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Switched Capacitor based High Step-up Cuk Converter

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ABSTRACT:Due to the increase in energy demand, the utilization of renewable energy sources is inevitable in various industrial and consumer applications. But it is difficult to use the conventional Cuk converter in situations where a wider input and output voltage range or a larger voltage conversion ratio is required. In ideal conditions, any voltage conversion ratio can be achieved by adjusting the duty cycle of the switch. But the capacity of converter limited by parasitic elements of the circuit, voltage drop across switch and diode take place in actual working conditions. To improve those factors, a new coat circuited Cuk converter based on switched capacitor is introduced. A group of passive circuits termed as coat circuits are proposed for Cuk converter. Not only improving the voltage conversion ratio, but also the stress across the components can be decreased for the Cuk converter introduced. The driver and control circuit of the basic Cuk converter does not change because of the absence of additional switches. The gain of the converter is 16.2 and the efficiency is about 89 %The performance study of the converter is carried out with MATLAB/ SIMULINK R2017a. It is observed that the proposed converter having high gain and less stress compared to the conventional Cuk converter. Also, the output voltage and output power are 777.5V and 753.69W respectively.

KEYWORDS: Cuk Converter, Switched capacitor, DC-DC Converter, Voltage gain

I.INTRODUCTION

In ideal conditions, by adjusting the duty cycle of the switch, any voltage conversion ratio can be achieved using converters. However, in actual working conditions, the boost capacity of these converters is greatly limited by parasitic elements of the circuit and the voltage drop across the switch and diode. And this also makes the application of basic DC/DC converters difficult in situations where a wider input and output voltage range or a larger voltage conversion ratio is required. Many of these conventional DC-DC converters have the disadvantages of operating at high duty-cycle, high switch voltage stress and high diode peak current[2]. To achieve a high voltage conversion ratio, many solutions such as the use of transformers, coupled inductors, cascade structures, switch-capacitors, voltage multipliers or combination of above mentioned techniques have been proposed.

However, the use of transformer would increase the overallsize and cost of the system in situation where isolation is not required. The permutations and combinations of the various voltage-boosting techniques with additional components in a circuit allow for numerous new topologies and configurations, which are often confusing and difficult to follow[2]. The leakage inductive energy of the coupled inductor needs to be considered as it not only increases voltage stress across the switching devices but also necessitates the deployment of complex snubber circuits. When cascaded converters are used several stages are required and that apparently increases the cost and reduces the efficiency of the system. Furthermore, it requires high voltage components at the output stage. Switched capacitor converters have some fundamental problems such as the requirement of large switches, pulsating input current and complex driving circuit.
High voltage conversion gain can also be achieved by combining voltage multipliers with the conventional boost converters where some common advantages like adjustable voltage conversion ratio, lower voltage stresses on semiconductor components are evident. However, there are also some common disadvantages, firstly, at least two-phase interleaved boost converters have to be used together with the Voltage multipliers, secondly, the combined duty cycle of the two switches has to be greater than 1 and there are limitations/boundaries of the selectable duty ratios. Based on buck-boost and SEPIC converters, two high step-up DC-DC converters capable of low voltage stress on the switch are proposed. These two converters do not need additional switches, the control and drive circuit is as simple as basic DC/DC converters. However, as the topological structure of these two converters is fixed, the high step-up voltage conversion capacity of such converters cannot be changed.

To achieve high step-up and high efficiency DC-DC converters is the major consideration in the renewable grid-connected power applications due to the low voltage of PV arrays and fuel cells[3]. [1] presents a family of generalized

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passive circuits termed as coat circuits for DC-DC converters to acquire a variable high voltage step-up capacity. These circuits are termed as coat circuits because such circuits surround theDC-DC converters like a coat and they only need additional passive elements to fit the voltage conversion ratio requirements. The coat circuits do not need any additional active switches, and they do not affect the control or driver circuit design.

Here presents a Cuk converter with switched capacitor. Those circuit elements help the proposed circuit having many advantages. It allows high voltages to be created from a low voltage power source. So,the overall gain of the converter is improved without using more number of components.

II. CIRCUIT CONFIGURATION

The topology of the Cuk converter with the coat circuit of two basic cells (Cuk) is explained. To simplify, Cuk-TBC has been analyzed.It is controlled by a single switch and consists of a coat circuit. An addition of diode and a capacitor is occurred in this diagram. This proposed circuit consist of four inductors and seven capacitors.

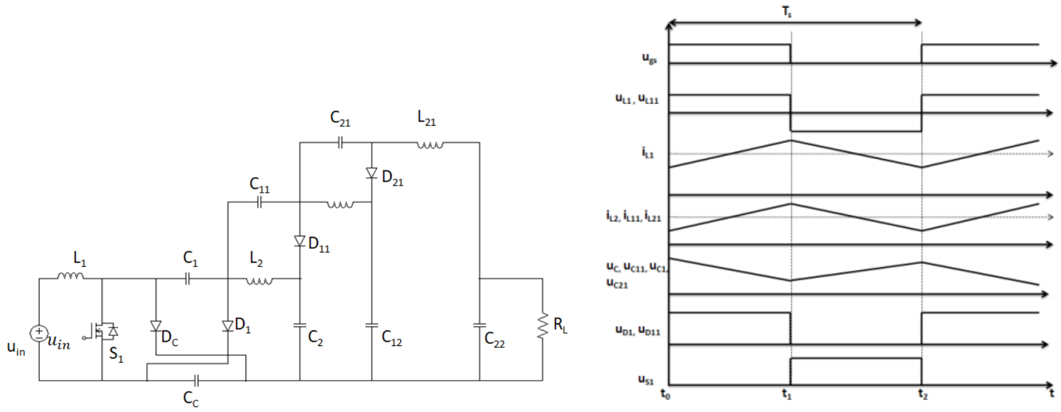

Fig.1 Proposed cuk converter with switched capacitor and corresponding waveform

III.PRINCIPLE OF OPERATION

The assumptions for the analysis are all components are considered to be ideal and all effects of parasitic parameters are neglected,all capacitors are larger and the influence of capacitor voltage ripple is negligible. Similar to Cuk converter, there are two modes when Cuk operates in continuous conduction mode (CCM).

A. Mode 1: Switch S_1 is on state and all diodes work in the reverse biased. In this stage, the input voltage source charges the inductor L_1, the capacitor C_1 charges the inductor L_2, the capacitor C_2, and capacitor C_C . The capacitor C_{11} and C_1 charge the inductor L_{11} and the capacitor C_{12}, the capacitor C_{21}, C_{11} and C_1 charge the inductor L_{21} and the output stage, and all inductor currents are increased linearly. In this interval, C_2, C_{12} and C_{22} are charged but C_1, C_{11} and C_{21} are discharged.

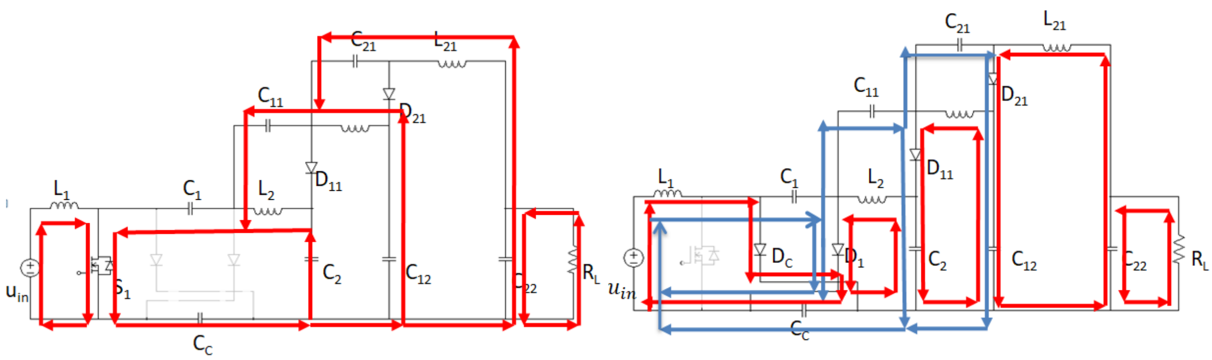

Fig.2 Mode 1 and Mode 2 operation

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B. Mode 2: Switch S_1 is turned off. During this stage, all diodes work in the forward biased state. The inductor current of L_1 branches off through four paths; firstly through C_1, D_1, C_c and u_{in}, secondaly through Dc, Cc and uin .thirdly through C_1, C_{11}, D_{11}, C_2 and u_{in}, and fourthly through C_1, C_{11}, C_{21}, D_{21}, C_{12} and u_{in}. The inductor current of L_2 flows through D_1 and C_2, the inductor current of L_{11} flows through D_{11}, C_2 and C_{12}, the inductor current of L_{21} flows through D_{21}, C_{12} and the output stage. In this interval, C_1, C_{11} and C_{21} are charged whileC_2, C_{12} and C_{22} are discharged, and all inductor currents are decreased.

IV. DESIGN OF COMPONENTS

The passive elements (inductors and capacitors) are sized according to a given limit for their state variable ripple. For inductors the maximum current ripple (ΔI_L) will be taken as a percentage of the inductor average current and voltge ripple (Δu_O) is taken as a percentage of the output voltage u_O.

$u_o / u_{in} = D(n+2)/(1-D)$ ---------------------- (1)

D get its maximum value at 0.8.

$L = (u_{in} * D * T/(\Delta I_L))$ ---------------------- (2)

Here all the inductors and capacitors are of equal values.

$C = (D * I_O * T)/ (\Delta I_C)$ ------------------------(3)

V. SIMULATION RESULTS

The prototype of switched capacitor based cuk converter has nominal power of 754W, 48V as input voltage, inductors and capacitors are of equal values are chosen. To avoid human audible noise we use a switching frequency of 20kHz. Power semiconductors selected were the UJC06505K for the MOSFETs. This converter is obtained with a duty cycle of 0.8 to the expected gain of this converter.

A. SIMULATION PARAMETERS

Parameters	Specification
Input voltage(u_{in})	48V
Switching frequency f_s	100kHz
Output voltage(u_o)	777V
Inductor L_1, L_2 L_{12}, L_{21}	500μH
Capacitors C_1, C_2, C_{11}, C_{21}, C_{12}, C_{22}, C_c	5μF
Load resistance(R_L)	800Ω

Fig.3 Simulation parameters

Simulation results are obtained by using MATLAB. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy way to use environment where problems and solutions are expressed in familiar mathematical notation. SIMULINK is a software package for modelling, simulating, and analysing dynamical systems.

The cuk converter is simulated in MATLAB/SIMULINK by choosing the parameters listed in the figure 3.

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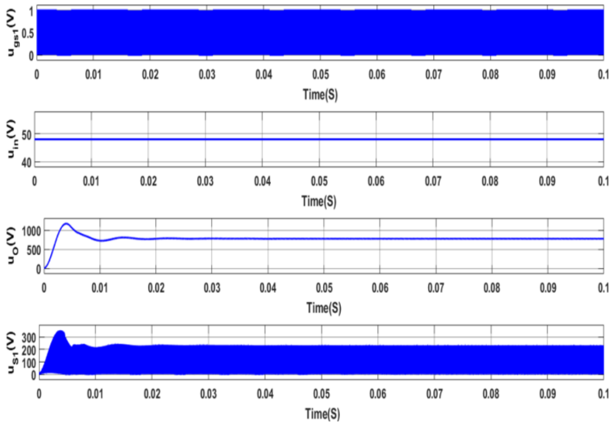

Fig.4. Gate pulse, Input Voltage,

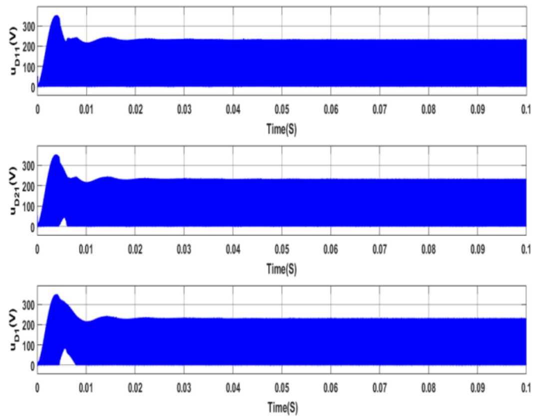

Fig.5. Diode voltages Output voltage, switching stress

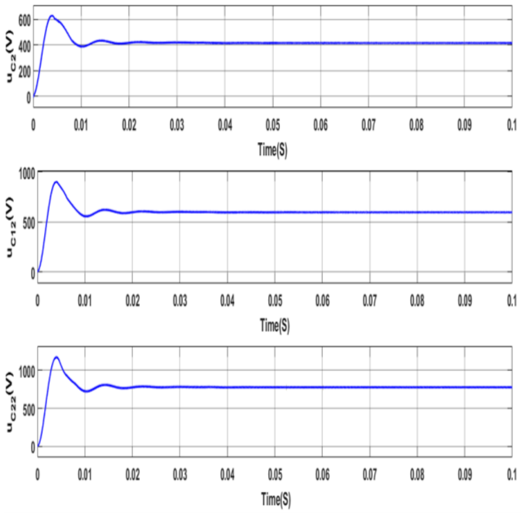

Fig.6.Capacitor voltages

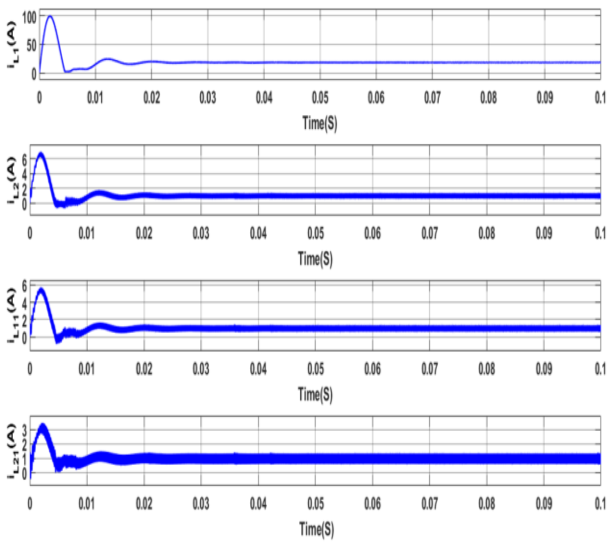

Fig. 7. Inductor Currents

From the figure above, it can be seen that the input voltage u_{in} is 48 V and the switching frequency is chosen to be 100 kHz and the duty ratio of switch is 0.8. The input current obtained has the value of 20A with a small current ripple.The output voltage obtained is 777V with a voltage ripple of 0.3V and its corresponding output current is 1.2A with a ripple of 0.002A. The stress across the switch is 220V.

From the Figure 7, the inductor current of L_1=18.4A and all other inductor currents are 1.2A.Voltage across the capacitorsu$_{C22}$= 777V, u_{C12}= 597V, u_{C2}= 415V, u_{C1}= 233V, u_{C11}=183V, u_{C21}=182V as shown in figure 6.

V. ANALYSIS

The analysis results of the coat circuit for cuk converter is carried out by considering parameters like efficiency, duty ratio, output voltage ripple and switching frequency.

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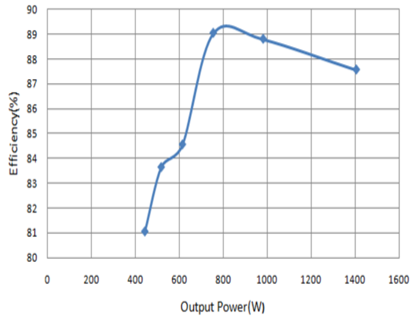

Fig.8: Efficiency Vs Output Power(R Load)

The efficiency tells us the fraction of input power delivered to the load. The converter efficiency is about 89 % for the R load.

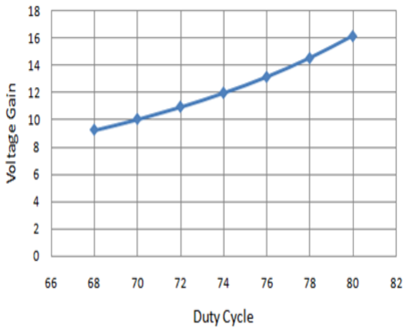

Fig.9: Voltage Gain Vs Duty cycle

The duty ratio of the converter is set as 80% and the corresponding voltage gainobtained is 16.19. Figure 9 discribes that the duty cycle is directly proportional to the voltage gain.

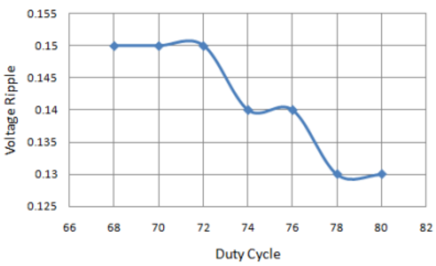

Fig.10: Voltage Ripple Vs Duty Cycle

The graph between voltage ripple and duty cycle is shown in figure 10. The voltage ripple corresponding to 80% duty ratio is about 0.13.

VI.CONCLUSION

Coat ciruit for cuk converter has good voltage conversion ratio by the addition of switched capacitor. Theoretical analysis shows that the converter having more advantages. With no additional active switches are needed, and the control and driver circuit are as simple as of basic DC-DC converters. The number of basic cells of the converter can be varied as per the required applications. The voltage gain of the DC-DC converter has been improved efficientlyand wide range input-output voltage conversion can be obtained. The number of basic units in the coat circuits can be

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optimized to meet the requirements of different applications. The use of transformers to achieve a high voltage conversion ratio would make the circuit bulky and cost of the system may be high,it can be avoided by this coat circuit.No need of snubber circuit to reduce the voltage stress developed by the use of coupled inductor for achieving high voltage conversion ratio. It is obtained that the converter having high efficiency, high gain and less ripple.

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