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Multiple Output Converter Based On Modified Dickson Charge PumpVoltage Multiplier

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Abstract—A multiple output DC-DC converter based on modified Dickson charge pump is proposed. This converter is capable of stepping up voltages as low as 20V to 200V and 400V. The modified Dickson charge pump based converter offers continuous input current and low voltage stress on its switches. The converter can draw power from a single source or two independent sources while having continuous input current, which makes it suitable for applications like solar panels. And also it requires lower voltage rating capacitors for its voltage multiplier circuit and also one less diode when compared to the conventional converter. This converter is simulated using MATLAB/SIMULINK R2017. The switching pulse for the control circuit is generated using PIC16F877A microcontroller. Hardware prototype of the multiple output high gain converter is implemented and observed the output voltages 45.7V and 95V with input 5V.
IndexTerms—Multiple output DC-DC Converter, Modified Dickson Charge pump, Voltage Multiplier.

I. INTRODUCTION

Distribution systems at high voltage DC have been gaining popularity as they offer better efficiency, higher reliability at an improved power quality, and low cost compared to AC distribution systems [3]. They offer a simpler integration of renewable energy and energy storage systems.

One of the challenges facing such systems is the power electronic converters for integrating renewable sources into the 400-V DC bus. A typical voltage range for solar panels is between 20V DC to 40V DC. Stepping up these voltages to 400-V DC using classic boost and buck-boost converters requires high duty ratios which results in high component stress and lower efficiency. Therefore, a typical choice would be using two cascaded converters which results in inefficient operation, reduced reliability, increased size, and stability issues. Isolated topologies like flyback, forward, half-bridge, full-bridge, and push-pull converters have discontinuous input currents and hence would require large input capacitors.

Theoretically, the conventional boost DC-DC converter can provide a very high voltage gain by using an extremely high duty ratio. Large duty ratios result in high current stress in the boost switch. Due to large duty ratio parasitic elementshas to be considered and their effects reduce the theoretical voltage gain.Some other alternative step-up DC-DC converters without step-up transformers and coupled inductors were presented in [4]–[5]. These kinds of DC-DC converters can provide high voltage gain by cascading diode–capacitor or diode-inductor modules. But the passive elements and switch were under high voltage stress in this cascaded converter. The modified multiple output DC-DC converter based on the modified Dickson charge pump voltage multiplier circuit is capable of stepping up voltages as low as 20V to 200V and 400V. It offers continuous input current and low voltage stress on its switches.

II. MULTIPLE OUTPUT DC-DC CONVERTER WITH INPUT BOOST STAGE

The working of the proposed converter is inspired from the modified Dickson charge pump [1]. Diode-capacitor voltage multiplier (VM) stages are integrated with two boost stages at the input. The voltage multiplier stages are used to help the boost stage achieve a higher overall voltage gain. The voltage conversion ratio depends on the number of voltage multiplier stages and the switch duty ratios of the input boost stages. This converter is capable of stepping up voltages as low as 20V to 200V and 400V. The proposed converter offers continuous input current and low voltage stress (1/4th of its one of the output voltage) on its switches. Thus offers gains of 10 and 20.

Fig.2 shows proposed multiple output DC-DC converter which consist of two stages. For a same output voltage, the voltages of all the capacitors in the multiple output Dickson charge pump are smaller than the voltage of capacitors in the Dickson charge pump. For output voltage of V_{out1} = 400V, V_{out2} = 200V the voltages of capacitors $C1$, $C2$, $C3$, and $C4$ are only 150V, 50V, 50V, and 150V respectively.

Therefore the volume of the capacitors used in the proposed multiple output Dickson charge pump voltage multiplier circuit is potentially less compared to the Dickson charge pump.

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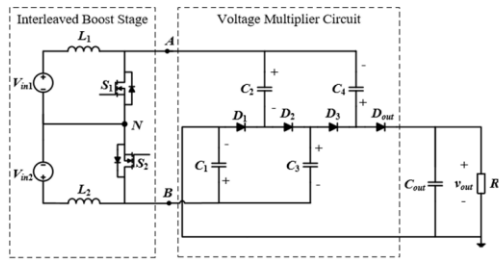

Fig. 1. High-voltage-gain DC-DC converter proposed in [1].

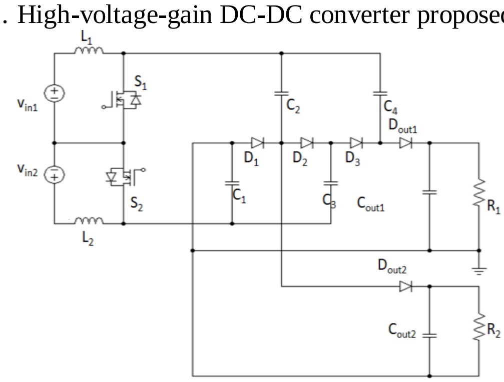

Fig. 2.Proposed multiple output DC-DC Converter

III. OPERATING PRINCIPLE

The proposed converter provides a high voltage gain using the modified Dickson charge pump voltage multiplier circuit. In Fig.1, it can be seen that the converter is made up of two stages. The first stage is a two-phase interleaved boost converter which outputs an MSW voltage between its output terminals *A* and *B*. The second stage is the modified Dickson charge pump voltage multiplier circuit that boosts the MSW voltage (*VAB*) to provide a higher dc output voltage.

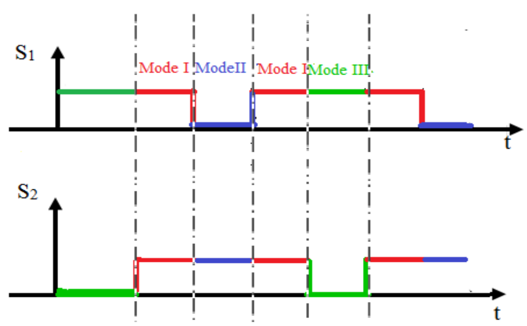

Fig. 3.The switching sequence of the Converter.

For the multiple output converter shown in Fig.2 to operate normally, both switches *S*1 and *S*2 must have an overlap time
where both are ON and also one of the switches must be ON at any point of time. This can be achieved by using duty ratios of greater than 50% for both the switches and having them operate at 180 degrees out of phase from each other. As can be seen from Fig.3, such gate signals lead to three different modes of operation which are explained as follows.
Mode 1: In this mode all the switches are ON. All the inductors are charged from their input sources. The current in the inductors rise linearly. The diodes in different VM stages are reverse biased and do not conduct. The VM capacitor voltages remain unchanged and the output diodes *Dout1*, *Dout2* are reverse biased (as shown in Fig.4), thus the loads *R1*, *R2* are supplied by the output capacitors *Cout1* and *Cout2*.

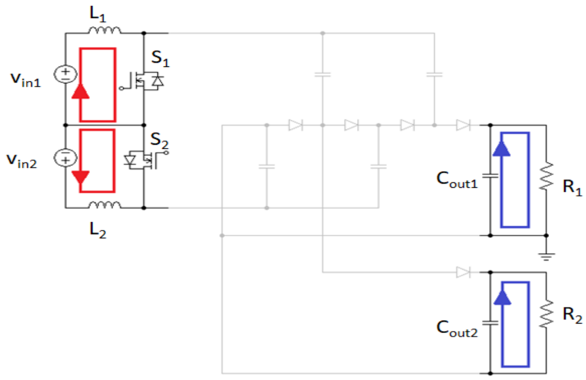

Fig. 4.Mode 1 Operation

Mode 2: In this mode, switch S1 is OFF and switch S2 is ON. Diodes D1 and D3 are OFF as they are reverse biased while diodes D2, Dout1 and Dout2 are ON as they are forward biased. A part of inductor current iL1 flows through capacitors C2 and C3 and thereby charging them. The remaining current flows through the capacitors C4, C1 discharging them to charge the output capacitors Cout1, Cout2 and supply the loads R1, R2 (See Fig.5).

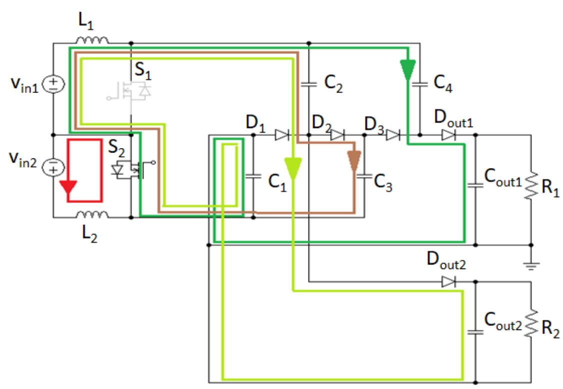

Fig. 5.Mode 2 Operation

Mode 3:In this mode switch S1 is on and switch S2 is off. Diodes D1 and D3 are on as they are forward biased while diodes D2, Dout1 and Dout2 are off as they are reverse biased. Inductor current iL2 flows through diode-capacitor voltage multiplier cell capacitors C1, C2, C3 and C4. While Capacitors C1 and C4 are charged, capacitors C2 and C3 are discharged. In this mode, the output capacitors Cout1 and Cout2 supplies the load.

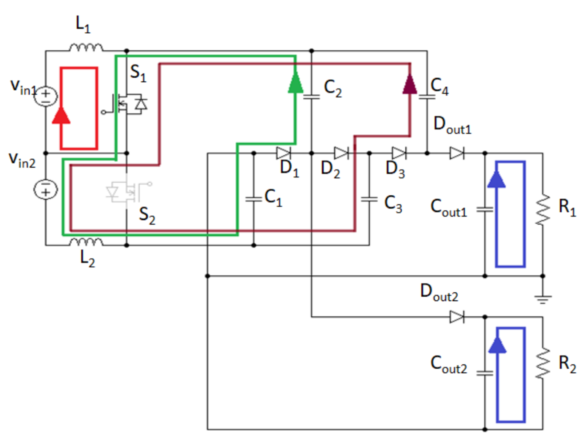

Fig. 6.Mode 3 Operation

IV.VOLTAGE GAIN

The charge is transferred progressively from input to the output by charging the VM stage capacitors. Here Vin1 = Vin2 = 20V. And duty ratio of all switches are same and equal to 0.8. From the working of modified Dickson charge pump.

$$V_{out1} = \frac{2*V_{in1}}{(1-d_1)} + \frac{2*V_{in2}}{(1-d_2)} \qquad (4.1)$$

$$V_{out2} = \frac{V_{in1}}{(1-d_1)} + \frac{V_{in2}}{(1-d_2)} \qquad (4.2)$$

The outputs are 200V with gain 10 and 400V with gain 20 respectively.

V. DESIGN OF COMPONENTS

The simulation of a converter rated at 200 W with Vin=20 V and Vo1=400V, Vo2 =200 V is simulated. So the Output currents are Io1 =0.5A and Io2 =0.25A respectively. Switching frequency fswis 100kHz.

5.1. Inductor Design.

The inductor currents in both phases of the interleaved boost stages are similar. The average inductor currents can be calculated using (5.1).

$$I_{L1\ avg} = I_{L2\ avg} = \frac{2*I_{out}}{1-d} \qquad (5.1)$$

The inductor design is similar to that of the normal boost converter. The inductor value is selected such that the boost stages operate in continuous conduction mode (CCM). The inductor value for the CCM operation of the boost stages is given by,

$$L_1 = L_2 = \mathrm{L} = \frac{V_{in} * d}{\Delta I_L * f_{sw}} \qquad (5.2)$$

So take L1 and L2 as 100uH.

5.2. Capacitor Design

The output capacitor is selected based on the amount of charge that is transferred to the output for a desired output voltage ripple. Assuming a voltage ripple of 0.02% of output voltage, the required capacitance is given by,

$$C_{out} = \frac{I_o * (1-d)}{f_{sw} * \Delta V_o} \qquad (5.3)$$

So take Cout1 and Cout2 as 22µF.

VI. SIMULATION PARAMETERS

The simulation parameters used for multiple input DC-DC converter are shown in Table I.

Table 1 Simulation parameters

Components	Rating
Input Voltage	20V
Output Voltage	200V, 400V
Load Resistance	800Ω
Duty Ratio	80%
Inductors	100µH
VM stage capacitors	60µF
Output Capacitors	22µF

VII. SIMULATION RESULTS

A model of converter is simuated in MATLAB/ SIMULINK environment. The simulated waveforms are shown below. Fig.7 shows input voltage and current to the converter. The input voltage and input current to the converter is 20V and 10.5A respectively.

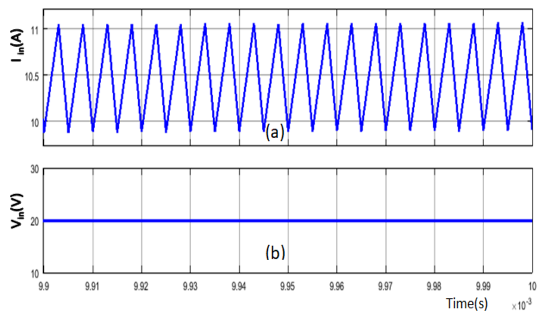

Fig. 7.(a) Input Current and (b) Input Voltage

Fig.8 and Fig.9 shows the current and voltage of both inductor L1 and L2 respectively. Both inductors carry same voltage and current due to its interleaved connection. Fig.10 and 11 shows the voltage stress across the switches. Compared to the output voltage of 400V the value is small (25%). So the switching stress is comparatively low.

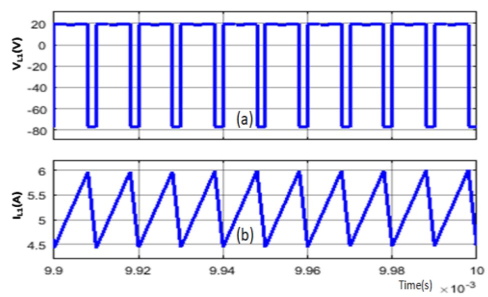

Fig. 8.Inductor L1 (a) Voltage and (b) Current

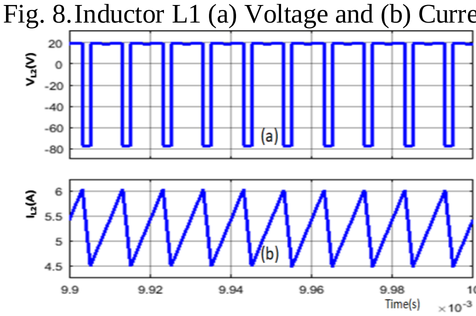

Fig. 9.Inductor L2 (a) Voltage and (b) Current

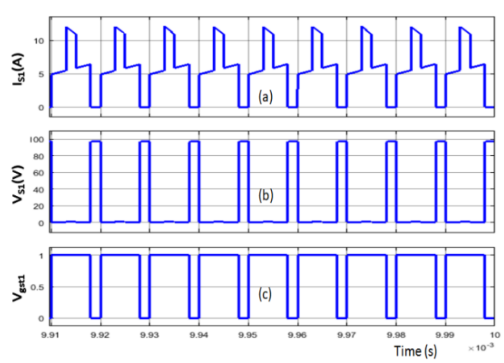

Fig. 10.(a) Current through S1 (b) Voltage Stress across switch S1 (c) switching pulse of S1

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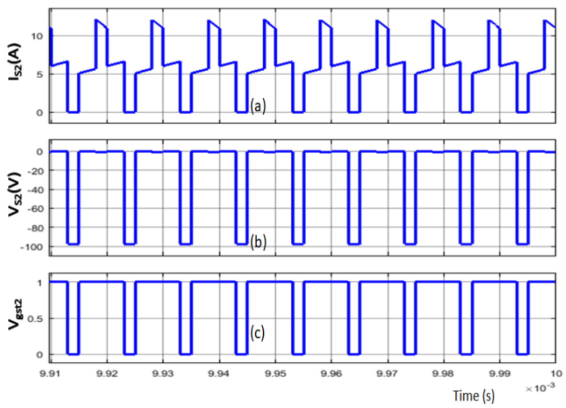

Fig. 11: (a) Current through S2 (b) Voltage Stress across switch S2 (c) Switching pulse of S2

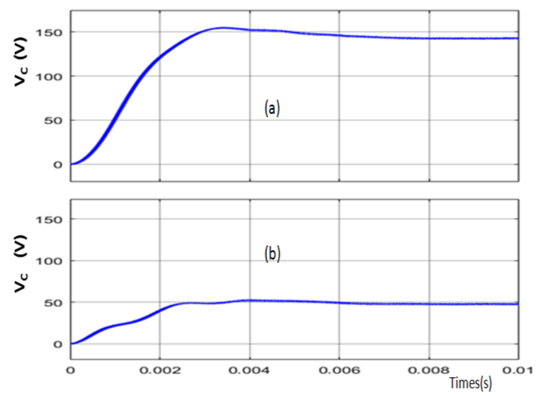

Fig. 12.Voltage across capacitor (a) C1 & C4 (b) C2 & C3

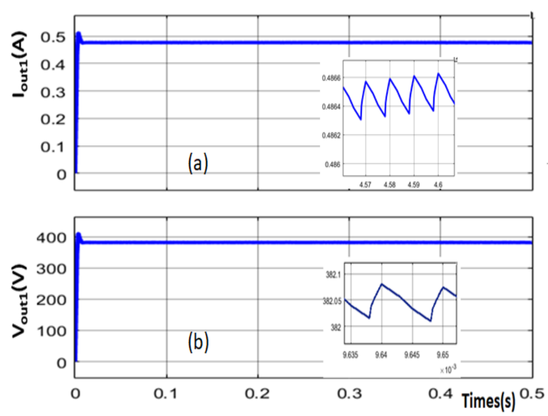

Fig. 13. First Output (a) Current and (b) Voltage

Fig. 12 shows the voltage across each voltage multiplier stage capacitors. Capacitors C1 C3are charged to 150V and capacitors C2 and C3 are charged to 50V.

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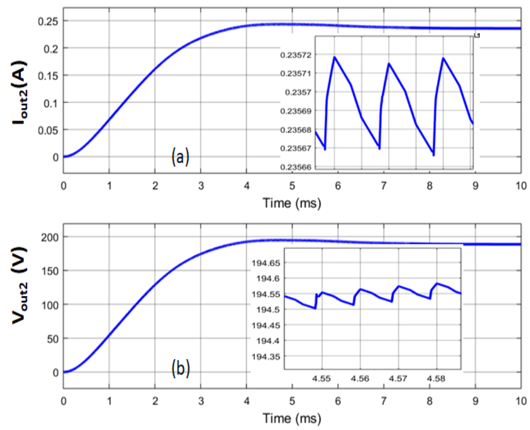

Fig. 14: Second Output (a) Current and (b) Voltage

Fig.13 shows the first output waveforms of obtained in the simulation. First output voltage is 400V and the output current is 0.5A. Fig.14 shows the second output waveforms of obtained in the simulation. Second output voltage is 200V and the output current is 0.25A.

VII. PERFORMANCE ANALYSIS

For analysis of the converter, it is assumed that all the components are ideal and the system is under steady state.

a

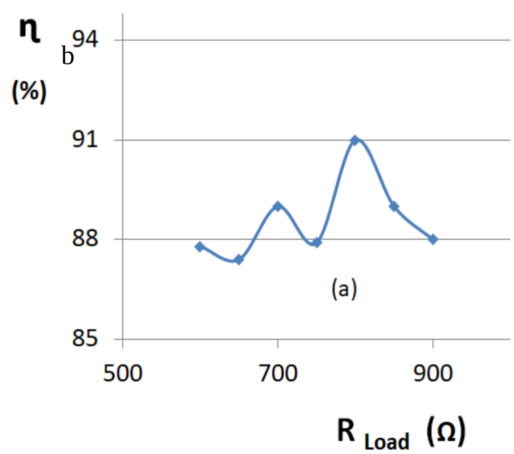

Fig. 15. Efficiency Vs R Load

Fig.15 gives the plot showing the variation of efficiency versus R load for a 20V input. At 800Ω efficiency is maximum which is 91%.

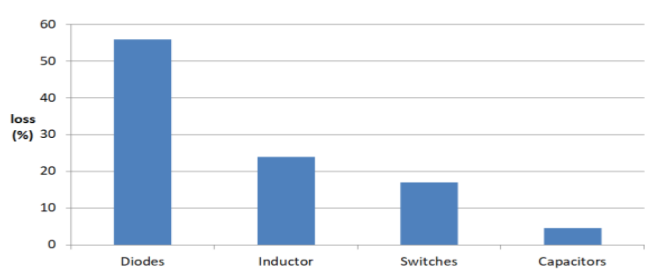

Fig. 16. Percentage distribution of losses in system components

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VIII. EXPERIMENTAL SETUP AND RESULTS

A 10W, 10kHz prototype of the DC-DC converter with high voltage gain and two input boost stages with input 5V is implemented. Table III shows the specification.

Table Ii:Components Used For Prototype

Components	**Rating**
Inductors	800µH
Capacitor	22µF
Diode	IN5819
Controller	PIC16F877A
MOSFET	IRF540
Driver IC	TLP250

The power supply consist of a step down transformer, full bridge diode rectifier, filter capacitor and a regulator IC (7812). IRF540 MOSFET is used as the switches. TLP250 driver is used to drive the MOSFET. To generate the switching signal PIC16F8771A was programmed in the laboratory and necessary waveforms were obtained. The Switches have a duty cycle of 0.8 and are working in 10kHz frequency.

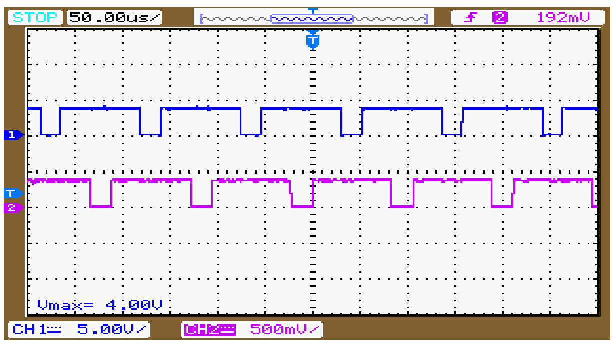

Fig.17: Switching pulses for switches S1 and S2

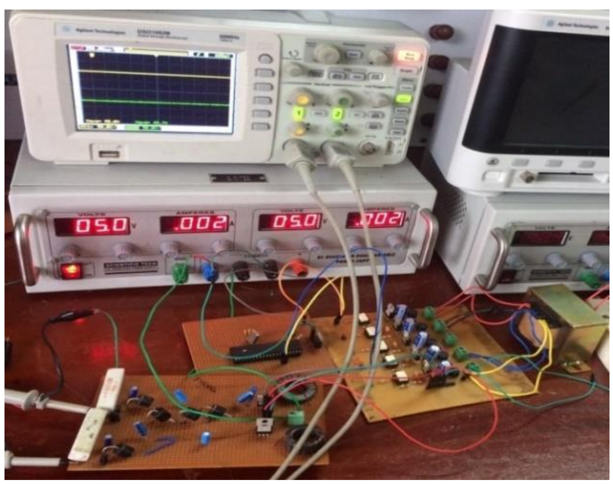
Fig. 18: Hardware implementation

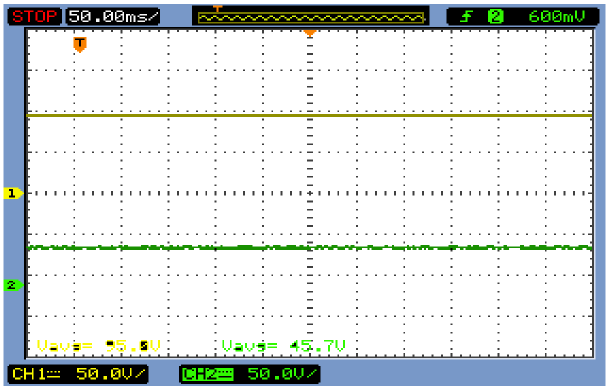

Fig.19: Output voltage waveform

IX. CONCLUSION

In the proposed converter, two of the input capacitors are series charged by the input and parallel discharged by the new two-phase interleaved buck converter so that it provides amuch higher step-down conversion ratio without adopting anextremely shorter duty ratio. Based on the capacitive voltage division, the main aim of new voltage-dividercircuit in the converter are both storing energy in blocking capacitors for increasing the step down conversion ratio and reducing voltage stresses of active switches. Asa result, it is observed that thevoltage stress across the switches is considerablyreduced.The presence of ZVS and ZCS in the circuit A multiple output DC-DC converter based on modified dickson charge pump voltage multiplier is proposed. The multiple output high-voltage-gain DC-DC converter which draws power from single source with continuous input current has a voltage gain of 20 and effeciency of 91% . The converter step up a 20V input to 200V, 400V outputs. This multiple output converter is based on a two-phase interleaved boost and the modified Dickson charge pump voltage multiplier circuit. As it is symmetric, its semiconductor components experience same voltage and current stresses which is then reduces the effort and time spent in the component selection during the system design. Because high frequency operation and absence of winding transformer the size of the converter would be less.The absence of coupled inductor makes this converter superior as leakage flux and stray magnetic field loss are not present. The output voltage and current, switching stress, inductor current and voltage, multiplier capacitor voltage are observed. The observed values are similar to the values that was obtained in the designing steps. A 5V input voltage, 50V output voltage with 2.5W output power and 100V output voltage with 5W output power prototype circuit has been implemented in the laboratory to verify the performance. contributes to a further reduction in the voltage stress. The voltage stress across the switches is 150V across S_{1a}, $S_{2b}$and S_{2a}, 120V across $S_{1b}$and S_{1c}, 36V across S_{2c} with an input of 290V. Thus, it requires semiconductor devices with lower voltage ratings. The Modified DC-DC buck converter gives an output voltage of 19.5V for the given input and finally, a 60V input voltage, 5V output voltage, and 20 kHz frequency prototype circuit has been implemented in the laboratoryto verify the performance.

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