Design of High Efficient Boost Converter for PV Applications

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Abstract-- **The rise of renewable energy systems (RES)-based electrification has raised the demand for compact DC converters. However, the converter that has been developed so far has the disadvantages of lesser efficiency. As a result, integration of Voltage Multipliers [VM] with boost converters are introduced. This results in high gain, reduced switching voltage, zero current at turn-on minimized reverse recovery current. This VM cells also functions as a regenerative clamper, which helps to reduce layout issues and Electro Magnetic Interference [EMI]. Hence, this work formulated a novel modified boost converter with VM cells. The operation's principle, the design process and the prototype's model are discussed in this work.The observations from both the experimental and simulation setups depicts that this proposed converter can be a viable solution for a PV system.**

Index Terms—**Boost converter, Voltage multiplier, PV system.**

I. INTRODUCTION

The vast development in industrial field technology has created a great demand in power generation. Presently all these demands are meet out by fossil fuels. Due to usage of these fossil fuels in larger amount, problems like pollution, depletion of fuels have been emerged. Hence, to sustain this problem, most of the countries in the world are grazing towards RES. Among those, solar energy plays a vital role due to its everlasting property. Hence, this is also widely Electric vrhicle, in medium sized grid etc. But the power obtained from PV is not constant due to variation in climate conditions or may be of partial shading problem. Simultaneously, the lower conversion efficiency also makes it more expensive. [1-2].

In order to override these drawbacks, many traditional converters are utilized. High steps up (DC) converters were implemented to convert the low voltage level to high in accordance to applications. However due to high inrush current, the efficiency of this converter gets reduced. To reduce the effect of inrush current, the switching frequency of the system is increased. This will reduce the stress (voltage) upon the switches. Therefore, soft-switching is required to minimize the loss due to switching and hence enhances the performance of the converter[3-4].

Apart from this, while implementing this in high gain applications, it suffers an input ripple current / stress (voltage or current) on the switching devices and undergoes higher switching loss while the duty cycle is widened. It also leads to Diode Reverse Recovery (DRR) loss. As a result, there will be decrease in efficiency of the converter. In order to overcome this, the converters with coupled inductance are proposed. However, while turning off switches, due to the presence of leakage inductance, voltage spike is created. This in turn lowers the efficiency and causes high EMI. This can be overcome by active/passive clamped methods [5-6]. But it leads to high cost. Hence to override the above problems design of non-isolated cascaded boost converters were proposed.

However, it may leads to many disadvantages such as less reliability, more complexity and high cost. Besides that, DRR problem is still a serious problem at high gain applications. Hence, Isolated Boost Converters (IBC) can be utilized to obtain high voltage gain with a help of transformer. But the leakage inductance will play a vital role and create problems such as voltage stress on switching devices, EMI problems etc., At the same time, the loss occurring in transformers will lead to high cost, low efficiency and more complexity in control strategy. The topology of boost convert with fly back converters can also be designed to achieve high transform ratio[7]. This design is feasibly simple when compared to other existing converters. But, maintaining voltage balance among the capacitor is tedious [8-9].

Interleaved boost converters (ILBC) can also be designed for PV applications; this will have higher power density with lesser thermal distribution. Hence ripple is reduced. But when it is connected with grid, the voltage stress will again appear across the switches and hence, efficiency gets automatically reduced [10-16].Though the power handling capability and efficiency is improved, presence of two switches and coupled inductors make the circuit slightly bulky and complex [17-22].Hence, this work proposed a single stage VM added with the modified conventional boost converter. In this work, the losses in the main switch and diodes are minimized by incorporating soft switching technique.

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II. MODIFIED BOOST CONVERTER

Figure. 1 depicts the schematic circuit of the proposed converter. The suggested converter combines a modified boost converter with a single VMC. Without the use of magnetic elements, this structure produces an output voltage, higher than the input voltage. Increasing the number of VM cells can provide further voltage boost-up.

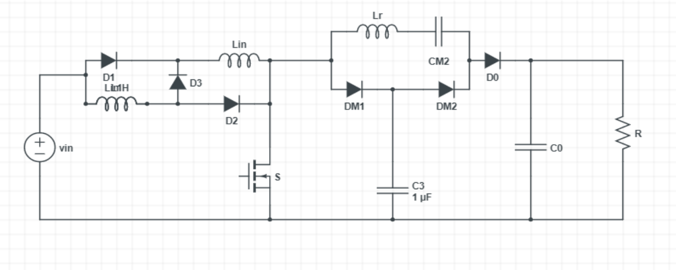

Fig. 1. Proposed converter circuit

A. Circuit Description

The basic structure of the single-phase VMcell is formulated by the diodes $(D_{M1} - D_{M2})$, the capacitors$(C_{M1} - C_{M2})$ and the resonant inductor L_r. This voltage multiplier cell can be integrated with the modified boost converter as presented in Fig. 1. The VM cell can work without the resonant inductor Lr. However, by including this tiny inductance (usually 1 to 4 H), the power switch can function with zero-current-switching (ZCS) turn-on and hence minimizes the impacts of the reverse recovery current. This can reduce commutation losses in the converter and high switching frequency operation can be obtained with high efficiency.

It is possible to add more multiplier cells in order to achieve higher step-up ratios. The reduction of the reverse recovery current of all diodes is obtained with only one resonant inductor in the first voltage multiplier cell.

The VM cell can boosts the traditional boost' converter gain by a factor of (M+1), where M -Number of multiplier cells.

Similarly, the maximum switch voltage is lower than the output voltage. Because of this property, low drain-source voltage and low rating MOSFETs can be used and hence, conduction losses across the switches can be reduced. The output voltage of the proposed converter is equal to the output voltage of the traditional boost converter multiplied by the factor (M+1).Similarly, the maximum switch voltage is lower than the output voltage and is independent of M.

B. Operation Analysis of the Single-Phase Converter

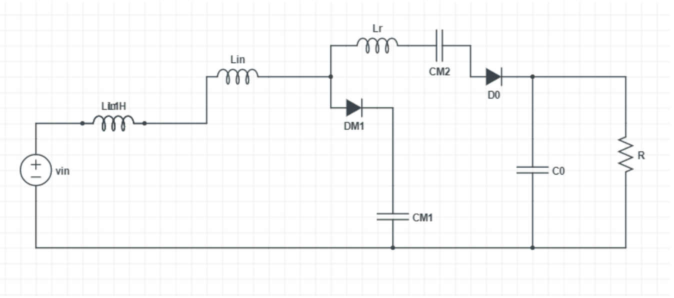

Fig. 2. First Stage (t_0, t_1)

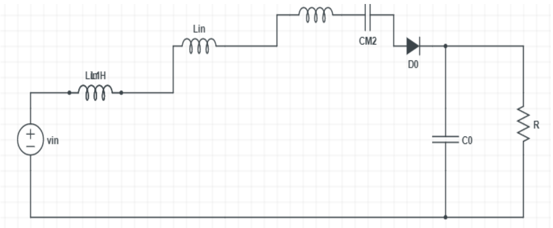

Fig. 3. Second Stage (t_1, t_2)

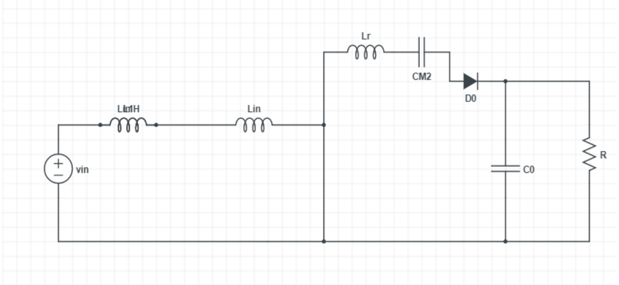

Fig. 4. Third Stage (t_3, t_4)

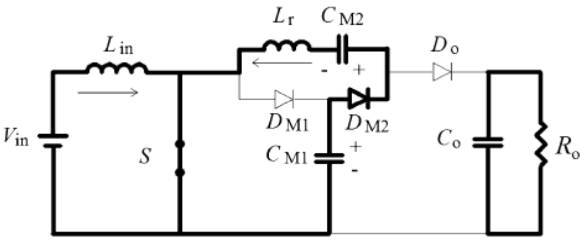

Fig. 5. Fourth Stage (t_4, t_5)

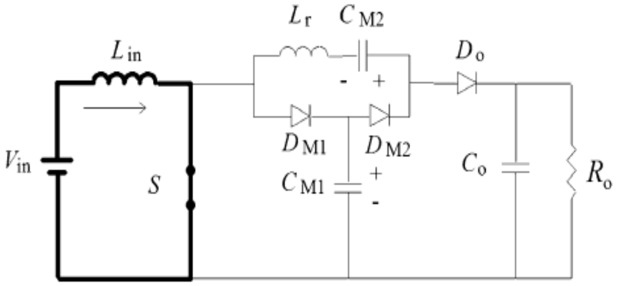

Fig. 6. Fifth Stage (t_5, t_6)

First Stage (t_o, t_1):

Switch S is turned off at time t_0, and the energy stored in the input inductor L in is transmitted to the output capacitor (C_0) via diode (D_0), as well as to the capacitor $CM_1$and DM_1. The resonant inductor current rises linearly until it reaches the magnitude of the input inductor current (i_{Lin}), and the current in the diode decreases proportionally.

The current in a resonant inductor is defined by (1).

$$i_{Lr}(t) = \frac{(V_{CM1}(t_5)+V_{CM2}(t_5)-V_0)}{L_r} . t \qquad (1)$$

As the capacitor CM_1 voltage increases and the capacitor CM_2 voltage declines almost at the same rate, the current variation can be regarded linear. This keeps the voltage delivered to the resonant inductor constant.

Equations (2) and (3) define the capacitor voltages

$$V_{CM1}(t) = V_{CM1}(t_5) + \left(\frac{i_{Lin}(t_o).t - \frac{(V_{CM1}(t_5)+V_{CM2}(t_5)-V_0).t^2}{L_r.2}}{C_{M1}} \right) \quad (2)$$

$$V_{CM2}(t) = V_{CM2}(t_5) - \left(\frac{\frac{(V_{CM1}(t_5)+V_{CM2}(t_5)-V_0).t^2}{L_r.2}}{C_{M2}} \right) \quad (3)$$

Second Stage (t_1, t_2):

The current in the diode is zero at time (t_1). During this step, the i_{Lr} is equal to the i_{Lin}, and the energy of the input inductor is transferred to the load via the diode D_0.

$$i_{Lr}(t) = i_{Lin}(t) \quad (4)$$

$$V_{CM1}(t) = V_{CM1}(t_1) \quad (5)$$

$$V_{CM2}(t) = V_{CM2}(t_1) - \left(\frac{i_{Lin}(t).t}{C_{M2}} \right) \quad (6)$$

Third Stage (t_2, t_3):

At the instant (t_2), the switch S is turned-on with ZCS commutation and the current in the resonant inductor L_r and in the output diode D_o reduce linearly to zero as defined by (7), at the instant (t_3). Thus the output diode also is blocked with low reverse recovery current. The Capacitor C_{M2} voltage can be considered constant due to the short duration of the third stage.

$$i_{Lr}(t) = i_{Lin} - \frac{V_o}{2.L_r}.t \quad (7)$$

$$V_{CM1}(t) = V_{CM1}(t_1) \quad (8)$$

$$V_{CM2}(t) = V_{CM2}(t_2) \quad (9)$$

$$i_{Lr}(t) = \frac{(V_{CM1}(t_3) - V_{CM2}(t_3)).\sin(\omega_0.t)}{\sqrt{L_r/C_{eq}}} \quad (10)$$

$$C_{eq} = \frac{C_{M1}.C_{M2}}{C_{M1} + C_{M2}} \quad (11)$$

$$\omega_o = \frac{1}{\sqrt{L_r.C_{eq}}} \quad (12)$$

$$V_{CM1}(t) = V_{CM1}(t_3) - (V_{CM1}(t_3)) - V_{CM2}(t).\cos(\omega_o.t) \quad (13)$$

$$V_{CM2}(t) = V_{CM2}(t_3) + (V_{CM1}(t_3)) - V_{CM2}(t).\cos(\omega_o.t) \quad (14)$$

Fourth Stage (t_4, t_5):

The current in the Lr becomes zero at time t_4 and the diode is blocked. The input inductor stores energy like a conventional boost until the switch S is turned off.

$$i_{Lr}(t) = 0 \quad (15)$$

$$V_{CM1}(t) = V_{CM1}(t_4) \quad (16)$$

$$V_{CM2}(t) = V_{CM2}(t_4) \quad (17)$$

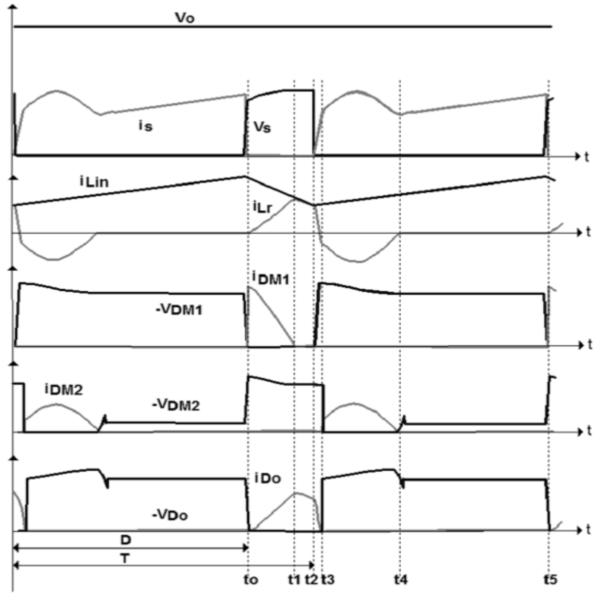

Fig. 7. Theoretical waveforms of the converter

As can be observed in Fig. 7, the switch turn on is ZCS. The resonant inductor L_r limits the current variation (di/dt) in all diodes, reducing the diodes reverse recovery current. The voltage in all semiconductors is half of the output voltage, considering a low voltage ripple in the multiplier capacitors.

C. Design considerations

Gain:

At the fourth stage, the voltage across CM_2 will be equal to the output voltage. Due to the stored energy in the input inductance, the capacitor is charged to twice the boost converter output voltage. As a result, the output voltage for a single stage is given by

$$V_{CM2} = V_{CM1} = Vin.\frac{(1+D)}{(1-D)}$$

$$V_0 = V_{CM2} + Vin.\frac{(1+D)}{(1-D)}$$

Therefore for M stages, the output voltage will be multiplied by M + 1. Thus the static gain is given by

$$Gain = \frac{V_0}{V_{in}} = (M+1)\,\frac{(1+D)}{(1-D)} \quad (18)$$

III. SIMULATION RESULTS

To examine the efficiency of the proposed converter, it is simulated in MATLAB. Thus, its efficiency is confirmed in both open and closed loop operation. Thus, the design limits of the components incorporated during simulation is tabulated in table 1.

Table 1. Design parameters and their values

Parameter	Values
V_1	24V
V_o	240V
C_{M1}, C_{M2}	3,300µF
fs	40 kHz
D	0.63
Lr	2mH

Thus, the converter is tested under open loop mode and the output obtained is depicted in fig.9.

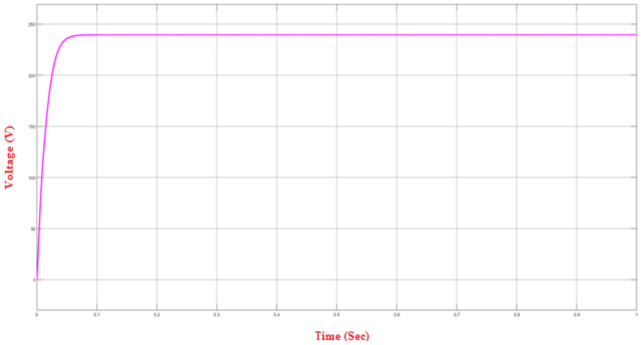

Fig 8.Output Voltage of the converter under open loop control

Table 2.Comparison of performance with classic converter topologies

Topology	Traditional converter	Proposed converter
Voltage gain	$\frac{1}{1-D}$	$(M+1)\frac{(1+D)}{(1-D)}$
No. of Switches	1	1
No.of. Diodes	1	3
Switching condition	Hard switching	ZVS

From the above table, the use of VMC in this converter boosts the voltage gain of the converter by more than ten times that of a traditional boost converter, according to the results. As a result, this converter can be used in PV applications. As a result, when compared to a Boost converter, the voltage across the Switch of the proposed converter is quite low. As a result, the suggested converter has less conduction loss.

Table 3. Comparisons with other relevant converters

Converters	Voltage Gain
Boost Converter	$\frac{1}{1-D}$
Chen et al. (2015)	$\frac{n+2-D}{1-D}$
Hu and Gong (2014)	$\frac{n+2}{(1-D)^2}$
Proposed Converter	$M+1)\frac{(1+D)}{(1-D)}$

Table 3 shows the results of comparisons with various converters that use a coupled inductor architecture. The proposed converter has a higher voltage gain than the others, according to the results.

IV. CONCLUSION

In this work, soft switched voltage multiplier cell based modified boost converter was proposed. The proposed converter used one multiplier stage to obtain the required voltage gain. The existing converter used hard switching as a result of which the efficiency was reduced. Experimental results obtained from the proposed converter prove that the proposed solution is more efficient and provides good load regulation. As the size of magnetic component is less, high power density can be achieved. Further, higher voltage gain can be easily obtained by adding required number of voltage multiplier cells. Thus, the proposed converter proves to be a good candidate topology for obtaining high gain compact converters with modular structure.

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