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Modified Interleaved High Gain DC/DC Converter

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Abstract:- In recent years, DC distribution systems are gaining more attention because of their high efficiency, reliability com- pared to AC distribution systems. Integration of lower voltage range renewable energy sources into 400 V dc bus is one of the major challenges to be faced by the power electronic converters. Typical voltage ranges of a solar panel is around20-30V . Conversion of these voltages to higher voltage range by normal boost converters with high duty ratios results in high voltage stresses and lesser efficiency. Since, the output DC voltage from the photovoltaic panel is very low, so a non- isolated interleaved high-gain DC/DC converter with a voltage multiplier cell (VMC) structure is presented. In order to achieve higher voltage gain and to reduce the voltage stress of the switching devices, the proposed high gain converter uses a two phase interleaved technology combined with a boost unit with a common ground, which has smaller input current ripple and gainfeatures of high coefficient. This high gain converter provides high voltage gain at low duty cycles and reduces the voltagestresses on the switches effectively when compared to the other boost converters. Results are obtained by simulating the converter in MATLAB/ SIMULINK R2020b. The simulation results shows that the proposed interleaved high gain converter improved the gain, reduced the stresses in switching devices and achieves a maximum operating efficiency of 85.

Keywords:- *Boost Converter, Interleaved, Gain, Efficiency.*

I. INTRODUCTION

The development and utilization of renewable energy such as solar photovoltaic energy and wind energy has attracted more and more attention recently. However, the output DC voltage from the photovoltaic panel is low, generally not exceeding 50 V, which cannot meet the requirements of the DC load or the voltage level required on the input sideof the grid-connected inverter. According to the different inverter structures, the DC side input voltage usually needsto be above 380 V. The traditional boost converter has been unable to meet this demand, therefore the need of new typeof converter arises which provides high gain and less voltage stress.

High-gain converters can be divided into two types: isolated and non-isolated according to whether they are isolated or not. The isolated converter achieves a higher voltage gain by increasing the transformer tFurns ratio. But due to their large input current ripple, low operating efficiency, high cost, they are used at applications where efficiency is not an important factor. There are many solutions for non-isolated converters, and the specific forms are mainly coupled inductors, converter cascades, switched inductors, switched capacitors, etc.

An interleaved high step-up DC/DC converter is derived by inserting a voltage multiplier cell into the conventional interleaved boost converter. The voltage multiplier cell is used to extend the voltage gain and to minimize the current ripple without extreme duty cycle. The interleaved converter proposed in [1] provides a higher gain but with no common ground. The step up converter in [2] employs coupled inductor as turns ratio of the same is varied to extend the voltage gain as well the switch voltage stress is reduced as the turns ratio of the coupled inductors increases. The voltage multiplier cell is composed of the secondary windings of the coupled inductors, the series capacitor and two diodes. However coupled inductor can greatly reduce the power density of the converter. The novel interleaved high-gain DC-DC boost converter with Greinacher voltage multiplier cells [3] consists of two stages: an interleaved boost stageto reduce the AC ripple on the input current and the voltage multiplier circuit to increase the voltage gain ratio. A novel interleaved high-step-up DC/DC converter with zero voltage switching (ZVS) with a built-in transformer voltage multiplier cell [4] achieves high voltage conversion ratio without the narrow duty. But the input current of isolated converters are pulsed and hence large input filter is required. An interleaved non isolated high step-up DC/DC converter based on the diode-capacitor multiplier [5] with two basic Boost cells and some diodecapacitor multiplier (DCM) cells enhances the the voltage conversion ratio and the extreme large duty ratio can be eliminated in the high step-up applications. The two boost cells are controlled by the interleaving technique where the phase difference between two PWM signals willbe 180 degree and the sum of two currents will be the input current which infact decreases the input current ripple and reduces the size of input filter. A Multiphase-Interleaved HighStep-up DC-DC Boost Converter [6] achieves high step-up voltage gain by using two coupled inductors and voltage multiplier cell.The voltage stresson the switching devices is lower than the output voltage. The converter provides a high voltage gain by mitigating the voltage stress on the diodesand also reverse recovery problem of the diodes are mitigated.

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A modified interleaved high gain dc/dc converter is proposed in this paper. This is a combination of a parallel interleaved high gain dc/dc converter with a new set of three stage voltage multiplier cells. In the proposed converter, there are two switches which adopts interleaved control, the drivingsignals are the same, but the phases are different by 180,and the duty ratios are equal and greater than 0.5. Thus this converter provides a high gain, less switching losses with a common ground.

II. METHODOLOGY

A novel interleaved parallel high gain dc/dc converter has the advantages of high efficiency and gain, low switching losses but there is no common ground available. So a new topology is introduced to avail a circuit with common ground and equal gain and efficiency with a new voltage multiplier structure. The circuit consists of two switches S_1 & S_2 with interleaved technique, inductors L_1 & L_2, capacitance C_1, C_2, C_3, C_4, C_5 & C_6, output capacitor C_0, diodes D_1, D_2, D_3,D_4, D_5 & D_6 and load resistor R_0. Fig. 1 shows the modified interleaved high gain dc/dc converter.

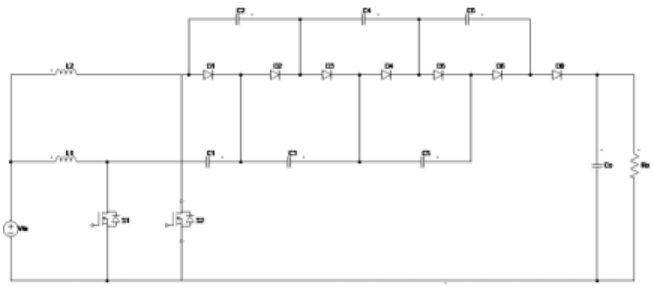

Fig. 1. Modified Interleaved high gain dc/dc converter

A. *Modes of Operation*

There are four modes of operation in one switching cycle. According to the different turn-on and turn-off conditions of the switches S_1 and S_2 ,the switching state of the converter can be divided into the following four modes within one switching period T_s. Fig. 2 shows the theoretical waveforms of the modified interleaved high gain dc/dc converter.

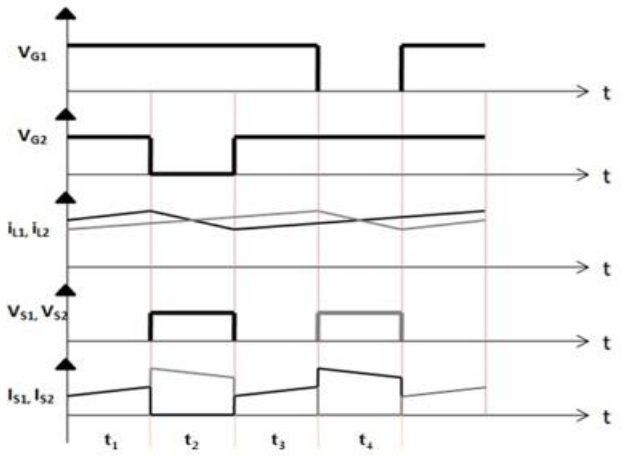

Fig. 2. Theoretical Waveforms of modified converter

1) *Mode 1:* At t = t_0, the switches S_1 and S_2 are all on and all diodes are off. The input power source charges the inductors L_1 and L_2 through switches S_1 and S_2 respectively.The voltage across the inductors L_1 and L_2 is the input voltage. The currents i_{L1} and i_{L2} flowing in L_1 and L_2 riseslinearly, and all the capacitor voltages in the converter remainsunchanged. Capacitor C_0 supplies power to the load. At timet_1, S_2 is turned off, S_1 continues to be turned on and the timefor switch mode 1 is over. Fig. 3 shows the operating circuitof mode 1.

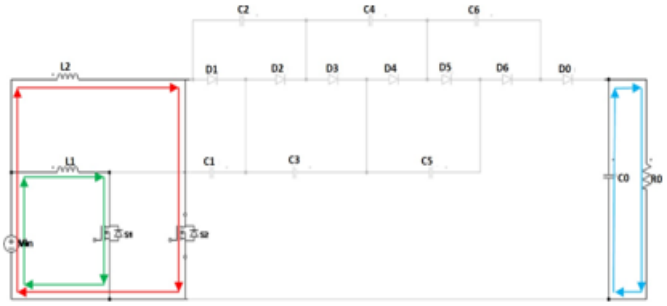

Fig. 3. Operating Circuit of Mode 1

2) *Mode 2:* At t = t_1, S_2 is turned off, S_1 continues to remain on, the inductor current i_{L1} continues to rise linearly, i_{L2} decreases linearly, and the current i_{L2} of inductor L_2 flowsthrough the diode D_1, D_3, D_5 , and the capacitors C_1, C_3 , C_5 and C_0 are charged. During this time, the inductance $L_2$and the capacitor C_2 , C_4 and C_6 are discharged. Therefore, the capacitor voltages V_{C1}, V_{C3} and V_{C5} rises, and V_{C2} , $V_{C4}$and V_{C6} decreases. Fig. 4 shows the operating circuit of mode 2.

3) *Mode 3:* This mode is same as that of mode 1 where the switches S_1 and S_2 are all on and all diodes are off. The input power source charges the inductors L_1 and L_2 through switches S_1 and S_2 respectively. The voltage across assumptions are taken for the design of modified interleaved high gain dc/dc converter. It consists of design of load resistance, inductors L_1 & L_2 and the capacitors .Some assumptions are taken for the design of interleaved parallel high gain dc/dc converter. The input voltage is taken as V_{in} = 20V. The output power and output voltage are taken as P_0 = 200W and V_0 = 400V. Switching frequency is taken as f_s = 100kHz. On solving (1) output current is obtained as 0.5A.

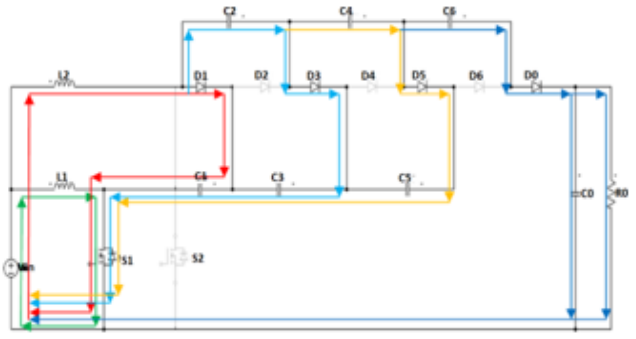

Fig. 4. Operating Circuit of Mode 2

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$$I_o = \frac{P_o}{V_o} \quad (1)$$

the inductors L_1 and L_2 is the input voltage. The currents i_{L1} and i_{L2} flowing in L_1 and L_2 rises linearly, and all Duty Ratio can be found by (2) which is taken as 0.65. Thevalue of load resistor is set as 800Ω in (3).

$$D = 1 - \frac{V_{in}}{V_o} \quad (2)$$

$$R_o = \frac{V_o^2}{P_o} \quad (3)$$

the capacitor voltages in the converter remains unchanged. Capacitor C_0 supplies power to the load. Fig. 5 shows the operating circuit of mode 3.

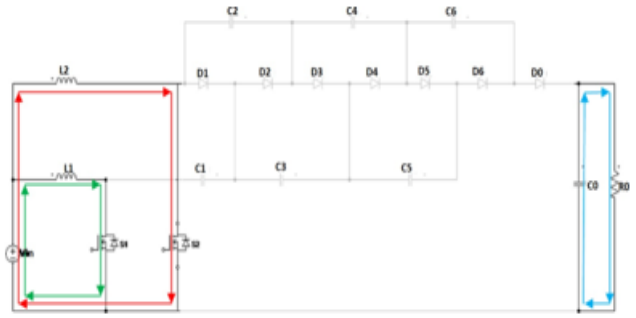

Fig. 5. Operating Circuit of Mode 3

The input current is determined by solving (4).Then the inductor currents I_{L1} & I_{L2} are obtained by solving (5)& (6).The current ripple are the taken as 30% of I_{L1} & I_{L2}. By substituting values to (7) & (8) the values of inductors L_1 &L_2 is approximated to 100 μH each.

$$I_{in} = \frac{7 * I_o}{1 - D} \quad (4)$$

$$I_{L1} = \frac{3 * I_{in}}{7} \quad (5)$$

$$I_{L2} = \frac{4 * I_{in}}{7} \quad (6)$$

$$I_1 >= \frac{D * V_{in}}{f_s * \Delta i_{L1}} \quad (7)$$

$$I_2 >= \frac{D * V_{in}}{f_s * \Delta i_{L2}} \quad (8)$$

Mode 4: At t = t_3, Switch S_1 is turned off and S_2 remains on, the inductor current i_{L2} rises linearly, i_{L1} fall down linearly, and the current of inductor L_1 flows through diode D_2, D_4, D_6 and the capacitors C_{22}, C_4 and C_6 are charged. During this process, the inductance L_1, capacitors C_1, C_3, and C_5 are in a discharged state, so the capacitor voltage in V_{C2}, V_{C4} and V_{C6} rises, and V_{C2}, V_{C4}, and V_{C6}falls down. At time t_4, the switch S_1 is turned on, the time of switch mode 3 is over, the current cycle ends, and the nextcycle is entered. Fig. 6 shows the operating circuit of mode 4. C_2 The design of the capacitor mainly considers the voltage stress across it. The voltage across capacitor C_1 is determined by the equation (9). The value of capacitor C_1 is obtained by substituting values to (10) which is approximated to 10μF.

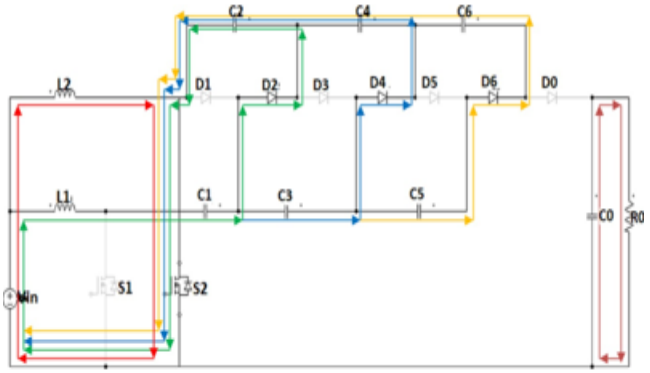

Fig. 6. Operating Circuit of Mode 4

$$V_{C1} = \frac{V_{in}}{1 - D} \quad (9)$$

$$C_1 = \frac{2 * P_{out}}{V_{C1}^2 * f_s} \quad (10)$$

The voltage across capacitors C_2, C_3, C_4, C_5 & C_6 is determined by solving the equation (11). By substituting the values to (12) the values of capacitors C_2, C_3, C_4, C_5 & $C_6$is approximated to 10μF

$$V_{C2} = \frac{2V_{in}}{1 - D} \quad (11)$$

$$C_2 = \frac{2 * P_{out}}{V_{C2}^2 * f_s} \quad (12)$$

B. Design of Components

In order to operate a converter properly, the components involved in the circuit should be designed appropriately. Some

III. SIMULATIONS AND RESULTS

The modified interleaved high gain DC/DC converter is sim- ulated in MATLAB/SIMULINK by choosing the parameters listed in Table 1. The switches are MOSFET with constant switching frequency of 100 kHz. A dc input voltage of 20V gives an output voltage of 400V for an output power, P_o of 200W. Figure 7 shows the input voltage and input current. Figure 8 shows the output voltage and output current.

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Table 1 Simulation Parameters Of Interleaved High Gain Converter

Parameters	Value
Input voltage V_{in}	20 V
Output voltage V_O	400 V
Output load R	800 Ω
Switching frequency f_s	100 kHz
Inductance L_1, L_2	100 µH
Capacitance $C_{1a} - C_{3b}$	10 µF
Capacitance C_o	22 µF

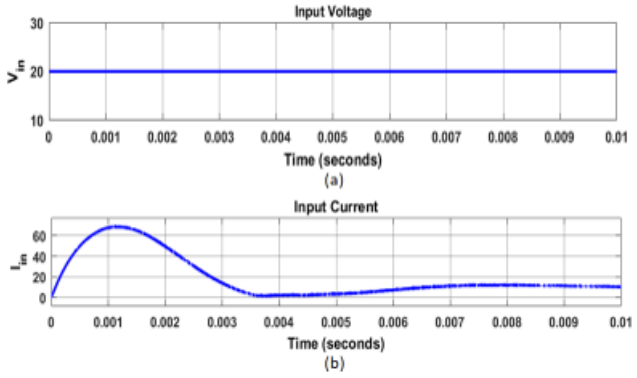

Fig. 7. (a) Input Voltage (V_{in}) and (b) Input Current (I_{in})

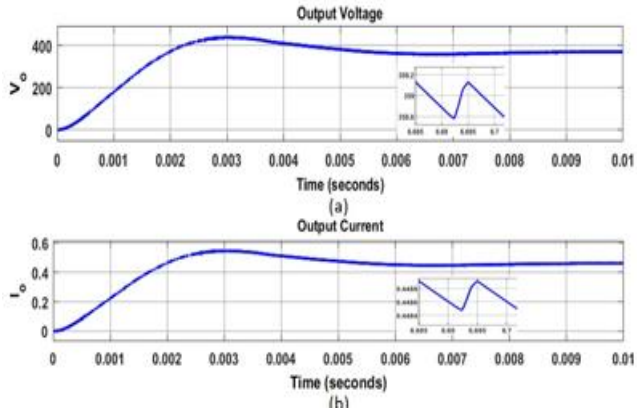

Fig. 8. (a) Output Voltage (V_0) and (b) Output Current (I_0)

The gate pulse and voltage stress across switch S_1 for switching frequency f_s = 100kHz is shown in figure 9. Also the gate pulse and voltage stress across switch S_2 is shown in the figure 10.

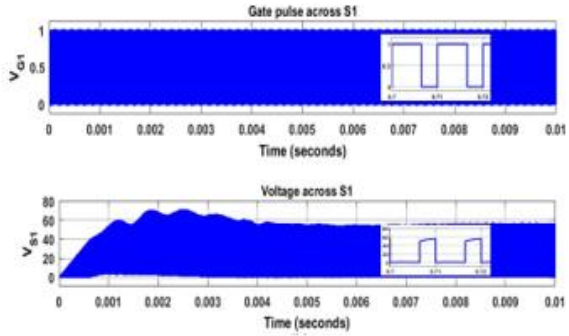

Fig. 9. Gate pulse of S_1 and Voltage stress of $S_1(V_{S1})$

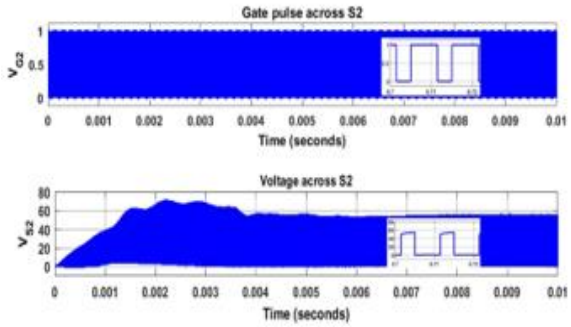

Fig. 10. Gate pulse of S_2 and Voltage stress of $S_2(V_{S2})$

Figure 11 shows the current through inductors L_1 and L_2.It can be seen that the current through inductor I_{L1} is 4.15Aand current through inductor I_{L2} is 5.77A.

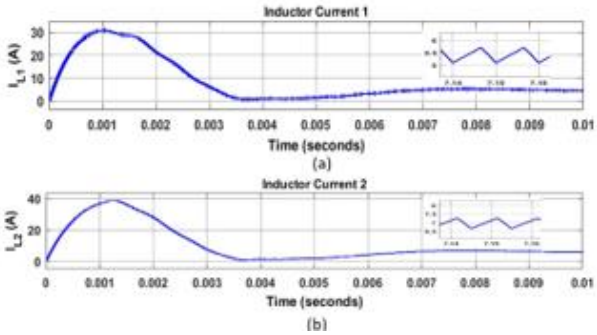

Fig. 11. (a) Current through inductance (I_{L1}) and (b)Current through inductance (I_{L2})

The voltage across capacitors C_1, C_2, C_3, C_4, C_5 and C_6 is shown in figure 12. The value obtained for V_{C1} = 57V and ΔV_{C1} = 2V. The value obtained for V_{C2} = 106V and $\Delta\ V_{C2a}$ = 2V. The value obtained for V_{C3} = 106V and $\Delta\ V_{C3a}$ = 1V. The value obtained for V_{C4} = 106V and $\Delta\ V_{C4}$ = 1V. The value obtained for V_{C5} = 106V and $\Delta\ V_{C5}$ = 0.5V. The value obtained for V_{C6} = 106V and $\Delta\ V_{C6}$ = 0.5V. Fig. 11 showsthe current across inductances L_1 and L_2. It can be seen that the current across filter inductances i_{L1} is 7.5A, i_{L2} is 4.7A.

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IV. PERFORMANCE ANALYSIS

Efficiency of a power equipment is defined at any load as the ratio of the power output to the power input. The efficiency

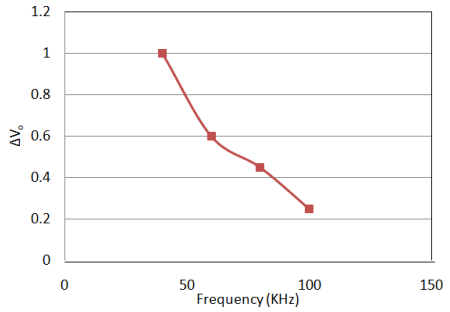

Fig. 12. Voltage across Capacitors

tells us the fraction of the input power delivered to the load. Here the efficiency Vs output power with R load and RL load are done for modified interleaved high gain converter . The graphs are shown in the figure 13. The maximum efficiency for R load is around 85.2% at power output of 190W and for RL load is around 88.2% at power output of 200W.

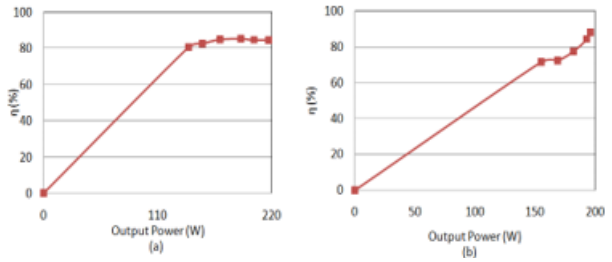

Fig. 13. Efficiency Vs Output Power for (a) R load, (b) RL load

The plot of Gain of the converter as a function of duty ratio shown in figure 14. It is observed that as the duty ratio varies ,the voltage gain for both basic converter and modified converter increments in an equal rate.

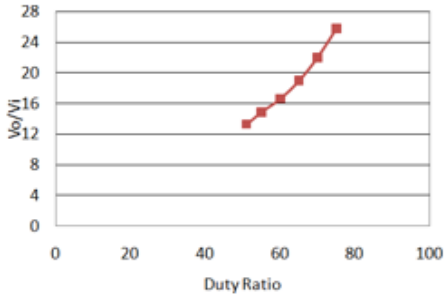

Fig. 14. Gain Vs Duty Ratio

The plot of Output voltage ripple as a function of switching frequency is shown in figure 15. It is observed that for both the converters, the output voltage ripple is decreased as the switching frequency is increased. The voltage ripple contentin modified converter is smaller than the basic interleaved converter.

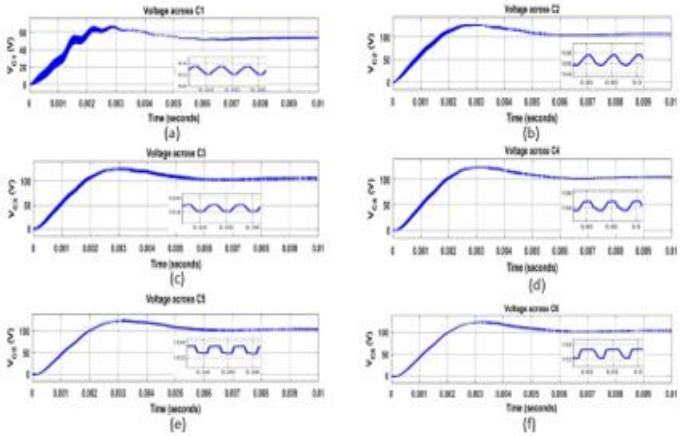

Fig. 15. Output Voltage Ripple Vs Switching frequency

The plot of output voltage ripple as a function of duty ratio is shown in figure 16. It is observed that for both the converters, the output voltage ripple is incrementing as the duty ratio is increased. The incremental rate of voltage ripple in modified converter is lower than the basic interleaved converter.

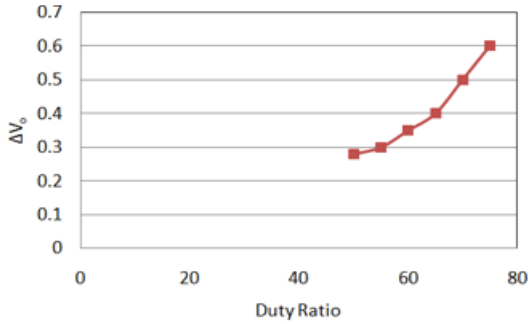

Fig. 16. Output Voltage Ripple Vs Duty Ratio

V. COMPARATIVE STUDY

The comparison between Novel Interleaved Parallel High gain DC/DC Converter & Modified Interleaved High gainDC/DC Converter is given in table 2. On the comparison it can be observed that, number of components used are same for both basic interleaved converter and modified interleaved converter. Keeping same values for input voltage & switching frequency as 20V & 100kHz, the required output voltage obtained is 400V with same rate of gain by both converters. The input current ripple and output current ripple of modified converter is lower when compared with basic interleaved converter.

Table 3 shows the component wise comparison between Modified Interleaved High gain DC/DC Converter & other converters. Comparison is based on the components used in the different converters. From table it can be observed that, the number of total components used in Modified Interleaved High gain DC/DC Converter is more than other converters. Butincrement in the stages of voltage multipier cells, the gain and efficiency of the modified converter has been increased.

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Table 2 Comparison Between Interleaved Parallel High Gain Dc/Dc Converter & Modified Interleaved High Gain Dc/Dc Converter

Parameters	Interleaved Parallel Converter	Modified Interleaved High Gain Converter
No. of switches	2	2
No. of inductor	2	2
No. of capacitor	7	7
No. of diode	7	7
Voltage gain	18.65	19.05
Output Voltage Ripple	0.25 V	0.3 V
Output Current Ripple	0.0002 A	0.0018 A
Voltage stress across switch	S_1=2.85V_{in} S_2= 2.85V_{in}	S_1=2.85V_{in} S_2=2.85V_{in}
Input current ripple	0.6 A	0.2 A

Table 3 Comparison Between Modified Interleaved High Gain Dc/Dc Converter & Other Converters

Parameters	Conventional Boost Converter	Converter with Coupled Inductor[1]	Converter with Greinacher VMC[2]	Modified Interleaved High Gain Boost Converter
No. of switches	1	2	2	2
No. of inductor	1	4	4	7
No. of capacitor	1	3	4	7
No. of diodes	1	4	4	7

Fig. 17. Experimental Setup

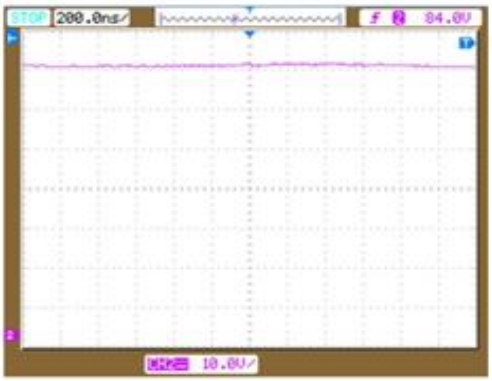

Fig. 18. Output Voltage of Proposed Converter

VI. EXPERIMENTAL SETUP WITH RESULT

For the purpose of implementing hardware, the input voltage is reduced to 5V and the switching pulses are generated using TMS320F28027F processor. The switches used are MOS- FET IRF3205. Driver circuit is implemented using TLP250H, which is an optocoupler used to isolate and protect the microcontroller from any damage and also to provide requiredgating to turn on the switches.

Experimental setup of modified interleaved high gain dc/dc converter is shown in Figure 17. Input 4V with 1.128A DC supply is given from DC source. Switching pulses are taken from TMS320F28027F microcontroller to driver circuit. Thus an output voltage of 65.2V, 100kHz is obtained from power circuit that is shown in Figure 18. Output voltage of converter is taken from the DSO oscilloscope.

VII. CONCLUSION

A modified interleaved high gain dc/dc converter with high gain is presented. A new voltage multplier circuit is introducedin order to achieve the common ground. The input current ripple is reduced by amount close to ideal value. Lower voltage stress across the switches when compared with other topologies aids the converter advantage. For a power of 190W,the interleaved converter provides an efficiency 85.2 %Ṫ he control of the proposed interleaved converter is implemented using TMS320F28027F microcontroller. Inverter prototype of10W provides a performance with an output voltage of 16.2V, considering the drop across the components. The overall analysis confirms that the proposed interleaved converter can be used in applications such as photovoltaic systems, micro grids etc..

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