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Self Lifted SEPIC-Cuk Combination Converter

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Abstract: **A DC-DC converter based on combination of both SEPIC and CUK converter with self lifting property is proposed. In this topology, a single switch is shared by SEPIC and CUK converter. Thus control strategy required for this converter is of less complexity. Voltage gain ratio of both converters can be varied by controlling the duty ratio of single switch. Two additional components: a capacitor and a diode are used in each converter to increase the voltage transfer gain. Voltage lifting is advantageous when duty ratio required is high (usually D<0.9), because D have a practical upper limit. This converter can be used in DC bipolar network as it has a positive voltage output and a negative voltage output. Compared with the classical Cuk and SEPIC converters, the converter increases the voltage boost ability significantly using self-lift techniques. Self lifted SEPIC-CUK converter is simulated in MATLAB/SIMULINK software and comparative study with conventional SEPIC-CUK converter (with two switches) and SEPIC-CUK converter with single switch are performed.**

Keywords: **SEPIC (Single-ended primary inductor converter), CUK, Self lift, SE-Cu CC (SEPIC-Cuk combination converter).**

I. INTRODUCTION

DC-DC step up converters are widely used in computer hardware and industrial applications such as computer power supplies, car auxiliary power supplies etc. The conventional step up converters such as SEPIC and Cuk converters are widely used in industrial applications due to their good characteristics compared to other step up or step down converters. Under different conditions of their duty ratio, both converters can perform step up or step down operation. However, because of the effect caused by parasitic elements, practical values of D have practical limits (usually < 0.9) [5]. So the output voltage and power transfer efficiency of these two converters are seriously restricted by their voltage transfer function. This disadvantage limits the application of SEPIC and Cuk converters in some area of development where it requires high transfer gains. An alternative solution to this problem is to use n-stages connected in cascade, such that the total conversion rate can be increased by an order of n. However, the resulting problems, energy losses, multiple power switches, and large switching surges in transformers significantly increase the control complexity and the cost of these converters [4]. In recent years many techniques are developed for increase the voltage transfer gain with reduced cost and control complexity. The voltage lift technique is a popular method which is widely used in many applications.

II. SEPIC-CUK COMBINATION CONVERTER

If SEPIC and Cuk configurations are compared, it is observed that have identical front end. Both converters have the same voltage conversion ratio with opposite polarities. Hence, it is possible to combine the two structures to build a bipolar-type converter [4] as it is shown in fig.1. As can be seen, the two combined structures share a common ground reference switch and an equivalent inductor at the input. The main advantage of the proposed configuration is that it allows implementation bipolar DC link with only one controllable switch, which simplifies the implementation of control strategies since it is not necessary synchronization of various switches. Moreover, control terminal is connected to ground which simplifies the implementation of the gate drive. In a static way the circuit operates as follows (see fig.1). From fig.1, the performance of SEPIC-Cuk combination converter (SE-Cu CC) can be evaluated in terms of devices stress, low input ripple, and size of magnetic components. It is assumed that SE-Cu CC is operating in CCM, as the SEPIC side requires a larger current across inductor L_2, moreover, Cuk side requires a larger voltage across capacitor C_2. The inductor L_1 and the switch can be operated in parallel for higher power ratings and can be easily reconfigured to obtain different ratings.

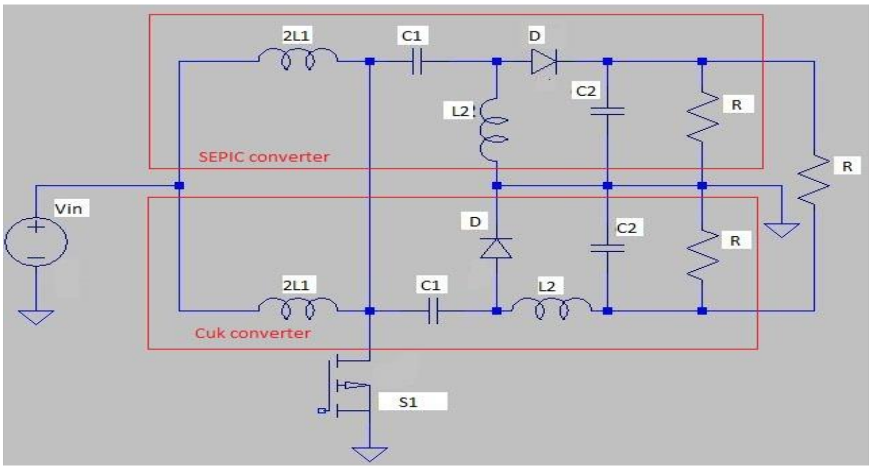

Fig.1. Circuit representation of SEPIC-Cuk converter

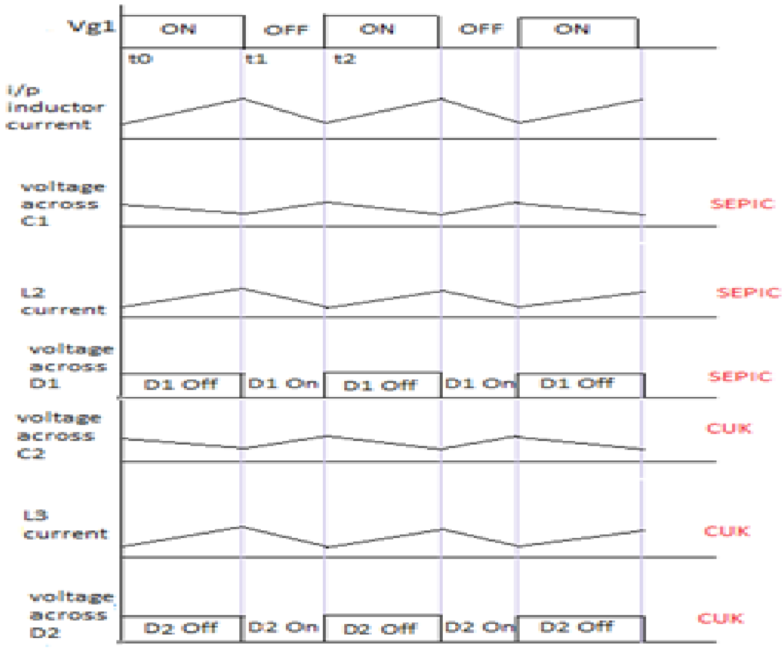

Fig.2. Theoretical waveform

A. Modes Of Operation

Mode 1: When the switch S is turned on, the energy supplied by the generator is stored in L_1 (where L_1 is equivalent inductance of the two inductors at the input with value $2L_1$); inductors L_2 and L_3 also stored energy due to the discharge of C_1 and C_2. During this interval the freewheeling diodes (D_1 and D_2) are off and the energy supplied to the loads is provided by the output capacitors labeled with C. Equivalent circuit of SEPIC-Cuk converter in mode 1 operation is shown fig.3.

Mode 2: When the switch S_1 is turned to OFF, inductors recharge capacitors C_1 and C_2 through the freewheeling diodes (D_1 and D_2) and supply power to the loads. Theoretical waveform is shown in fig.2.

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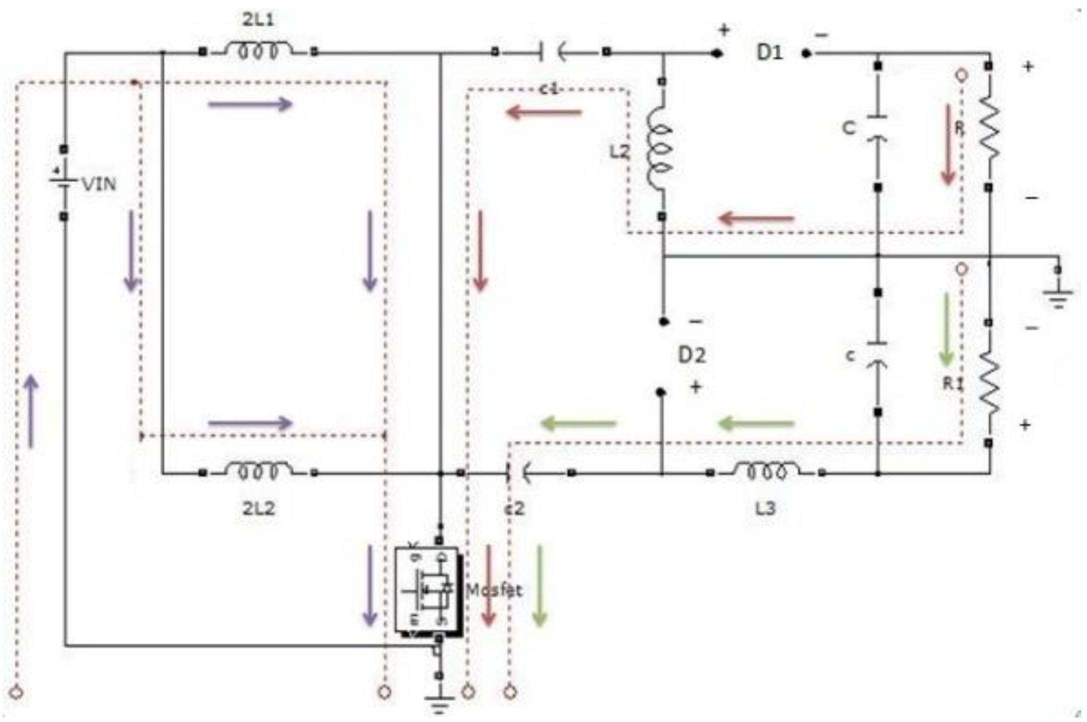

Fig.3. Equivalent circuit of SEPIC-Cuk converter in mode 1

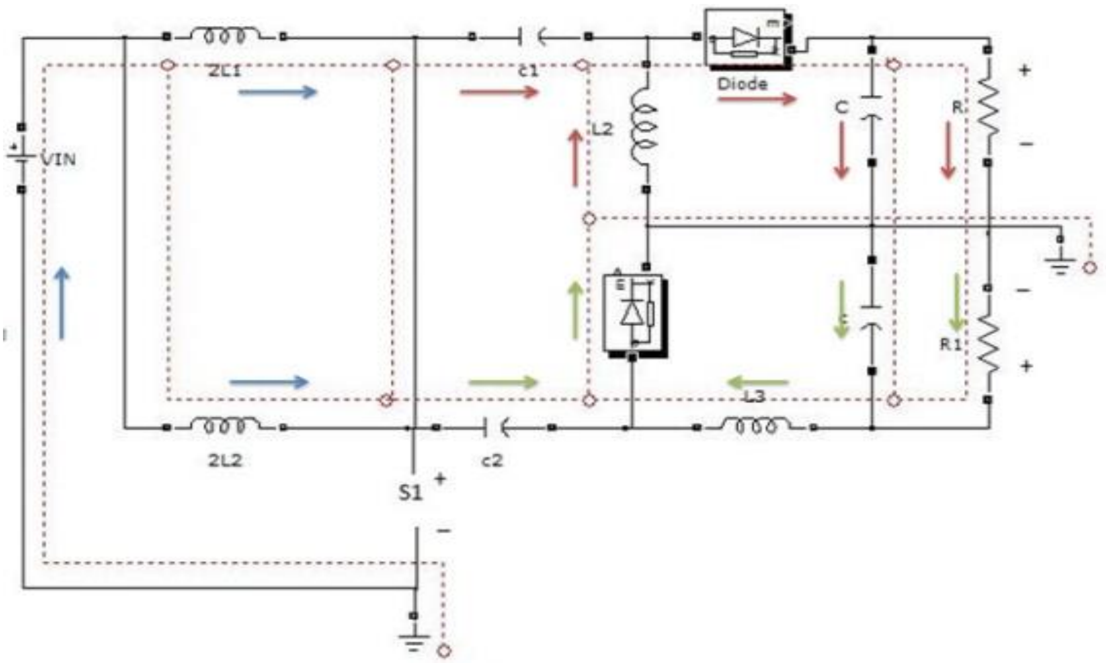

Fig.4. Equivalent circuit of SEPIC- Cuk converter in mode 2

III. SELF LIFTED SEPIC-CUK CONVERTER

SEPIC-Cuk converter is modified into a high gain self lifted SEPIC-Cuk converter by adding a diode and capacitor to each converter. Circuit diagram of self lifted SEPIC-Cuk converter is shown in fig.5. SEPIC converter consists of a link capacitor C_1 and a lift capacitor C_2. Energy stored in these capacitors is transferred to output. Similarly Cuk converter also consists of a link capacitor C_4 and a lift capacitor C_5.

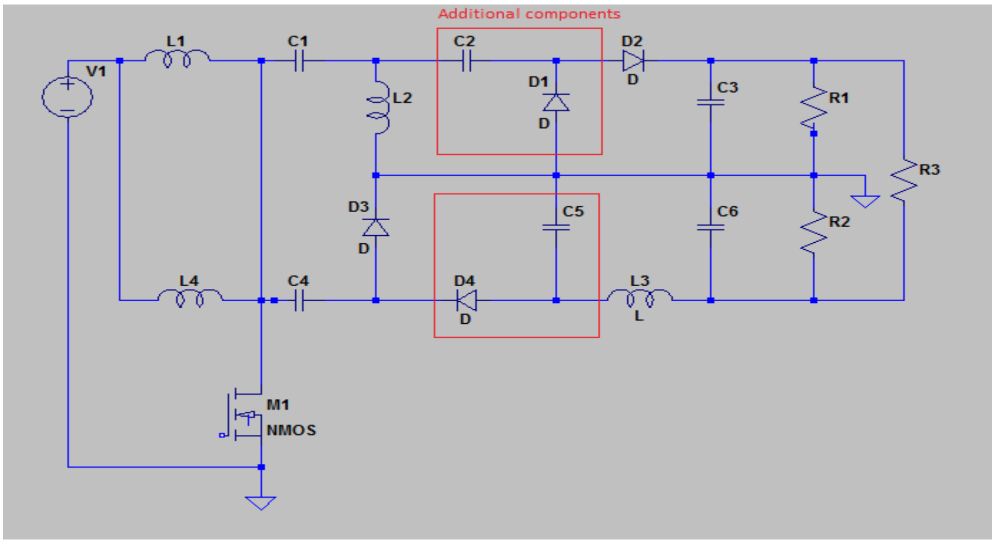

Fig.5. Self lifted SEPIC-Cuk converter

A. Modes Of Operation

Mode 1: When switch is ON, diodes D_1 and D_4 are ON, D_2 and D_3 are OFF. Equivalent circuit in mode 1 operation is shown in fig.6.In this mode, input inductor L_1 is charging from the input supply. In SEPIC converter, link capacitor C_1 and inductor L_2 will be discharging through the path shown. At the same time inductor L_2 charges the lift capacitor C_2. Output is provided by the output capacitor. In Cuk converter, link capacitor C_4 and inductor L_3 are discharging. At the same time it charges the lift capacitor C_5 and provides the output.

Mode 2: When switch is OFF, diodes D_2 and D_3 are ON, D_1 and D_4 are OFF. Equivalent circuit of self lifted SEPIC-Cuk converter in mode 2 operation is shown in fig.7. In this mode, input inductor L_1 is discharging. In SEPIC converter, link capacitor C_1 and inductor L_2 will be charging through the path shown. At the same time inductor L_2 charges from the input supply. Lift capacitor C_2 along with the input inductor provides the output voltage. In Cuk converter, link capacitor C_4 and inductor L_3 are charging. Lift capacitor charges the inductor L_3 and provide negative output voltage.

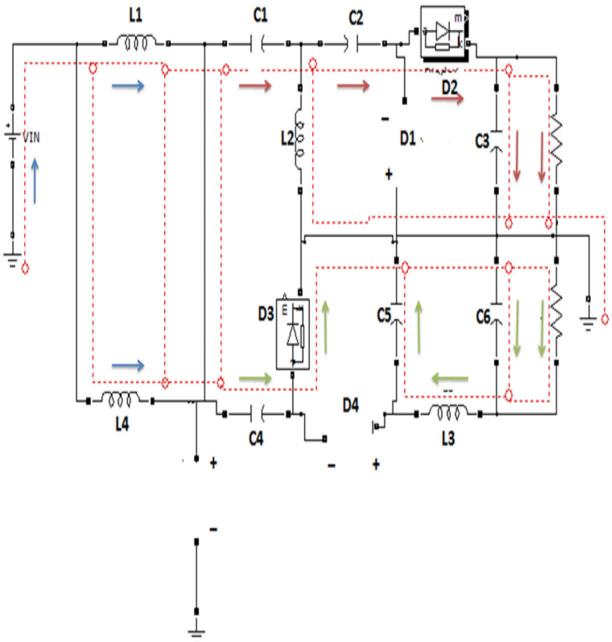

Fig.6. Equivalent circuit of self lifted SEPIC-Cuk in mode 1

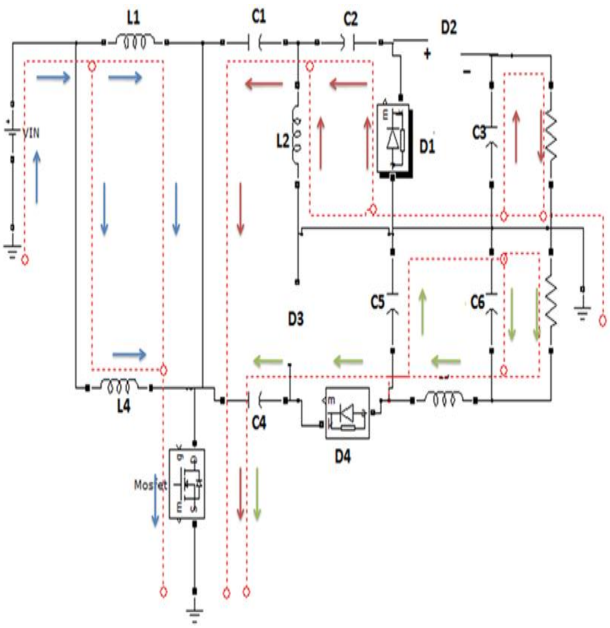

Fig.7. Equivalent circuit of self lifted SEPIC Cuk in mode 2

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IV. SIMULATION RESULTS

A. Simulation Of SEPIC-CUK Combination Converter

In this simulation work, SEPIC-Cuk converter and self lifted SEPIC-Cuk converter are done by using MATLAB SIMULINK 2010.Simulation parameters of SEPIC-Cuk converter are shown in Table.I.

TABLE.I : Simulation Parameters

V_{in}	12V
Input inductor, $2L_1$	3 mH
Inductor L_2, L_3	1 mH
Link capacitor C_1, C_4	167 µF
Output capacitor C_3, C_6	14 µF
Switching frequency fs	50 kHz
Duty cycle	75%
Output resistor, R	108Ω
V_{out}	36V

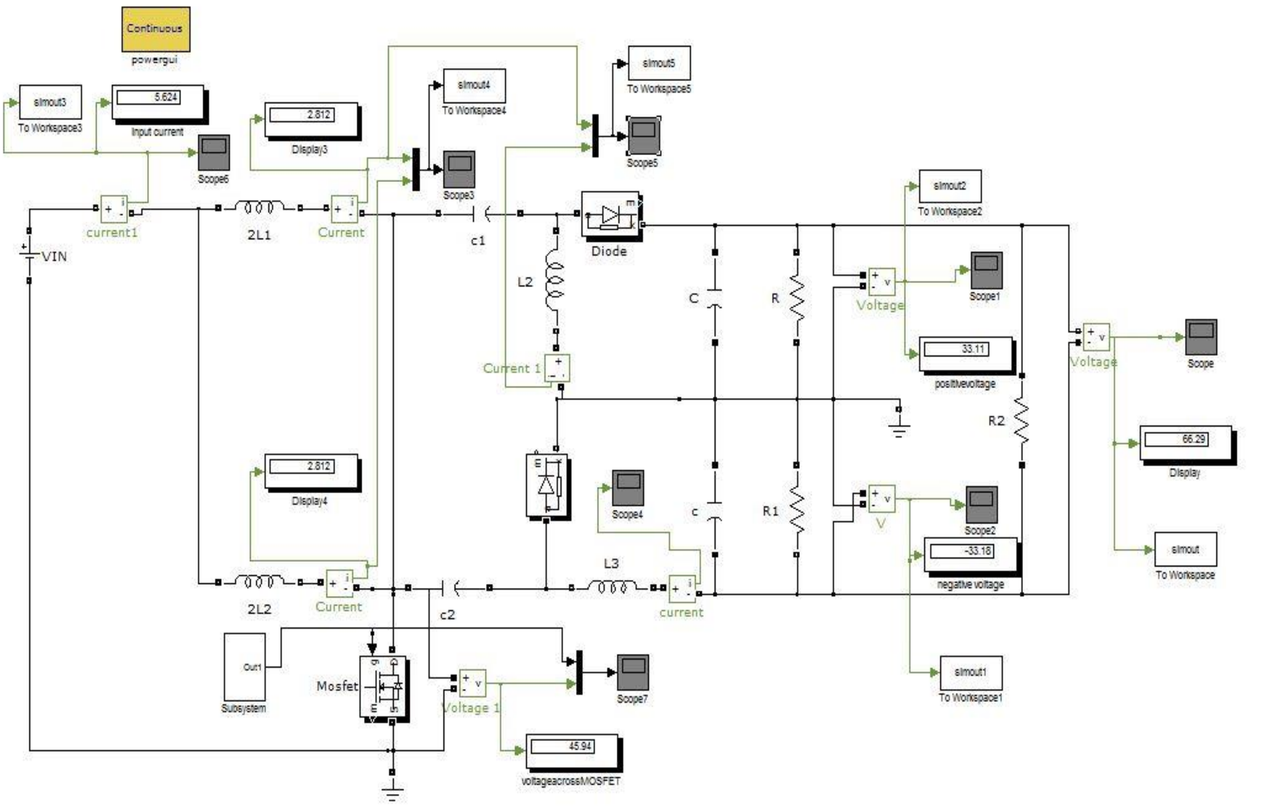

Fig.8. Simulink model of SEPIC-Cuk Converter

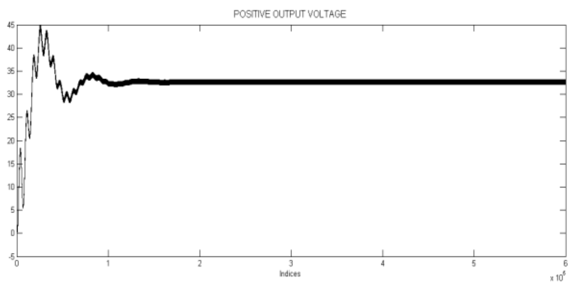

Fig.9. Positive output voltage

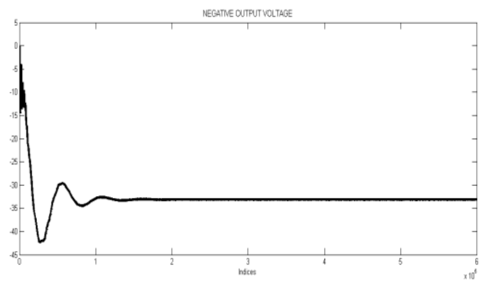

Fig.10. Negative output voltage

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Pulse generating circuit required is of less complexity as there is only one switch. PWM is shown as a subsystem in the SIMULINK MODEL. From simulation results input voltage 12V, output voltage 33.11V (SEPIC) and -33.18V (Cuk), input ripple current 0.25A, voltage stress across switch 45.1V are measured.

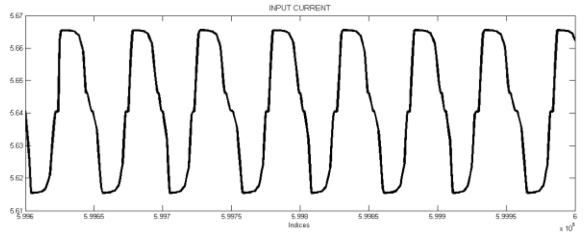

Fig.11. Input current

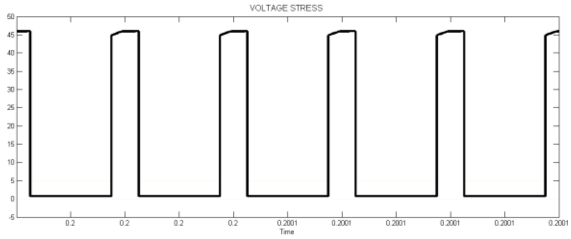

Fig.12. Voltage stress across switch

Input inductors current can be measured as 5.65A. The input current of converter is twice as inductors current and it is equal to 11.20A.

B. Simulation Of Self Liftes SEPIC-CUK Combination Converter

A self lifted circuit is designed for conversion of 12V to 48V by using the same duty ratio as that of SEPIC-Cuk converter, but by adding two more components: a diode and capacitor. Simulation diagram of self lifted SEPIC-Cuk converter is shown in Fig.13. Parameters used for simulation are shown in Table.II.

TABLE.II: Simulation Parameters

V_{in}	12V
Input inductor, $2L_1$	3 mH
Inductor L_2, L_3	1 mH
Link capacitor C_1, C_4	167 µF
Output capacitor C_3, C_6	14 µF
Voltage lift capacitor C_2, C_5	167 µF
Switching frequency fs	50 kHz
Duty cycle	75%
Output resistor, R	108Ω
V_{out}	48V

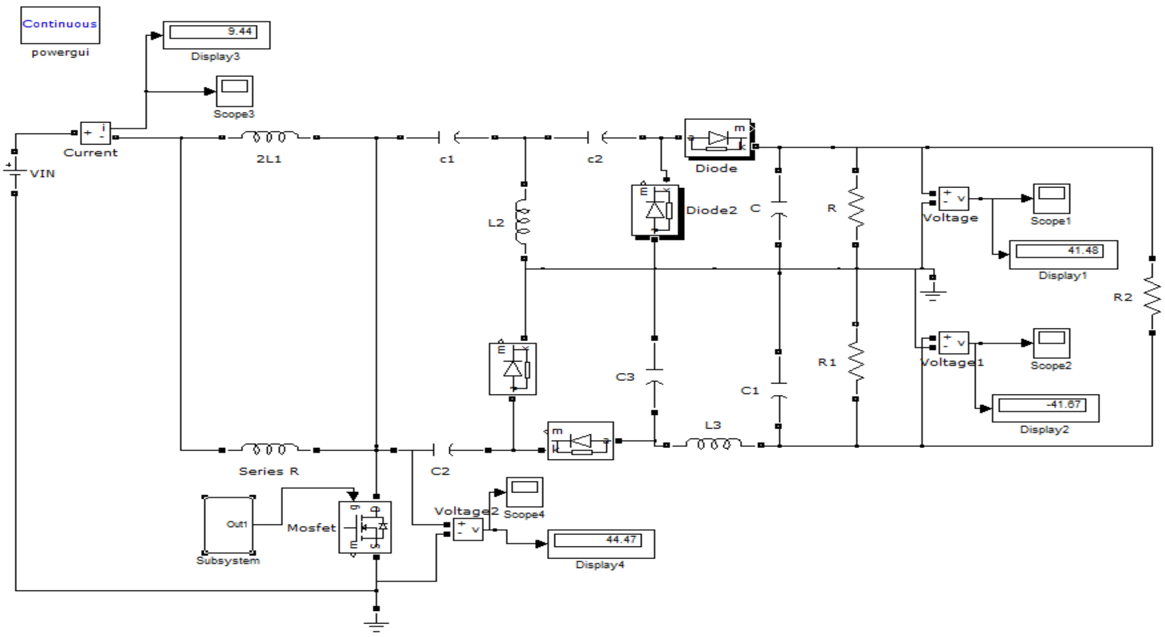

Fig.13. Simulink model of Self Lifted SEPIC-Cuk converter

TABLE.III : Comparative study

Parameters	SEPIC-CUK converter	Self lifted SEPIC-Cuk combination converter
Voltage transfer gain	D/1-D	1/1-D
Output voltage	33.11V -33.18V	41.48V -41.67V
Voltage stress across switch	$V_{in}+V_o$ 46V	V_o 43.02V
Voltage stress across diode	$V_{in}+V_o$ 46V	V_o 42V

Output of self lifted SEPIC-Cuk converter is shown in Fig.14 and Fig.15. The output voltage from the resulting graph is 41.48V for SEPIC and -41.67V for Cuk converter.ie. Output voltage transfer gain is increased by about 9V.Input current is shown in Fig.11 and is measured as 9.45A. Voltage across lift capacitors and link capacitors are analysed from the Fig.18 to Fig.21. In SEPIC converter voltage across link capacitor is of about 12V which is equal to its input voltage. For Cuk converter voltage across link capacitor is 41.63V which is approximately equal to its output voltage. Similarly for lift capacitors also, voltage across it is 12V (approx) in SEPIC and 41.54V (approx) in Cuk converter. A comparative study table is shown in Table.III.

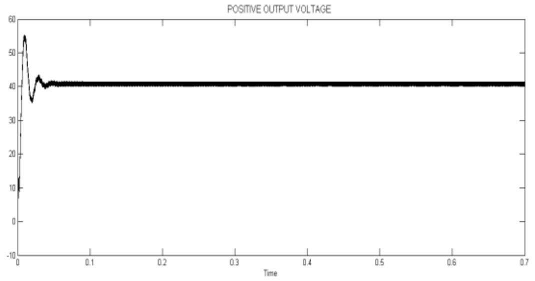

Fig.14. Positive output voltage

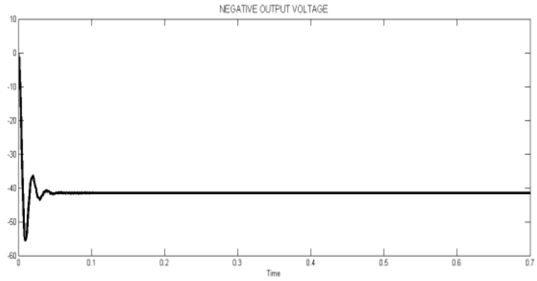

Fig.15. Negative output voltage

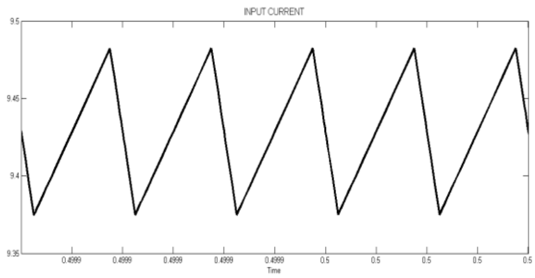

Fig.16. Input current

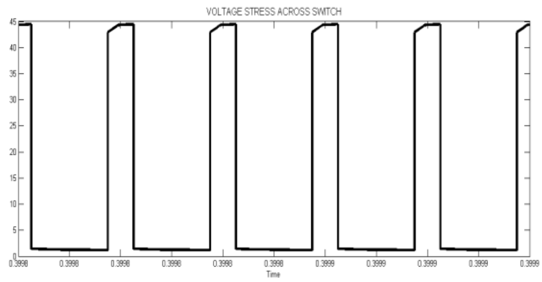

Fig.17. Voltage stress across switch

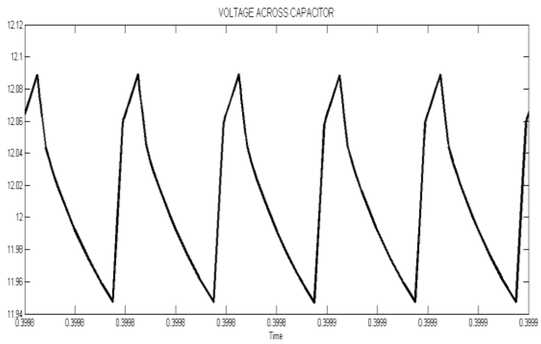

Fig.18. Voltage across link capacitor (SEPIC)

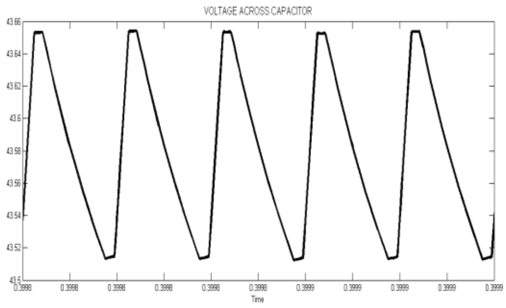

Fig.19. Voltage across link capacitor (Cuk)

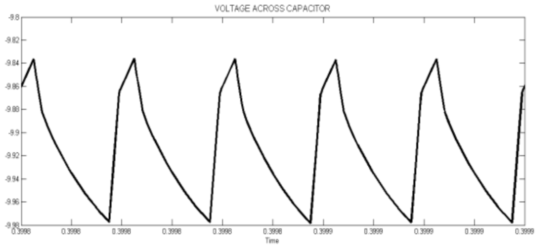

Fig.20. Voltage across lift capacitor(SEPIC)

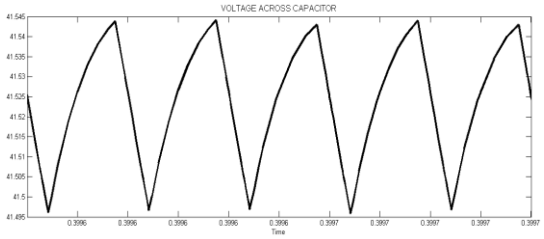

Fig.21. Voltage across lift capacitor (Cuk)

V. CONCLUSION

A self lifted SEPIC-Cuk converter with a higher voltage transfer gain, lower voltage stress and reduced control complexity is introduced. In this converter synchronization between two switches are not required, because only a single switch is used to control both converters. Output of both converters can be controlled by varying the duty ratio of a single switch. Thus the control complexity is reduced. Self lift technique increases the voltage transfer gain of SEPIC-CUK combination. Transfer gain is increased by 27.7 %. Voltage stress across switch for self lifted SEPIC-Cuk converter is less than that of conventional combined SEPIC-Cuk converter. And also diode has less voltage stress in this new configuration. This circuit has simple structure, gate driver circuit required is simple, because of only single switch. This SEPIC-Cuk combination can be used in bipolar DC link based applications.

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