Design of High Gain Switched Capacitor Z-Source Converter with Extended SC Cells

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Abstract: In this paper, a switched capacitor-based z source converter is proposed and extended with switched capacitor cells to further improve the voltage conversion ratio(1). The proposed converter minimizes the stress of the power electronic switches and diodes less than that of half the load voltage and provides a high voltage conversion ratio unaccompanied by any changes in the duty ratio and also minimizing the requirement of passive or active components. The modes of operation of the converter is analysed and comparison of proposed converter with similar structures of dc-dc converters are provided. The simulation work is carried out in MATLAB/Simulink software. A hardware model is developed and the performance of the converter is validated.

1 INTRODUCTION

Recently, greater focus has been placed on the technological advancement of renewable energy generation, such as Solar and wind energy. The low voltage output of the solar panels is one of the primary limitations of PV generating. To increase the Solar panel voltage to values like 400 V in order to fulfil the DC MG's voltage requirements, a converter with a large voltage conversion ratio is needed. The PV voltage can be increased using two usual methods: pairing solar panels in series, or using a standard boost converter. Because the entire system is affected if one of the solar panels fails, the series connection is unreliable. The typical boost converter offers extremely high duty cycle and great voltage gain. However, it frequently has serious output diode reverse-recovery issues, low efficiency, and excessive stress from voltage over the power electronic switches and output diode. In order to increase the PV voltage and get around the issues that the serial arrangement of solar panels and the traditional boost converter present, sophisticated high boost DC-DC converters are being investigated (Habibi, S,2021). Due to the extensive use of components, architectures constructed around SL and SC modules are both expensive and complex. With a converter constructed using coupled inductor or built in transformer to hold onto the energy from inductance leakage and lessen the strain caused by voltage across the power switches, a clamping circuitry is necessary. Recently, the idea of increasing voltage through quasi-source (qZS) and Z-source (ZS)converter topologies are being used. The voltage conversion ratio for traditional ZS and (qZS) topologies, however, is insufficient. A novel of higher boosting ZS converters was created by integrating the SL technique into traditional ZS network and was utilised as an input phase of a two stage, 3ϕ Z-Source inverter. There are many components and a duty cycle limit of 0.33, a value below the threshold of 0.5 for the traditional ZS topology, despite the voltage conversion ratio being raised and voltage is contrasted to the traditional similar topologies. The inclusion of the SC cells and the traditional (qZS) network produced a novel converter with a high voltage conversion ratio and minimal voltage strain on the semiconductors (Rahimi,2020).

In this paper, a new structure of Z Source converter (Naser Vosoughi Kurdkandi,2020) is designed by the integration of switched capacitor cells to the traditional Z source impedance network, in order to achieve high voltage conversion with reduced switch voltage stress and minimum number of passive components(Hu, X et al.,2020). The proposed

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converter topology eliminates the limitations on the duty ratio. It is further extended by introducing the switched capacitor cells controlled by an auxiliary switch which further improves the voltage conversion ratio without adding to the voltage stress.

2 SYSTEM DESCRIPTION

The proposed system is provided below in Fig 1.

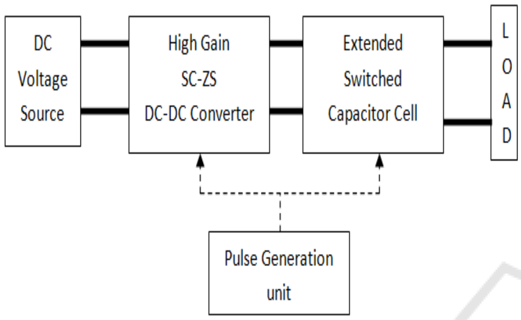

Figure 1: Proposed system Block diagram.

The DC voltage source is connected to the proposed converter which provides boosted voltage to the load based on the pulse provided by the pulse generation unit. The proposed converter is of two parts switched capacitor-based Z Source converter and extended SC cells so that the voltage conversion ratio is improved.

The ZS DC-DC converter below is comprised of single mosfet S with inductors (L1, L2), diodes (D1, D2, D3, D4) and capacitors (C1, C2, C3, C4, Co). The traditional ZS impedance network is coupled with switched capacitor cells, a new impedance converter is designed (SC-ZS converter) which possess a symmetrical composition, improves the voltage conversion ratio and also minimizes the switch voltage stress across the diodes and power electronic switch.

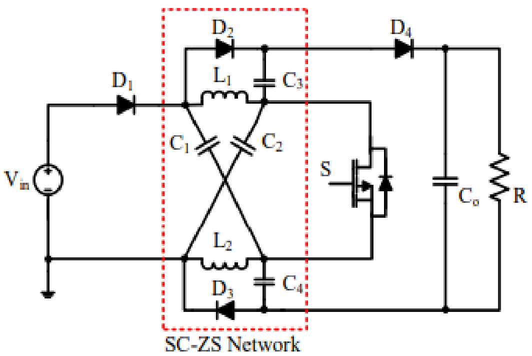

Figure 2: SC-ZS converter.

The operational stages of the above-mentioned converter is provided below:

Stage 1:

When the switch is ON, the capacitors C1 and C2 are discharging along with inductors L1 and L2. The capacitors C3 and C4 are charging. The output capacitance Co provides energy to the load.

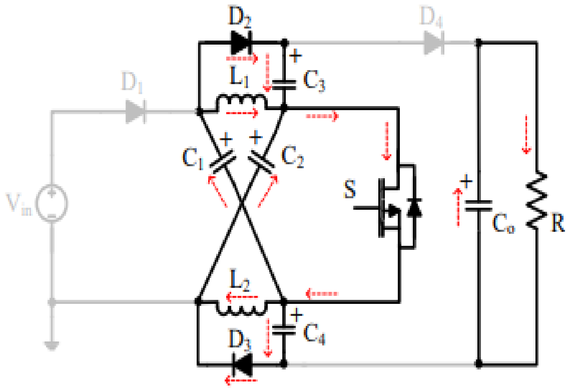

Figure 2(a): Stage 1 operational circuit of SC-ZS converter.

Stage 2:

When the switch is OFF, the capacitors C1 and C2 are charging along with inductors L1 and L2. The capacitors C3 and C4 are discharging provides supply to the load.

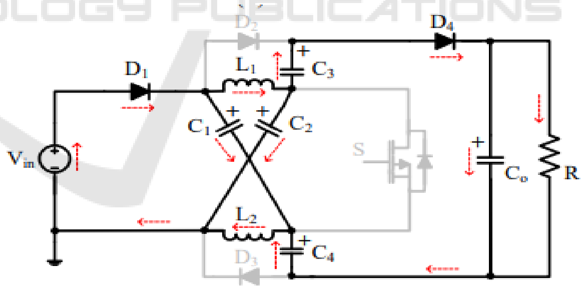

Figure 2(b): Stage 2 operational circuit of SC-ZS converter.

The voltage conversion ratio G is:

$$G = \frac{V_o}{V_{in}} = \frac{3-2D}{1-2D}$$

The voltage across the power electronic switch S and diodes D1-D4 are calculated as:

$$V_{D_j} = V_S = \frac{1}{1-2D} V_{in} = \frac{G-1}{2G} V_o, \quad for\ j = 1,\ 2,\ 3,\ 4$$

Extended Switched Capacitor cell:

It is further extended by adding switched capacitor cell with auxiliary switch to improve the voltage conversion ratio without increasing the stress on the diodes and power electronic switches.

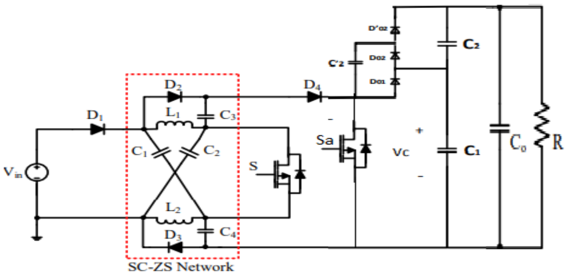

Figure 3: Improved SC-ZS converter with extended SC cells.

The operation of this proposed converter is same as conventional SC-ZS converter for modes 1 and 2.

Stage 3:

In this, the capacitor C2 and C2' are used to improve the voltage conversion ratio. When the switch Sa is ON, the C1 discharges and charges capacitor C2' through the diode Do2. Diode Do2' is reverse biased where Do2 conducts.

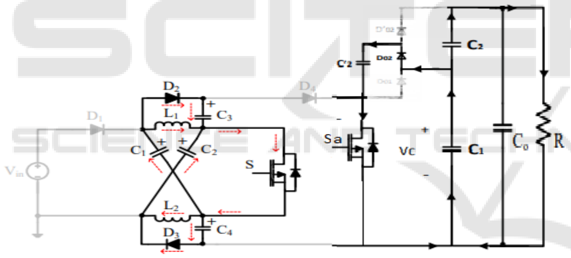

Figure 3(a) Stage 3: operational circuit of proposed converter.

Stage 4:

When the switch Sa is OFF, C2' discharge and provides energy to load along with C1 and C2. The diodes Do1 and Do2 are reverse biased where Do2' conducts.

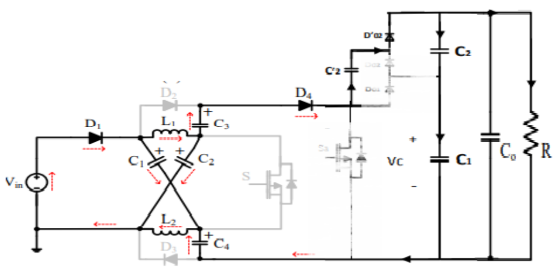

Figure 3(b) Stage 4: operational circuit of proposed converter.

3 SIMULATION SETUP & RESULTS

The simulation parameters for the proposed converter are shown below in Table 1.

Table 1: Simulation Parameters.

Input Voltage	12 V
Input power	450W
Switching Frequency	5 KHZ
Inductor	91.1mH
SC cell Capacitor	56µF
Output Capacitor	20mF
Load voltage	220V
Load Resistance	100 ohm

The simulation circuit of the high gain voltage converter is provided below:

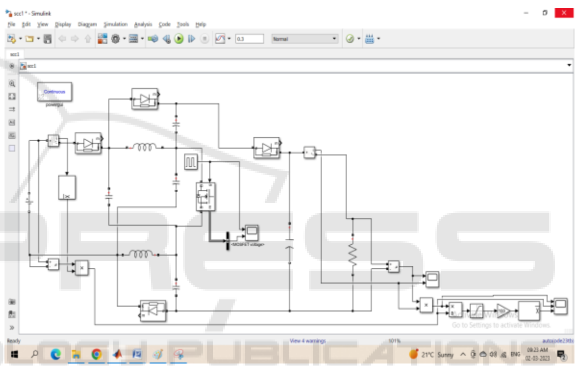

Figure 4: Simulation circuit of SC-ZS converter.

In this, the input voltage is provided as 12V and the output voltage is designed for 220V. The duty ratio is around 0.44 for gating pulse of 5KHz switching frequency. The waveforms of the load voltage and current is shown below:

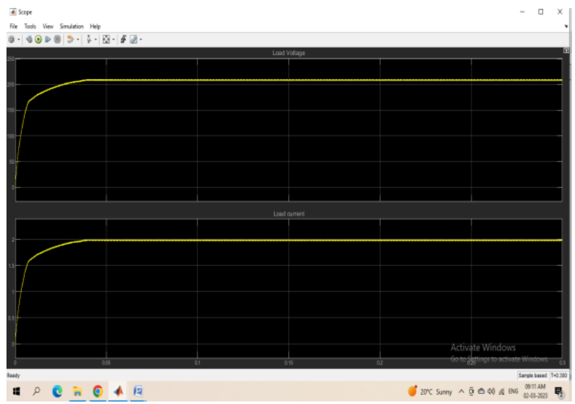

Figure 5: Simulation Waveforms of load voltage and current of SC-ZS converter.

The load voltage is around 220V and current is 2A. The switching gate pulse and the switch voltage stress is provided below:

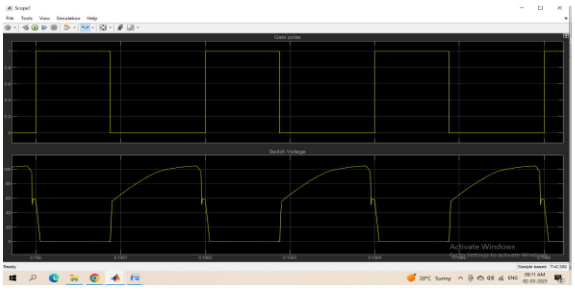

Figure 6: Gate Pulse and voltage waveforms of SC-ZS converter.

The switch voltage is calculated as 104V and here we achieve the switch voltage around 104.5V in simulation of the high gain converter. The efficiency of power curves of the converter is provided below:

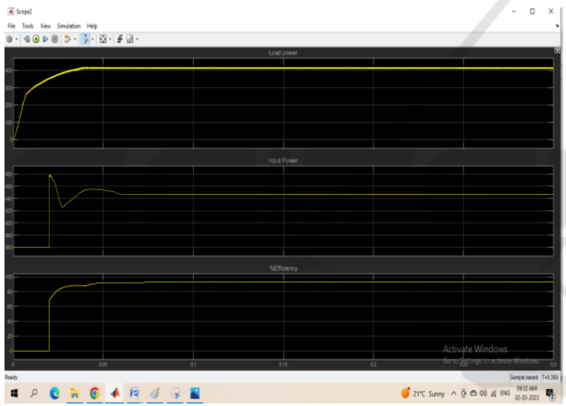

Figure 7: Input Power, Load Power and %Efficiency waveforms of SC-ZS converter.

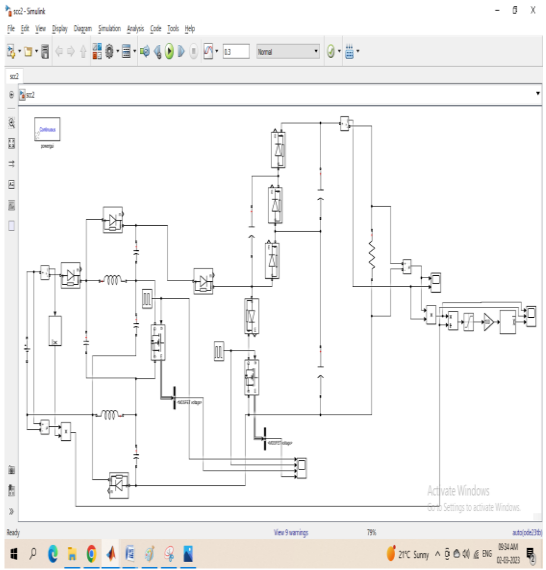

Figure 8: Simulation circuit of the SC-ZS converter with extended SC cells.

The input power is around 447W and load power is around 415W with efficiency as 93.65%. The extended cell is added to the high gain converter and is given in figure 8.

In this, a switched capacitor cell is connected along with the high gain converter and provides supply to the load. The waveforms of load voltage and current of the proposed converter is provided in figure.9 The load voltage is around 275V and load current is 2.6A for the same duty ratio of 0.44. The voltage conversion ratio is further improved by 1.25 times than that of converter without extended switched capacitor cell.

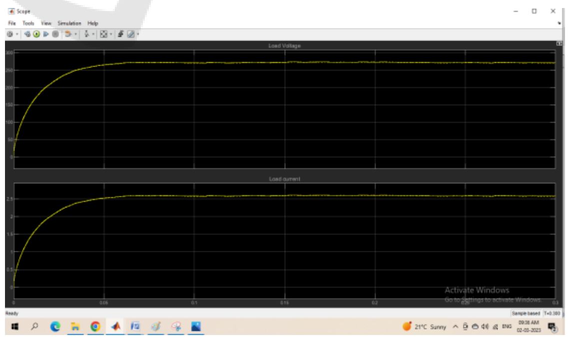

Figure 9: Simulation waveforms of Load voltage and current of SC-ZS converter with extended SC cells.

The efficiency of power curves of the converter is provided below:

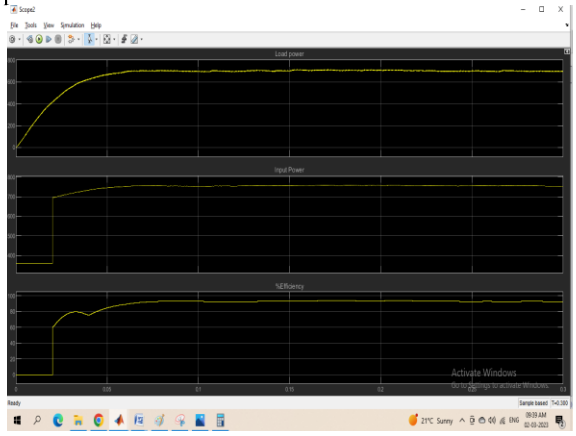

Figure 10: Input Power, Load Power and %Efficiency waveforms of SC-ZS converter.

The input power is around 745W and load power is around 700W with efficiency as 93.1%.

A hardware prototype model of proposed converter with input voltage of 12V is developed with output voltage of 220V with load resistance of 1KΩ. The hardware parameters is provided below in the following Table 2.

Table 2: Hardware Parameters.

IRF 250N - MOSFET	200v, 30A
U1560-DIODE	200-400-600v, 15a
Capacitor	1000µF, 25V 1000µF, 100V
TRANSFORMER	12V, 1A
TLP 250 – DRIVER IC	12V, 1.5A
CD 4050 BUFFER IC	3-18V, 0.32mA
12V REGULATOR 7812	12V, 1A
IN 4007 DIODE	700V, 1A
ARDUINO UNO CONTROLLER	7-12V, 20mA

Arduino uno control is used for generating the pulses for the proposed converter and it is provided to driver circuit (TLP 250) in order to drive the mosfets IRF 250.

The load voltage is provided below:

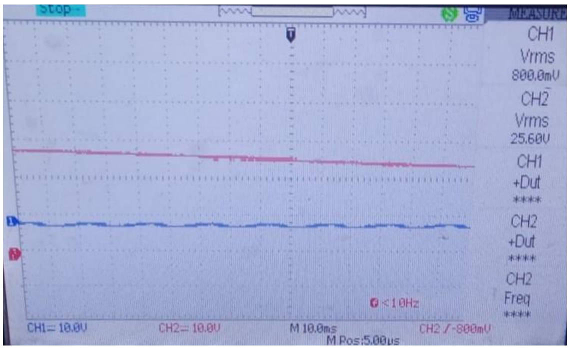

Figure 11: The load voltage of the proposed converter is around 240V with 100V/div in the above waveform.

Figure 12: Hardware Setup of proposed system.

4 CONCLUSIONS

In this paper, switched capacitor based z source converter is designed and the operational modes of the converter was analysed with extended switched capacitor cells. The voltage stress of the switch was calculated and verified with the simulation results. The voltage conversion ratio of sc-zs converter was 18.33 and further improved by 1.25 times by adding switched capacitor cells without any changes in duty ratio. The efficiency of the proposed converter is measured as 93.1% for the input power of 750W and load of 100 ohm. A hardware prototype model was developed and the operation of the proposed converter is verified with the results.The main advantages and applications of this proposed converter are, the voltage gain can be increased without increasing the pulse width and hence the voltage stress is kept lower.

The voltage gain can be further extended by increasing the switched capacitor cells compared to the literature and It can be used for battery charging applications, dc drives, renewable energy.

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