Voltage-Lift Switched Inductor Cuk Converter Structure Using PV Module

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Abstract—*The photovoltaic (PV) generation is one of the most important renewable sources of energy and presents significant worldwide growth every year.The classical cuk DC-DC converter is a step-up/step-down topology with input and output current source characteristics. The step-up static gain of the classical cuk converter may not be enough for a low voltage PV module and the operation at steady-state with an extreme value of duty-cycle cause high current and voltage stress with low efficiency operation. In order to solve these drawbacks a voltage-lift switched inductor technique is applied to the classical cukconverter. The structure presents a voltage-lift topology and two input inductors and two switches comparing with the classical topology that presents only one switch and one input inductor. But the input current is shared in these components and the switch voltage is reduced. These characteristics are interesting for applications with high input current that is the case of low input voltage source. The simulation is done using MATLAB/Simulink R2017a software. The control circuitwas implemented using dsPIC30F2010 controller and results are verified. Experimental results obtained from a 180W converter prototype confirm the theoretical considerations and the simulation results.*

Keywords— *DC-DC converter, cuk converter, voltage-lift switched-inductor.*

I. INTRODUCTION

One of the major concerns in the power sector is the day-to-day increase in power demand but the unavailability of enough resources to meet the power demand. Demand has increased for renewable sources of energy to be utilized along with non-renewable energy resources to meet the energy demand [6]. Renewable energy sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard.

The solar or the Photovoltaic (PV) cell is a source of electric energy which is eco-friendly, free and though it is a renewable source of energy, it is relatively costlier and inefficient nowadays which includes the difficulties related to complete harnessing of solar power. The MPPT or the maximum power point tracking of the PV panel for every type of environmental and climatic circumstances is the vital strategy to get the maximum power output thusincreasing the efficiency of solar power extraction mechanism.

DC-DC converters are widely used in industrial application and renewable energy system. In many applications' high efficiency and high voltage DC-DC converter are required to interface between low voltage sources to high voltage load side. The conversion efficiency and high voltage gain are not easy to achieve with conventional boost converter due to parasitic component. In order to obtain high output voltage, the traditional boost converter should operate at extreme duty cycle this limits the switching frequency and converter size, also increase the electromagnetic interference (EMI) levels.

Many research papers are being proposed several compensation topologies for overcoming these challenges and improving quality. The converter with the coupling inductor can provide high voltage gain in non-isolated DC-DC converters in proportion to winding turns-ratio, but their efficiency is degraded due to the accompanying leakage inductance. Higher switching losses in cascaded topologies prove to be an obstacle to obtain high gain. Isolated converter topologies are used to achieve high voltage gain. Transformers and coupled inductors would increases the size, cost and losses of the isolated converter topologies. And because of transformer used, there is the limitation as to the maximum operating temperature above which the magnetic core heating due to core losses. Avoiding the transformers or/and coupling inductors brings obvious benefits of cost, size and absolutely efficiency. In non-isolated converter topologies are used to overcome the drawbacks of isolated converter topologies.

The proposed structure presents a voltage lifting cell with two input inductors and two switches comparing with the classical topology that presents only one switch and one input inductor. But the input current is shared in these components and the switch voltage is reduced [1]. These characteristics are interesting for applications with high input current that is the case of low input voltage source.

II. VOLTAGE-LIFT SWITCHED INDUCTOR CUK CONVERTER

Fig. 1 shows a voltage-lift switched inductor cuk converter. The converter with PV module as input with 30 V.

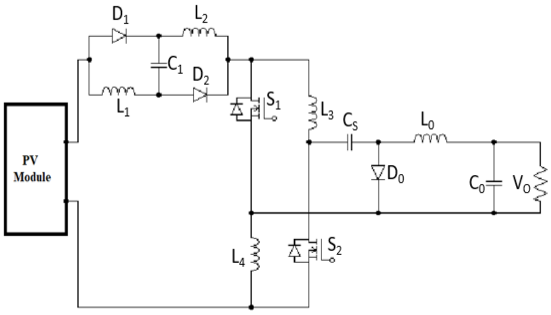

Fig 1: VLSI Cuk DC-DC Converter

The converter has voltage-lift technique with a switchedinductor cuk converter structure. The voltage-lift cell is composed of two inductors L_1 and L_2, two diodes D_1 and D_2, and a charge pump capacitor C_1. Switches S_1 & S_2 and inductors L_3& L_4forming switched-inductor network and both switches S_1-S_2 are commanded simultaneously and the input inductors store energy in parallel during the switches conductions. When the switches are turned-off simultaneously, the energy stored in the input inductors is transferred in series, obtaining a high static gain.

There are three modes of operations and eachmode is explained in the following section.

A. Modes of Operation

There are three modes of operation.

*1) **Stage 1:*** During the switching on period, inductors L_1 and L_2 are charged in parallel by supply voltage V_{IN}. The corresponding voltage across both inductors is equal to V_{IN}. The inductors L_3 and L_4 also gets charged in parallel with DC input source.

Therefore, the equations are

$$V_{L1} = V_{L2} = V_{IN} \quad (1)$$

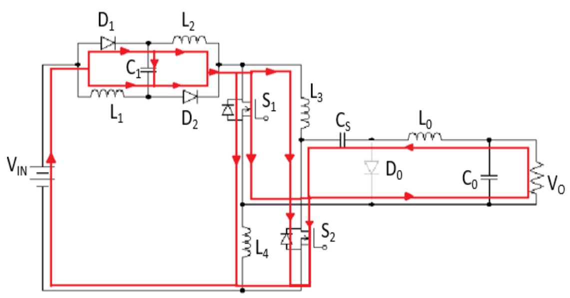

Fig 2: Stage 1

At the same time capacitor C_1 is charged by V_{in} through diode D_1. The energy stored in the capacitor C_s is transferred to the output through the switches S_1

and S_2 and inductor L_o. The diode D_o is blocked during this stage.

$$V_{c1} = V_{IN} \quad (2)$$

*2) **Stage 2:***Switches S_1& S_2 turned OFF and inductors L_1,L_2 and the capacitor C_1 gets discharged. This mode shown in Fig. 3. The inductor L_3 and L_4 decreases from maximum to minimum value until it becomes equal to output current -I_o. When the current in all inductors are equal to -Io the current at the output diode D_o is zero blocking this diode.

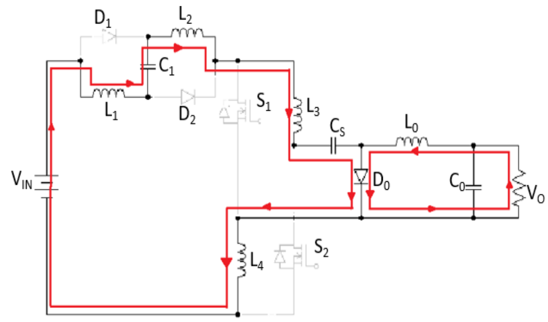

Fig 3: Stage 2

By using volt-second balance principle and thus obtain

$$\frac{V_0}{V_{IN}} = \frac{2D}{1-D} \quad (3)$$

*3)**Stage 3:*** When the diode D_o is blocked the switches S_1 and S_2 are still turned off. The voltage applied across all inductor is zero and the current in all inductor remain constant and equal to -I_o.

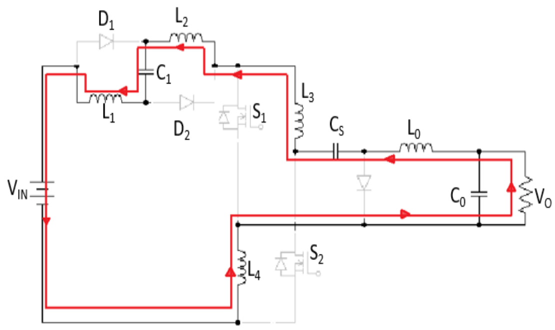

Fig 4: Stage 3

Equations used for modelling the PV module are:

$$I_{Ph} = [I_{sc} + K_i(T - T_{Ref})]\frac{I_r}{1000} \quad (4)$$

$$I_O = I_{rs}\left(\frac{T}{T_{Ref}}\right)^3 exp\left[\frac{qE_g}{nk}\left(\frac{1}{T_{Ref}} - \frac{1}{T}\right)\right] \quad (5)$$

$$I_{PV} = N_P I_{Ph} - N_P I_O \left(\exp\left\{ \frac{V_{PV} + IR_S}{kTN_S n/q} \right\} - 1 \right) - I_{sh} \quad (6)$$

$$I_{Sh} = \frac{V + IR_S}{R_{sh}} \quad (7)$$

III. SIMULATION AND EXPERIMENTALRESULTS

In order to validate the performance of the proposed VLSIDC-DC converter, MATLAB simulations and experiments are carried out. The designed parameters are listed in TABLE I. Duty ratio for switches S_1 and S_2 are given as 75%. The load selected with an R load of 180Ω. The simulation results are shown below.

TABLE I
SIMULATION PARAMETERS

System Specification	Parameters
DC Input Voltage	30 V
Output Voltage	200 V
Switching Frequency	40 kHz
Output Power	180 W
Capacitor C_s	35 mF
Inductor L_o	5 mH
R Load	180 Ω

A. Simulation Results

VLSI converter is working with an input voltage of 30 V. An output voltage of 218 V is getting in the load side. Here 180Ω resistance load is used.The PV voltage and current with irradiance and temperature are shown in Fig. 5. Voltage and current waveforms of input and output are given in Fig. 6. Output voltage and current ripples are also shown in the same figure, it is found that ripples are less than 1%.

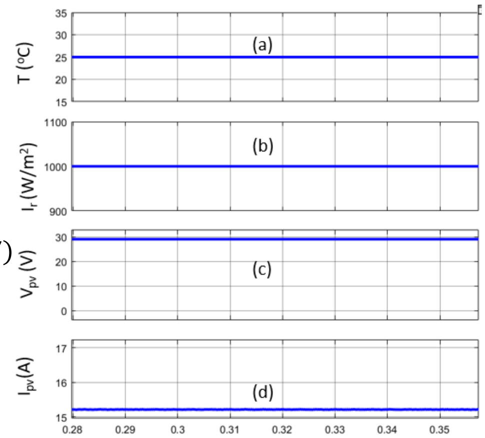

Fig 5: PV Panel(a)Temperature (b)Irradiance (c) Voltage (d) Current

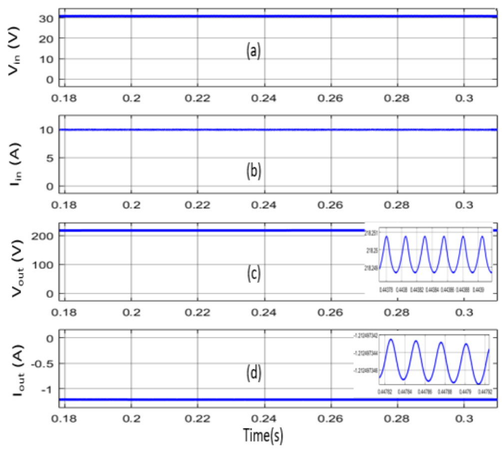

Fig 6: (a)Input Voltage (b)Input Current (c)Output Voltage (d)Output Current

Gate pulses for switches and corresponding voltage stresses are shown in Fig. 7. For switches S_1 and S_2 75% duty ratio is chosen and voltage stress is nearly 160 V.

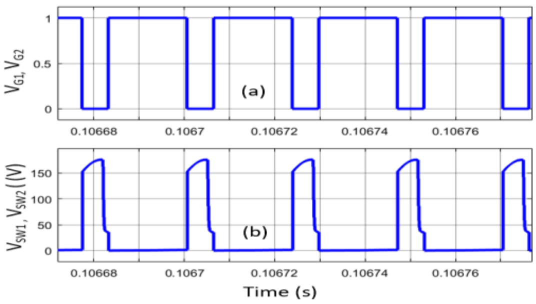

Fig 7: (a)Gate Pulse for Switches S_1 and S_2 (b)Voltage Stress for S_1 and S_2

Current across capacitors and current through inductors are shown in Fig. 8.

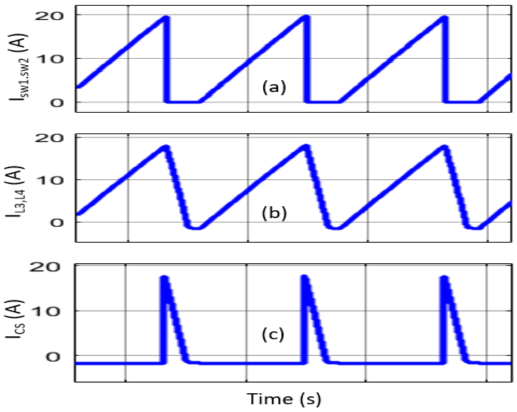

Fig 8: (a) Current across switches S_1 and S_2 (b) Inductor current of L_3& L_4(c) Current across capacitor C_s

B. Analysis of the Converter

Efficiency gain versus duty ratio curve is plotted in Fig. 9. Here efficiency increases as duty ratio increases for the given converter.

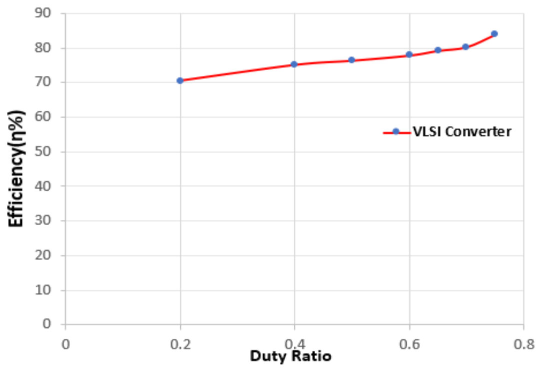

Fig 9: Efficiency Vs Duty ratio

The variation of efficiency in different converters is shown in Fig. 11.

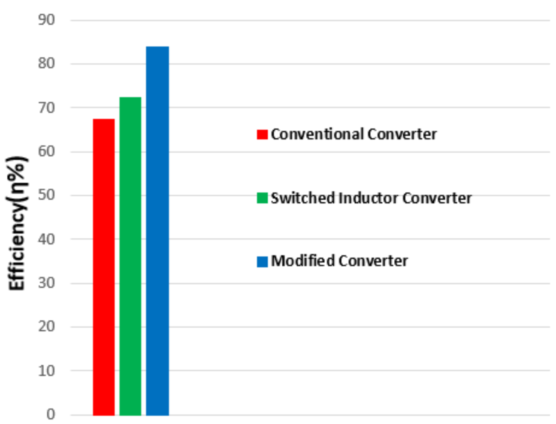

Fig 10: Comparison of Converter

IV. EXPERIMENTAL RESULTS

Inorder to verify the performance of the VLSI DC-DC converter the experimental setup is implemented. A 180 W prototype is implemented in the laboratory.The parameters used for PV modelling used as input for the VLSI converteras given in TABLE II was built. The power supply consists of astep-down transformer, full bridge diode rectifier, filter capacitor and a regulator IC (7812). IRF840 MOSFET is used as switches. TLP250 driver isused to drive the MOSFET. To generate the switching signal dsPIC30F2010 was programmed in the laboratory and necessary waveforms are obtained. The switches are working in 40kHz frequency and have a duty ratio of 0.75. An output voltage of 202V is obtained. The experimental test setup is presented in Fig. 11 and results of converteris given in Fig. 12.

TABLE II
PARAMETERS USED FOR PV MODELLING

Specification	Parameter
Open circuit voltage (V_{OC})	32 V
Short circuit current (I_{SC})	8.5 A
No. of series cells (N_{s})	36
No. of parallel cells (N_{P})	1
Boltzmann constant (k)	$1.3805*10^{-23}$
Electron charge (q)	$1.62*10^{-19}$
Shunt resistor (R_{Sh})	600 Ω
Series resistor (R_{S})	0.0081
Energy gap (E_{g})	1.2
Diode ideality factor (n)	1.3

Fig 11: Experimental Setup

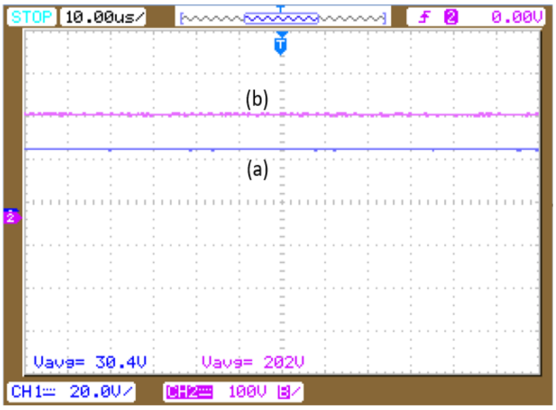

Fig 12: (a)Input Voltage (b)Output Voltage

II. CONCLUSIONS

In this project VLSIDC-DC converter with switched-inductor and voltage lift cell is presented. The DC-DC converter presented here has a high step-up conversion ratio of7.01. The converter using a reduced number ofsemiconductors and a simple structure, which provides current flow just in two switchesduring the switch-on stage. The converter has an efficiency of 83.86 % in P & O method and 90.72%in FOCV method using PV module. The experimental prototype of the VLSI converter is implemented and output voltages are verified.

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