SI-VM based High Gain Non-Isolated DC-DC Converter for DC Microgrid

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***Abstract*—DC microgrids are popular due to the integration of renewable energy sources such as solar photovoltaics and fuel cells. Owing to the low output voltage, highly efficient high gain dc-dc converters are needed to connect the dc microgrid. In this paper, a high gain DC-DC converter with 36V/380V, 100W is proposed. The proposed topology employs Switched-Inductor (SI) and Voltage Multiplier Cell (VMC) for gain extension mechanism. The simulation results are carried out in MATLAB/Simulink and results are presented.**

Keywords: Voltage Gain, high gain DC-DC Converter, Switched Inductor, Voltage Multiplier Cell

Nomenclature

V_{in} = input supply to the proposed converter
I_{in} = input current flow to the proposed converter
I_{L1} = current flowing through inductor L_1 of switched inductor cell
I_{L2} = current flowing through inductor L_2 of switched inductor cell
V_{d1} = voltage across diode D_1 of switched inductor cell
V_{d2} = voltage across diode D_2 of switched inductor cell
V_{d3} = voltage across diode D_3 of switched inductor cell
V_g = gate pulse applied to switch
V_{S1} = voltage stress across the switch
I_{S1} = current flowing through the switch
V_{d4} = voltage across diode D_4 of voltage multiplier cell
V_{d5} = voltage across diode D_5 of voltage multiplier cell
V_0 = output voltage of proposed converter
I_0 = current flowing through the load

I. INTRODUCTION

The combinations of basic step-up converter with gain extension techniques to obtain required voltage gain are introduced in [1] with low component count and medium duty ratio, to reduce switching stress and diode stresses. Voltage Multiplier Cells are incorporated in basic boost topology to extend gain value in [2]. An isolated current-fed AC to DC power converter is suggested in [3] for electric vehicle applications. This converter has high voltage gain with fewer components and constant input current. Paper [4] proposes hybrid switched inductor converter (non-isolated type) with huge voltage conversion ratio for PV applications. The converter proposed in [5] is designed for 24V input and 72W rating and operates in BCS and BDS.

A Multistage Switched Capacitor Quadratic Boost (MSC-QBC) DC-DC converter with dual outputs is discussed in [6]. The boosting operation with dual output is achieved by a conventional Boost Converter and Quadratic Boost Converter utilizing a single switch. A high gain DCM based DC-DC converter with low device stress and input current ripple is proposed in [7]. DC-DC converters with two boost stages at the input has been proposed in [8]. The gain of diode–capacitor Voltage Multiplier converter is increased by increasing the number of VM stages. Low input high output voltage converter topologies are designed in [9] [10] for renewable energy-based applications with high efficiency.

Coupled-inductor-based non-isolated DC converter with ultra-high voltage-conversion ratio is demonstrated in [11] with low voltage stress across diodes and capacitors. A converter with voltage lift stage, clamp mode stage and second boost stage is designed in [12] with voltage gain of 11.5. Converters in [13] [14] achieve high gain by incorporating voltage-lift technique in boost converter. Switched Inductor-Switched Capacitor based high gain converter with minimum stress on semiconductor devices is proposed in [15]. The converter has high voltage gain and stages can be extended to give higher voltage gain.

In this paper, a high gain DC-DC converter is proposed by incorporating switched inductor and voltage multiplier cells. Section I gives introduction and section II gives types of converters. Section III discusses types of non-isolated converters. Proposed converter power circuit, modes of operation and design equations are discussed in section IV. Simulation results and conclusion are discussed in V and VI respectively.

II. TYPES OF CONVERTERS

There are three types of power conversion devices in use today: the AC/DC power supply, the DC/DC converter, and the DC/AC inverter. Of the three, AC/DC power supplies and DC/DC converters are the most commonly used. The converters are classified into isolated and non-isolated type converters. Non isolated converters are again classified as Single input single output converters, Single input multi output converters.

III. TYPES OF NON-ISOLATED CONVERTERS

The Non-Isolated converters are classified as:

i). Coupled inductor-based converter.

ii). Coupled inductor and switched capacitor-based converter.

iii). Coupled inductor and voltage multiplier-based converter.

iv). Diode capacitor multiplier-based converter.

v). Quadratic Boost converter.

vi). Switched capacitor-based converter.

vii). Switched capacitor and voltage multiplier-based converter.

viii). Switched inductor-based converter.

ix). Switched inductor and switched capacitor-based converter.

x). voltage lift based converter.

In the proposed circuit, combination of switched inductor and voltage multiplier are taken to obtain required gain value.

IV. PROPOSED CONVERTER

A. *Power Circuit Description*

Figure 1 shows the power circuit of the proposed converter. The proposed circuit is operated from solar source to meet the load requirements. The basic converter structure is obtained by incorporating voltage multiplier cell in conventional switched inductor-based boost converter. V_{in} is power input to the proposed converter, switched inductor cell consists of three diodes and tw3o inductors, they are named as D_1, D_2, D_3 and L_1, L_2 respectively. Voltage multiplier cell consists of two diodes D_4, D_5 and two capacitors C_1, C_2. "S" is the switch employed in the circuit, "D_0" is the output diode and "C_0" is output capacitor. The operating principle is described in the next section.

B. *Modes of operation*

The operating principle of proposed converter is explained using two modes in one switching cycle. The following assumptions are made in analysis in the circuit:

1. Converter operations in continuous conduction mode.
2. Switch and all the diodes are ideal and loss less.

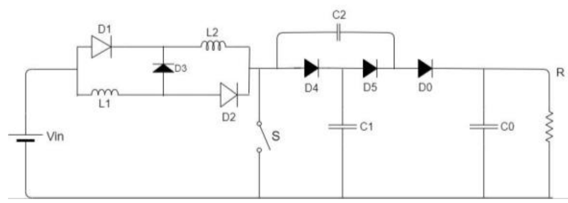

Fig 1: Power circuit of proposed converter

MODE 1: (t_0-t_1)

In mode1 switch 'S' is turned ON at time $t=t_0$, when the switch is ON current flowing through the inductors L_1 & L_2 increase linearly. Therefore, Energy is stored in the inductors and stored energy equal to input supply voltage (V_{in}). Capacitor "C_1" starts discharging into capacitor "C_2" through diode "D_5". The output capacitor "C_0" discharges into load, Figure 2.a shows the circuit operation during mode 1.

$$V_{Lon} = V_{L2} = V_{in} \rightarrow 1$$

$$L \frac{\Delta iL}{T_{on}} = V_S \rightarrow 2$$

MODE 2: (t_1-t_2)

Mode"2" starts at time $t=t_1$, when switch "S" is turned OFF. The previous stored energy in the inductors starts discharging through diode "D_3" and "D_4" into capacitor "C_1". The capacitor "C_2" present in the VMC cell starts discharging into capacitor "C_0" through diode "D_1" and also discharges into load. Figure 2.b shows the circuit operation during mode 2.

$$V_{Loff} = \frac{V_{in}-V_O}{2} \rightarrow 3$$

$$-L \frac{\Delta i_L}{T_{off}} = \frac{V_{in}-V_O}{2} \rightarrow 4$$

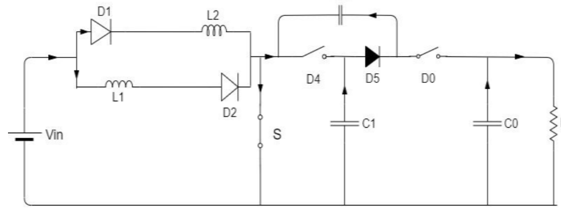

Fig 2a: Mode 1 of proposed converter

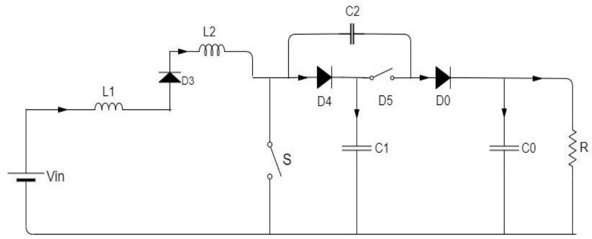

Fig 2b: Mode 2 of proposed converter

C. Design Equations

The voltage gain of switched inductor cell is given by

$$\frac{V_O}{V_{in}} = \frac{1+D}{1-D} \rightarrow (5)$$

The voltage gain of voltage multiplier cell is given by

$$\frac{V_O}{V_{in}} = \frac{1}{1-D} \rightarrow (6)$$

Using volt second balance of inductor, the voltage gain of the circuit is given by

$$\frac{V_O}{V_{in}} = \frac{2+D}{1-D} \rightarrow (7)$$

D. Design equations of inductor and capacitor

The design equation of inductor is given by

$$L = \frac{V_{in}\,D}{f\Delta i_L} \rightarrow (8)$$

The design equation of capacitor is given by

$$C_O = \frac{I_O\,D}{f\Delta V_O} \rightarrow (9)$$

V. SIMULATION RESULTS

A. Switching pulse of proposed converter

In fig 3, an input of 36V is applied, the voltage across the load is 380V and output current is 263mA. Thus, output is obtained when the switch is operated at 70% duty ratio.

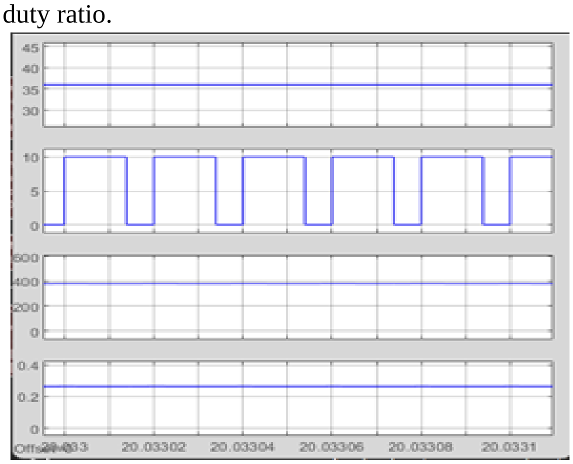

Fig 3: Graph showing input voltage, gate pulse, output voltage and output current from top to bottom (V_{in} V_g V_0 I_0)

B. Input and output currents of the designed converter

When input 36V is applied and input current of 2.77A is flowing through the circuit. The current flowing through the inductors L_1 and L_2 is equal to half of the Input current. The charging and discharging of the inductors is shown in figure 4. When the switch is turned ON the inductor charges and discharges when the switch is turned OFF.

C. Voltage stress across diodes present in switched inductor cell of proposed circuit

When the switch is turned ON, Diodes D_1 and D_2 in the switched inductor cell are forward biased. The Diode D_5 in the voltage multiplier cell is also Forward biased. Diodes D_3, D_4, D_0 are reverse biased, when diodes D_1, D_2, D_5 are ON the diodes D_3, D_4 and D_0 are in OFF condition. The voltage across the diodes D_1, D_2 is given the equation. The voltage across the diodes D_1 and D_2 is 80V. The corresponding results are shown in fig 5.

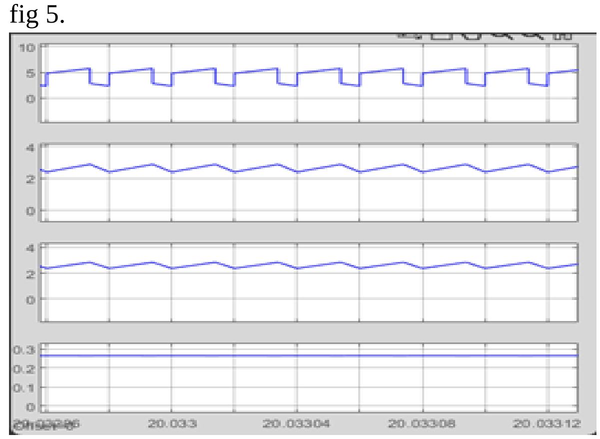

Fig 4: Graph showing input current, current through inductors and output current from top to bottom (I_{in} $I_{L1}I_{L2}I_0$)

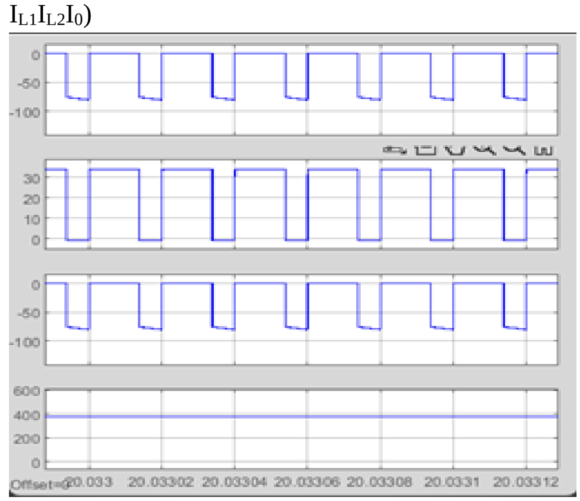

Fig 5: Graph showing voltage across the diodes in switched inductor cell. (showing $V_{d1}V_{d3}V_{d2}V_0$ from top to bottom)

D. *Voltage stress across diodes of VMC*

The diodes in the voltage multiplier cell behave in complimentary manner. Therefore, when Diode D_4 is ON, D_5 will be OFF and Vice-versa. This complementary nature is captured and shown in figure 6.

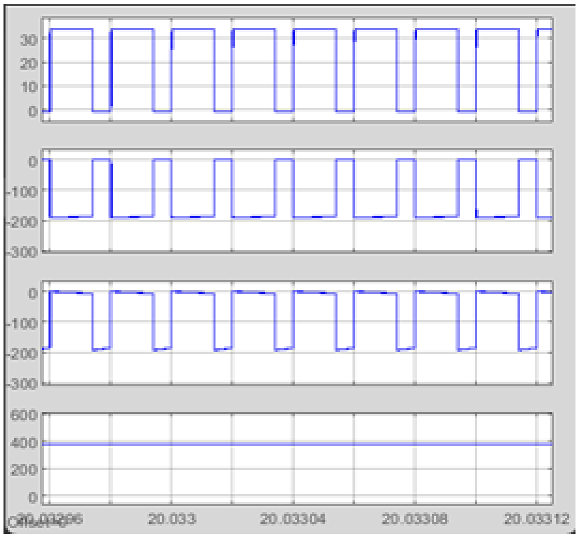

Fig 6: Graph showing voltage across the diodes in voltage multiplier cell. (Showing $V_{d3}V_{d4}V_{d5}V_0$ from top to bottom)

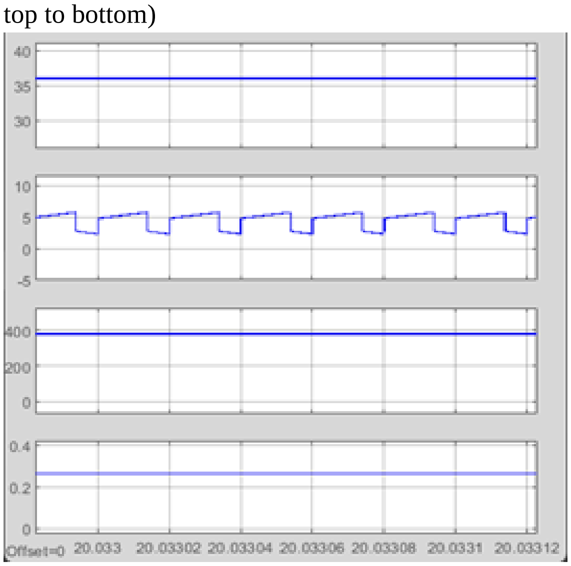

Fig 7: Graph showing voltage gain of proposed converter. (Showing $V_{in}I_{in}V_0I_0$ from top to bottom)

E. *Voltage gain measurement*

For 36V input, I_{in} = 2.77A and the output voltage is 380V with an output current of 263mA. The gain of the proposed converter is 10.55 as shown in fig 7. For duty ratio, D = 0.74 and the voltage gain of switched inductor circuit is (1+D)/(1-D) and voltage gain of VMC is 1/(1-D). The higher output voltage is obtained by employing these gain cells.

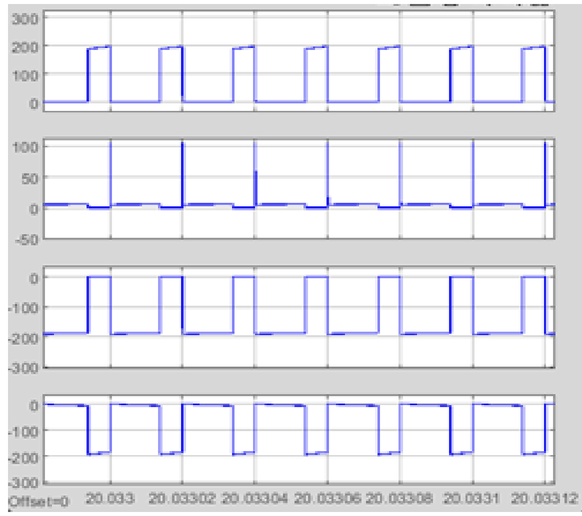

Fig 8: Graph showing voltage and current through switch of proposed converter. (Showing $V_{S1}I_{S1}V_{d4}V_{d5}$ from top to bottom)

F. *Voltage and current Stress of switch*

The voltage across the switch and current through the switch are captured in figure 8. The voltage stress across the switch is 200V and current through the switch is 3A, the voltage across the diodes D_4 and D_5 is 180V. When the switch is ON, D_5 will conduct and switch is in OFF, D_5 will conduct. So, the complementary nature of switch and Diode D_4 is observed.

VI. CONCLUSION

A high gain Switched Inductor - Voltage Multiplier based DC – DC converter is proposed. The proposed converter has a gain of 10.55. The main advantage of the circuit is: it employs single switch and the voltage stress across the switch is 45% of output voltage. Therefore, the switch stress is low. The simulation results of 36V/380V, 100W converter proves to be a viable solution for DC Microgrid applications.

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