International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 05, May-2020

A High Voltage Gain Switched Capacitor based Boost DC-DC Converter

Ms. Anziya Nazeer
P G Scholar
Electrical and Electronics Engineering Department
Ilahia Collage of Engineering and Technology
Muvattupuzha

Dr. S. Karthikumar
Professor and HOD
Electrical and Electronics Engineering Department
Ilahia Collage of Engineering and Technology
Muvattupuzha

***Abstract:*-This paper, going to propose a high voltage gain switched capacitor based boost DC to DC. For reducing the stress of the diodes, MOSFETs and conduction loss on the switches, uses small duty cycle. This converter has an advantage of high voltage gain and a simple structure. The converter can make 300V output from a 50V input with a duty cycle of 17%. MATLAB/SIMULINK R2017a is used for simulation works. From the analysis a voltage gain of 6 is obtained at 360W output. Based on the simulation results analysis is done. Arduino microcontroller is employed to produce the switching pulses for the control circuit . To verify the performance and operating principle output voltage of 300V and input voltage of 50V with output power of 360W prototype is constructed and the results are validated.**

Keywords — Boost converter, dual-switch, switched capacitor, non isolated DC–DC converter, high voltage gain continuous conduction mode (CCM).

I. INTRODUCTION

DC-DC converter with high gain has increasing demands in recent days. High step-up DC-DC converter is a class of converter switch can boost a low voltage to a relatively high voltage. As we known, the output voltage of fuel cell stacks, single PV module, battery sources, or the super capacitors is relatively low; it should be boosted to a high voltage to feed the ac grid or other applications like un interruptible power supplies, new energy vehicles, and so on.Lots of research works have been done to provide a high step-up without an extremely high duty ratio. The isolated converters can boost the voltage ratio by increasing the turns ratio of the high-frequency transformer. However,the leakage inductor should be handled carefully; otherwise, it will cause voltage spike across the power switches or diodes. Moreover, isolated DC-DC converters have the shortages in system volume and efficiency due to multistage DC-AC-DC conversion

F. L. Tofoli [2] introduced a step-up DC-DC topologies that feature high efficiency, reduced stress, low cost, simplicity and robustness. W Li [3] introduced a power system for the downstream DC-AC grid-connected inverter which require a DC-DC converter to step up the low voltage of fuel cell or PV to a high bus voltage. Y. P. Siwakoti [4] introduced a new DC-DC converter, derived from the traditional Y-source network. The proposed circuit inherits all the advantages of the Y-source including very high boost capability and flexibility to choose multiple circuit parameters to tune the gain. Minh-Khai Nguyen, Truong-Duy Duong, and Young-Cheol Lim [1] proposes boost dc-dc converter which employs the use of switched capacitor. It consists of two switches S_1, S_2, three diodes D_0, D_1, and D_2 and one inductor L and three capacitors C_0, C_1 and C_2. V_g is the input voltage and output voltage is denoted as V_0. Figure 1 shows a typical arrangement of the converter. The circuit is analysed on continuous conduction mode carries some assumptions such as all devices are ideal and lossless, the capacitor values are large, the current flowing through the inductor decrease or increase linearly.

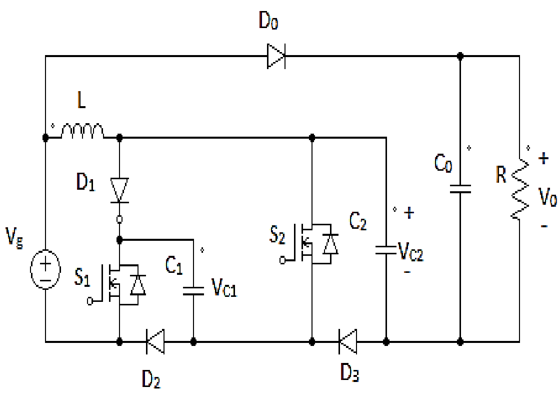

Fig. 1.Switched Capacitor Based Converter

In mode 1, switch S_1, S_2 are turned on. At the same time diode D_0 will conduct and diodes D_1, D_2 and D_3, will not conduct. The inductor L gets charged and the capacitor C_1 C_2 will discharges its energy. D*T is the time duration taken for this mode, where T and D shows its switching period and duty cycle of the converter. Both the switches are turned off in mode 2. The diodes D_1 and D_2will conduct and diode D_0 will not conduct. The time duration for this mode is D*(1-D).During this mode the energy stored in the inductor L will discharges , and the energy will stored in capacitors C_1 and C_2. In order to improve the voltage gain of the circuit pointed above modified the circuit by adding a switched inductor circuit in the input side. By adding switched inductor circuit in the input, it is observed that the gain can improved to 6. There is no any difference in designing aspects.

II. PROPOSED CONVERTER

Proposed high voltage gain Switched capacitor based boost DC–DC converter is shown in fig.2. It consists couple of power switches (S_1 and S_2), two inductors (L_1 and L_2), three

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ISSN: 2278-0181
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capacitors (C_0 − C_2), seven power diodes (D_0 – D_6) and a resistive load (R).

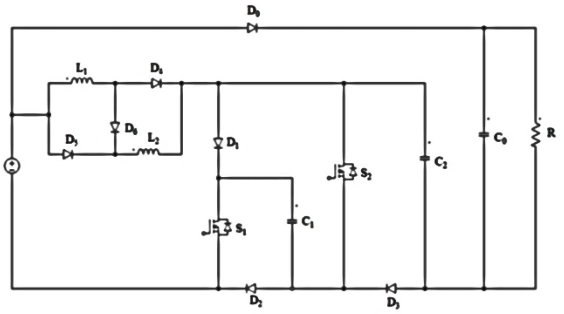

Fig. 2. Proposed converter

The following assumptions are taken consideration while designing the converter:

1) All components are taken as ideal and lossless;
2) To maintain the constant capacitor voltage, capacitance of the capacitors are made high; and
3) The current in the inductor will increases or decreases linearly.

The circuit diagram of the high voltage gain switched capacitor based boost DC–DC converter in continues conduction mode is shown in figure 2.

III. OPERATING PRINCIPLES

The working of the circuit can be explained by 2 modes of operation. Figure 3(a) and 3(b) shows the operating modes of high voltage gain switched capacitor based boost DC –DC converter in continues conduction mode .Switches S_1 and S_2, will turned on in mode one and off in mode 2.

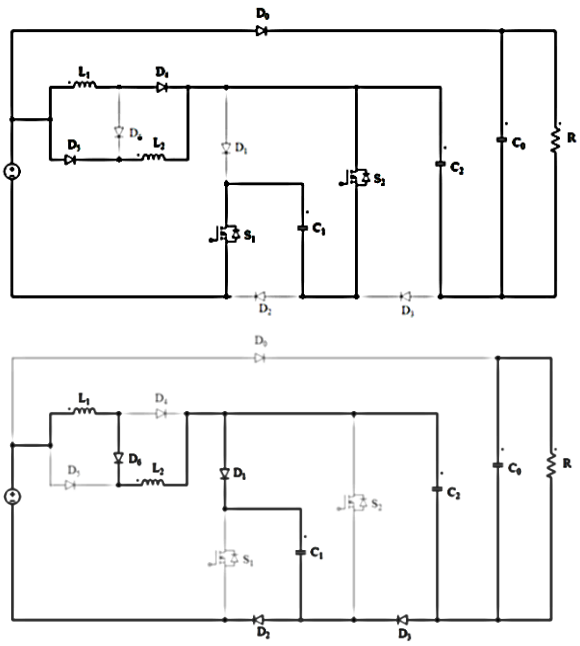

Fig. 3. Operating modes of the high gain switched capacitor based boost DC-DC converter: (a) mode 1 (b) mode 2.

Mode 1 : Fig. 3(a) shows the circuit .diagram in mode 1. SwitchesS_1 and S_2 are turned “ON” in this mode. The switches allows a path to charge the inductor L_1 and L_2 and discharge the capacitors C_1 and C_2.The diodes D_0, D_4, and D_5 are forward-biased, and the diodes D_1, D_2 and D_3 is in blocked state. D*T is the time duration taken for this mode, where T and D shows its switching period and duty cycle of the converter. By applying KVL in Fig. 3(a) the following formula is derived:

$$L_1 \frac{diL_1}{dt} + L_2 \frac{diL_2}{dt} = V_g + V_{C1} \qquad (1)$$

$$V_0 = V_g + V_{C1} + V_{C2} \qquad (2)$$

Mode 2: Figure 3(b) shows the operating mode 2. S_1 and S_2 switches are turned “OFF” at this mode. The diodesD_1, D_2, D_3 and D_6 will conduct and the diodes D_0, D_4 and D_5 are block the current flow. (1– D)*T is the time duration taken for this mode. During this mode, the inductor L_1 and L_2 are discharged through the diodes D_1, D_2, D_3 and D_6 while capacitors C_1 and C_2 are charged through the same path, and the following formula is derived:

$$L_1 \frac{diL_1}{dt} + L_2 \frac{diL_2}{dt} = V_g - V_{C1} \qquad (3)$$

$$V_{C1} = V_{C2} \qquad (4)$$

Substitute equation (1) to equation (4) after applying volt balance law to the inductor gives the following equation:

$$V_{C1} = V_{C2} = V_g \qquad (5)$$

Proposed converter’s Output-voltage gain in the CCM can be obtained by substituting equation (5) in equation (2) and is shown in equation(6):

$$\text{GCCM} = \frac{V_0}{V_g} = \frac{3-2D}{1-2D} \qquad (6)$$

The output current of the proposed converter is equal to the average current of the diode D_0. By applying KCL in node A of Figure 2, average inductor current of the converter is as follows

$$I_{L_1} + I_{L_2} = I_{in} - I_0 \qquad (7)$$

IV. DESIGN CONSIDERATIONS

A. Voltage and Current Stress on the Switches

By analyzing the operating mode, the input current is equal to the switch current (I_S) in mode 1, and is equal to the inductor current in mode 2; following equation shows the average input current:

$$I_{in} = \frac{Po}{Vg} = DI_S + (1-D)I_L \qquad (8)$$

The peak current of the switches S_1 and S_2can find out by substituting equation (7) in (8) and is as follows:

$$I_S = \frac{P_0}{D(3-2D)V_g} \qquad (9)$$

B. Voltage and Current Stresses on the Diode D_0

The peak current of the diode D_0 is calculated based on the operation in mode 1 shown in figure 3(a) is as follows:

$$I_{D0} = I_S - I_{L1} - I_{L2} \qquad (10)$$

C. Inductor Selection

Using equation (1), we can calculate the peak-to-peak inductor current .By considering the ripple current of the inductor $\Delta I_L = r_i\%I_L$ the value of the inductor should be as follows:

$$L_1 = \frac{D*(1-D)*(3-2D)*T*V_g^2}{r_i\%*(1-2D)*P_0} \quad (11)$$

Similarly,

$$L_2 = \frac{D*(1-D)*(3-2D)*T*V_g^2}{r_i\%*(1-2D)*P_0} \quad (12)$$

D. Capacitor Selection

The capacitor voltage ripple is considered while designing the capacitor value. By analysing the current flow, the switch S_1'speak current and current flow in capacitor C_1 in mode 1 is seems to be same. The peak current of the diode $D_0$is equal to the current flow in the capacitor C_2, therefore the equations be like:

$$I_{C1} = \frac{P_0}{D(3-2D)V_g} \quad (13)$$

$$I_{C2} = \frac{P_0}{D(3-2D)V_g} - I_L \quad (14)$$

The capacitances for the capacitor C_1 and C_2 of the converter is as follows: by considering capacitor peak-to-peak voltage ripple, the capacitor voltage is restricted in amount by $r_v\%$:

$$C_1 = \frac{(1-2D)TP_0}{r_V\%(3-2D)V_g^2} \quad (15)$$

$$C_2 = \frac{(1-2D)^2 TP_0}{r_V\%(3-2D)V_g^2} \quad (16)$$

The output current in mode 2 is equal to the current flow in output capacitor C_0as shown in figure 3(b).The C_0 capacitance is designed so as to reduce the ripple on the output voltage.

$$C_0 = \frac{(1-D)(1-2D)^2 TP_0}{r_V\%(3-2D)V_g^2} \quad (17)$$

V. SIMULATION RESULTS

The simulation parameters of high voltage gain switched capacitor based boost DC –DC converter is given in table 1. An input voltage V_{in} of 50V gives an output voltage V_O of 300V for an output power P_O of 360W. The switches are MOSFET/Diode with constant switching frequency of 50 KHz. The duty cycle of switches is taken as D = 0.17. The high voltage gain switched capacitor based boost DC –DC converter is simulated in MATLAB/SIMULINK by choosing the parameters listed in table 1 and the Simulink model is shown in figure 4

TABLE 1. SIMULATION PARAMETERS

Parameter	Values
Output voltage	300 V
Input voltage	50 V
Output power	450 W
Capacitors C_1, C_2 C_0	C1, C2 22 µF/100 V 110 µF/450 V
Inductor L_1,L_2	0.5 mH
Switching frequency	50 kHz

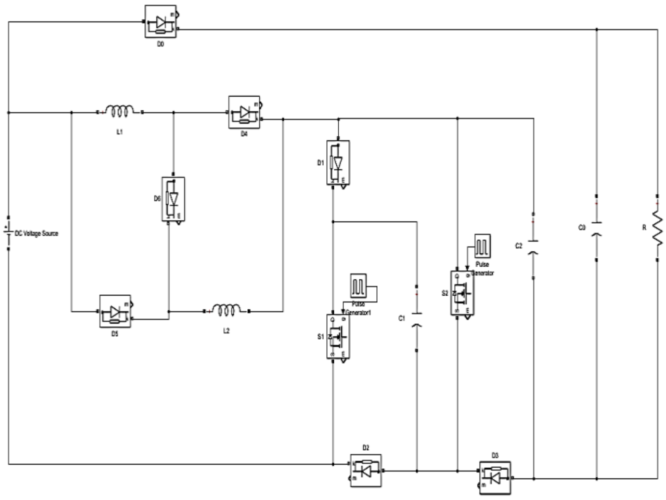

Fig. 4. Simulink model of proposed converter

The simulation results of the high voltage gain switched capacitor based boost DC–DC converter is shown in the following figures.

The switching frequency is 50 kHz. The gate pulse of main power device has fixed duty cycle of 17%.

It can be seen from the Figure 5(a) and Figure 5(b) and 5(c) that the output current is 1.2A, the output voltage V_0 is about 300 V and output power is 360W. This allows high voltage gain of low-stress converter. The output voltage has a ripple of 0.2%.As shown in Figs. 5(f) and 5(g), the voltage of the capacitor C_1 and C_2 is boosted to 129V.

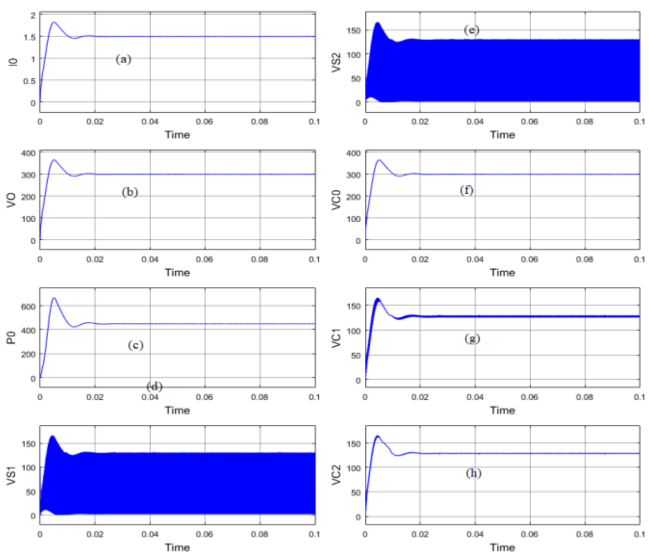

Figure 5:(a)Output Current (b) Output Voltage (c) Output Power (d) Voltage Stress S_1 (e) Voltage Stress S_2 (f) Voltage across C_0 (g) Voltage across C_1 (h) Voltage across C_2

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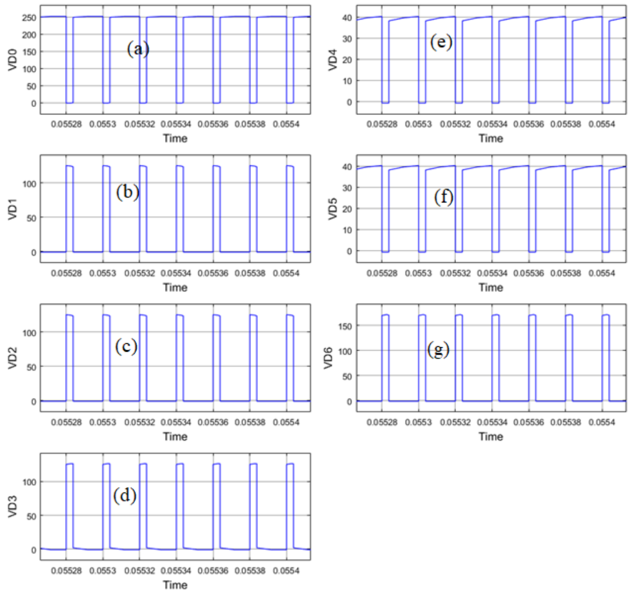

Figure 6: (a) Voltage across D_0 (b) Voltage across D_1 (c) Voltage across D_2 (d) Voltage across D_3 (e) Voltage across D_4 (f) Voltage across D_5 (g) Voltage across D_6

VI. ANALYSIS

The analysis of high voltage gain Switched capacitor based boost DC–DC converter is carried out by considering parameters like voltage gain, efficiency and duty cycle etc.

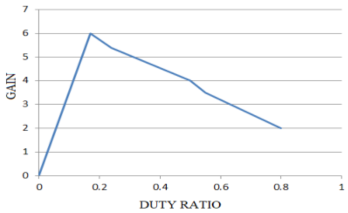

Fig.7.Voltage gain Vs duty cycle

A typical curve for the voltage gain Vs duty cycle is shown in figure 7. For a duty cycle of 17% the efficiency is 97 % .
A typical curve for the efficiency Vs duty cycle is shown in figure 8. For a duty cycle of 17% the efficiency is 97%. Thus the efficiency of a switched Capacitor DC-DC Converter decreases with increase in the duty ratio.

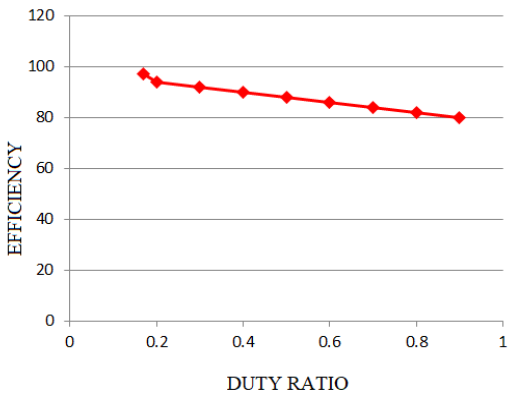

Fig. 8. Efficiency Vs duty cycle

The comparison of modified converter with conventional SCDC converter is given in table 2.

TABLE 2. COMPARISON

Parameter	SCDC converter	Proposed converter
No of inductors	1	2
Output current ripple	0.2A	0.2A
Voltage gain	4	6
Output voltage ripple	0.4V	0.2V
No of capacitors	3	3
Switches	2	2
Output voltage	200V	300V
Output Power	200W	360W
Output Current	1A	1.2A
Input Voltage	50V	50V

A prototype of high voltage gain switched capacitor based boost dc –dc converter with input voltage of 50V is implemented. The top view of the experimental setup is shown in Figure 9. It consists of control circuit, driver circuit and power circuit. Control circuit is composed of Arduino microcontroller and its power supply. The control pulses for MOSFET switches are generated using Arduino microcontroller. The pulses from microcontroller are amplified by driver circuit. It also provides isolation between control and power circuit.

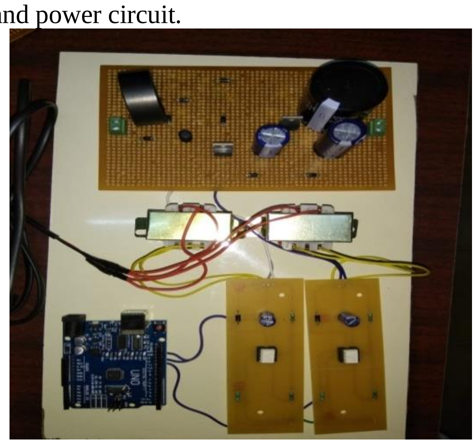

Fig.9.Experimental Setup

VII. CONCLUSION

High voltage gain Switched capacitor based boost DC –DC converter boost input voltage to a very high Value, moreover it has low switch voltage stress, and conduction loss on the power switches. The switches and diodes have relatively low voltage stresses and hence the switching and conduction losses are reduced. It achieves an improved overall efficiency. The input and output voltages of the converter verify the high boost voltage gain. The converter has an efficiency of 97% and voltage gain of 6.A duty ratio of up to 0.17 is suitable for this converter so as to keep the voltage stress across the switches and diodes to a safe limit. The converter can be used for applications with high output voltage and can handle small output current. Moreover it can be used as LED driver and can be also used in solar system .High voltage gain Switched capacitor based boost DC –DC converter can be also introduced in dc motor drives, electric automobiles ,and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 05, May-2020

marine hoists. Moreover it is used in high voltage low current applications such as accelerating purpose in cathode ray tube

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