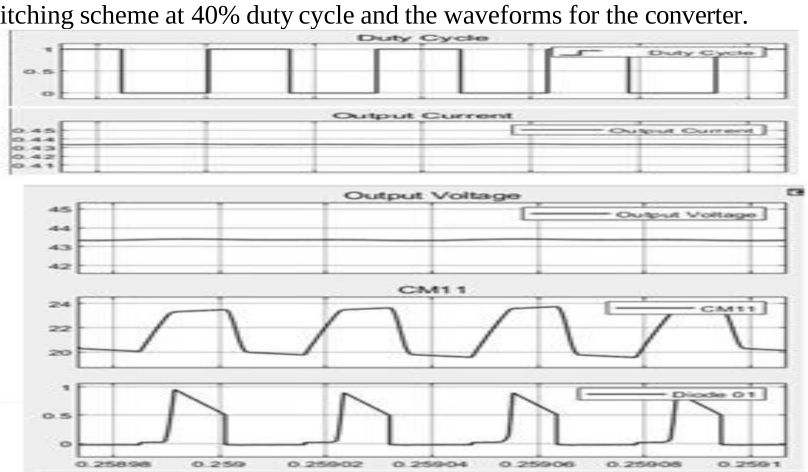


Fig. 9. Switching Scheme: Duty Cycle (40%), Output Current, Output Voltage, Capacitor Voltage CM11 and Diode Current Do1

The gain of the proposed converter compared to a typical boost converter is shown in Fig. 10, this clearly shows that for the same duty cycle the proposed topology has more static gain.

Table II: Gain comparisonof Conventional and Proposed Topology for the range of duty cycles

DutyCycle	Conventional Topology	Proposed Topology
10	0.25	0.5
20	0.5	1
40	1.5	3
60	2.5	5
80	5	10

Fig. 10. Duty Cycle vs Gain for Conventional and Proposed Topology

IV. CONCLUSION

This paper has presented a novel high step-up dc-dc converter, which can step-up a low input voltage to a high level without an extremely large duty cycle. Thus, the proposed converter is suitable for photovoltaic system applications or other renewable energy applications that need high step-up voltage conversion ratio. The proposed converter topology is based on the incorporation of the voltage multiplier module and the conventional boost converter in order to achieve a high voltage gain.

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