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High Gain Interleaved Cuk Converter with Phase Shifted PWM

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----------ABSTRACT----------
DC-DC converters with ripple on input source current inject harmonics to the power system which in turn cause harmful to other connected devices. These converters with high efficiency and low input current ripple are essential in most common applications. Cuk converter provide reduction in the ripple of input and output current compared to other traditional converters which can be used for either step up or step down applications. Generally, a conventional cuk converter in continuous conduction mode brings in large current ripple on input side which in turn injects harmonics to the source. This undesirable input current ripple is mitigated by employing the interleaved cuk converter (ICC). Simulation results of ICC shows that the input ripple current has been reduced significantly from 7.5A to 1A compared to conventional cuk converter. The energy-transfer-capacitor in basic cuk converters is splitted into two capacitors. The rectifier diode is replaced by two diodes that form with the two capacitors a switched-capacitor circuit, which appears connected between the input and output inductances of the original converter. A hybrid circuit, presenting a higher DC voltage ratio than the classical Cuk circuit can be obtained. A high gain interleaved cuk converter is designed and simulated in MATLAB/SIMULINK for 40V with an input of 20V.

Keywords: *Cuk converter, Pulse Width Modulation (PWM), High gain ICC, Interleaved cuk converter (ICC), Phase shifted PWM.*

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I. INTRODUCTION

DC-DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. The DC-DC converter is an electrical circuit that transfers energy from a DC source to a load. The energy is first transferred through electronic switches to energy storage devices and then subsequently switched from storage into the load[5].DC-DC converters with ripple on input source current inject harmonics to the power system which in turn cause harmful to other connected devices. Converters with high efficiency and low input current ripple are essential in most of the operations. Common applications are in most of the operations of battery chargers, ups, computers, solar energy etc [1].

Cuk converter is essentially a boost converter followed by a buck converter with a capacitor to couple the energy. The main applications of this circuit are in regulated dc power supplies. A negative polarity output may be desired with respect to the common terminals of the input voltage. The average output is either higher or lower than the dc input voltage. The cuk converters have low switching losses and the highest efficiency. It can provide better output current characteristics due to the inductor on the output stage. Cuk converter provides reduction in the ripple of input and output current [6]. Interleaved converters are used for improving the dynamic input current performance which enhances the power quality so that it helps to trim down injection of harmonics to the power system. The current stress of the switch is not increased which provides advantages over conventional interleaved converter circuit [2].

In this paper, modified cuk circuit is used inorder to extend the idea of inserting a capacitor circuit into a classical converter. DC supplies already contain an inner capacitor which plays the role of energy transferring element. The energy-transfer-capacitor in basic Cuk converters is splitted into two capacitors [7]. These hybrid converters have many advantages: good efficiency, less voltage stress, and allows a choice of lower-rated transistors and diodes, which results in low conduction losses and good transient performance [7].

II. INTERLEAVED CUK CONVERTER

An interleaved cuk converter is used to overcome the drawbacks input current ripple and switching stress of traditional cuk converter without sacrificing its efficiency and provide better performance. An ICC topology consists of four inductors, three capacitors, two switches and two diodes. Hence the switching stress reduced to half compared all conventional DC to DC converters.

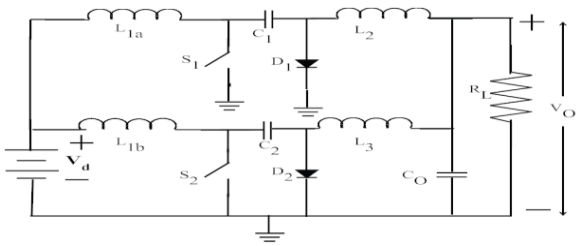


Fig. 1. Circuit diagram of Interleaved Cuk converter

2.1. Modes of operation

Mode 1 - S_1 ON and S_2 OFF (t_0-t_1): When switches S_1 ON and S_2 OFF where L_{1a} charges and at the same time inductor L_{1b} discharges. The stored energy in L_{1b} transfers to C_1 and it charges. Also the capacitor C_1 discharges through C_1, S_1, C_o, L_2 and R_L, hence transfers stored energy in the capacitor to the load. The load current is assumed constant and flows in negative direction.

Mode 2 - S_1 OFF and S_2 OFF (t_1-t_2): When both switches S_1 and S_2 is in OFF condition, both inductors L_{1a} and L_{1b} are discharging and stored energy transfers to capacitors C_1 and C_2 respectively and C_1 start charging. At the same time inductors L_2 and L_3 are discharging and transfer its energy to load and driving it.

Mode 3 - S_1 OFF and S_2 ON (t_2-t_3): When the switches S_1 OFF and S_2 ON where L_{1b} charges and at the same time inductor L_{1a} discharges. The stored energy in L_{1a} transfers to C_1 and it continues to charge. Also the capacitor C_2 discharges through C_2, S_2, C_o, L_3 and R_L, hence transfers stored energy in the capacitor to the load.

Mode 4 - S1 OFF and S2 OFF (t_3-t_4): The operation is as same as that of mode 2.

III. HIGH GAIN INTERLEAVED CUK CONVERTER

A high gain interleaved cuk converter is introduced with Phase Shifted PWM technique to overcome the drawback of switching stress of traditional Cuk converter without sacrificing its efficiency and provide better voltage gain. The input capacitor in a classical Cuk converter is splitted into two equal capacitors. The rectifier diode is replaced by two diodes, which are re-arranged such that to form a switched-capacitor circuit S_2, C_2, D_2, C_3, D_3 in its operation, it changes cyclically the capacitors interconnection from a series to a parallel one. Thus, a high gain ICC consists of four inductors, four capacitors, two switches and three diodes.

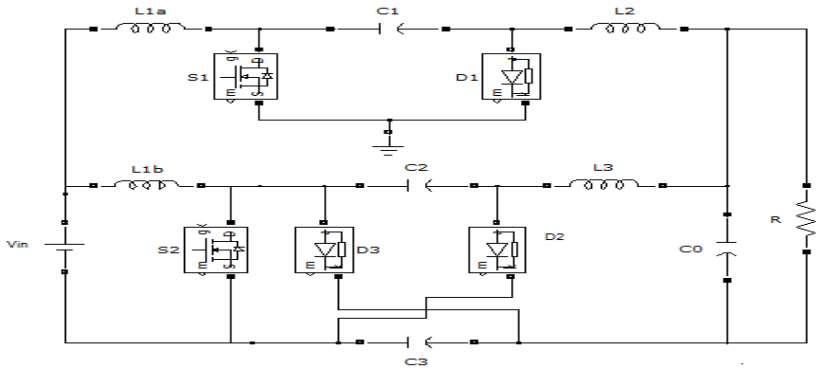
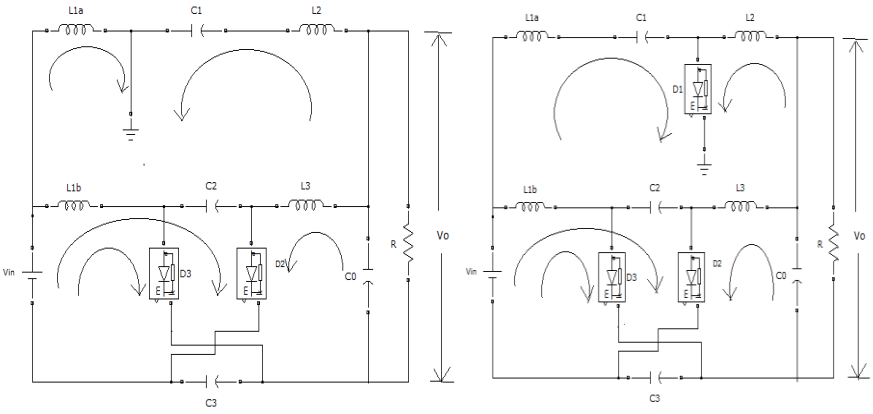


Fig. 2. Circuit diagram of High Gain Interleaved Cuk converter

3.1. Modes of operation

Mode 1 - S_1 ON and S_2 OFF (t_0-t_1): When switches S_1 ON and S_2 OFF and the diagram is shown in the figure where L_{1a} charges and at the same time inductor L_{1b} discharges. When S_2 is off diode D_2 and D_3 will be forward biased. The stored energy in L_{1b} transfers to C_2 through diode D_2 and to C_3 through diode D_3 and it charges. Also the capacitor C_1 discharges through C_1, S_1, C_o, L_2 and R_L, hence transfers stored energy in the capacitor to the load. The load current is assumed constant and flows in negative direction.



(a) (b)

Fig.3. Modes of operations a) Mode 1 b) Mode 2

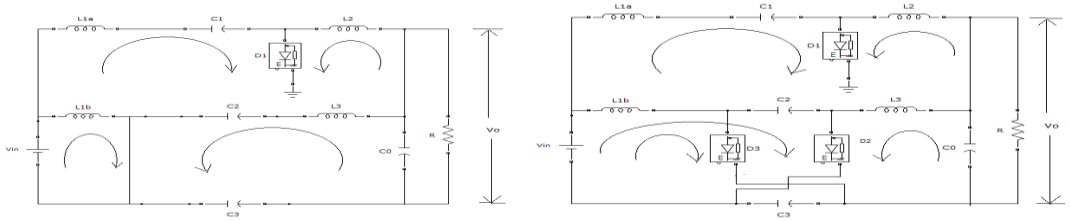
Mode 2 - S_1 OFF and S_2 OFF (t_1-t_2): When both switches S_1 and S_2 is in OFF condition, both inductors L_{1a} and L_{1b} are discharging and stored energy transfers to capacitors C_1, C_2 and C_3 respectively and C_1 start charging. The diodes D_1, D_2 and D_3 will be forward biased. At the same time inductors L_2 and L_3 are discharging as shown in Figure, transfers its energy to load and driving it.

Mode 3 - S_1 OFF and S_2 ON (t_2-t_3): When the switches S_1 OFF and S_2 ON as shown the equivalent circuit in figure where L_{1b} charges and at the same time inductor L_{1a} discharges. The stored energy in L_{1a} transfers to C_1 and it continues to charge. Also the capacitor C_2 discharges through C_2, S_2, C_o, L_3 and R_L and C_3 discharges through C_3, C_o, L_3 and R_L hence transfers stored energy in the capacitor to the load.

Mode 4 - S_1 OFF and S_2 OFF (t_3-t_4): The operation is as same as that of mode 2.

IV. SIMULATION MODELS AND RESULTS

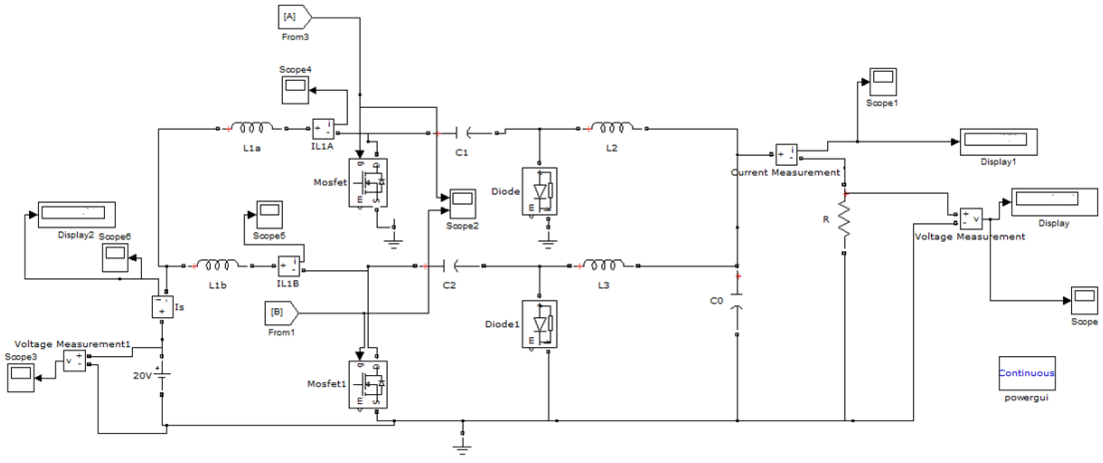
The performance of the circuit is studied by using MATLAB/Simulink model. The high gain interleaved cuk converter is designed with an input voltage of 20V and output voltage of 40V for an output of 80W.The switching frequency is kept to a nominal value of 10 kHz. Let the input current ripple be equal to 7.5A and voltage current ripple equal to 100V.



(a) (b)

Fig.4. Modes of operations a) Mode 3 b) Mode 4

4.1. Interleaved Cuk Converter



(a)

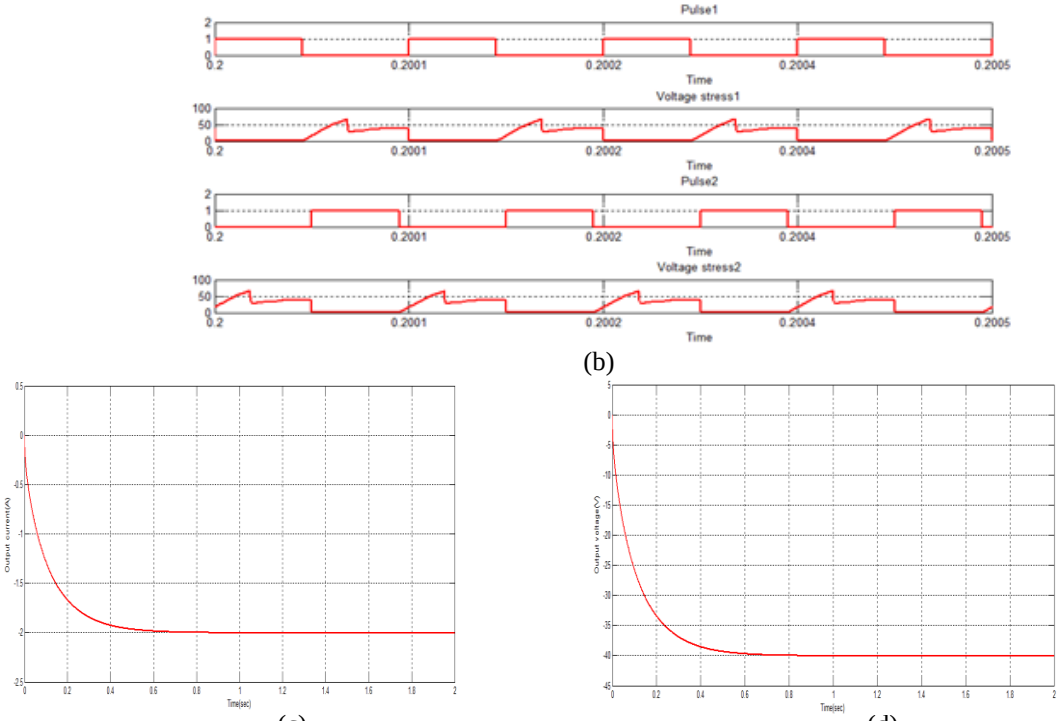
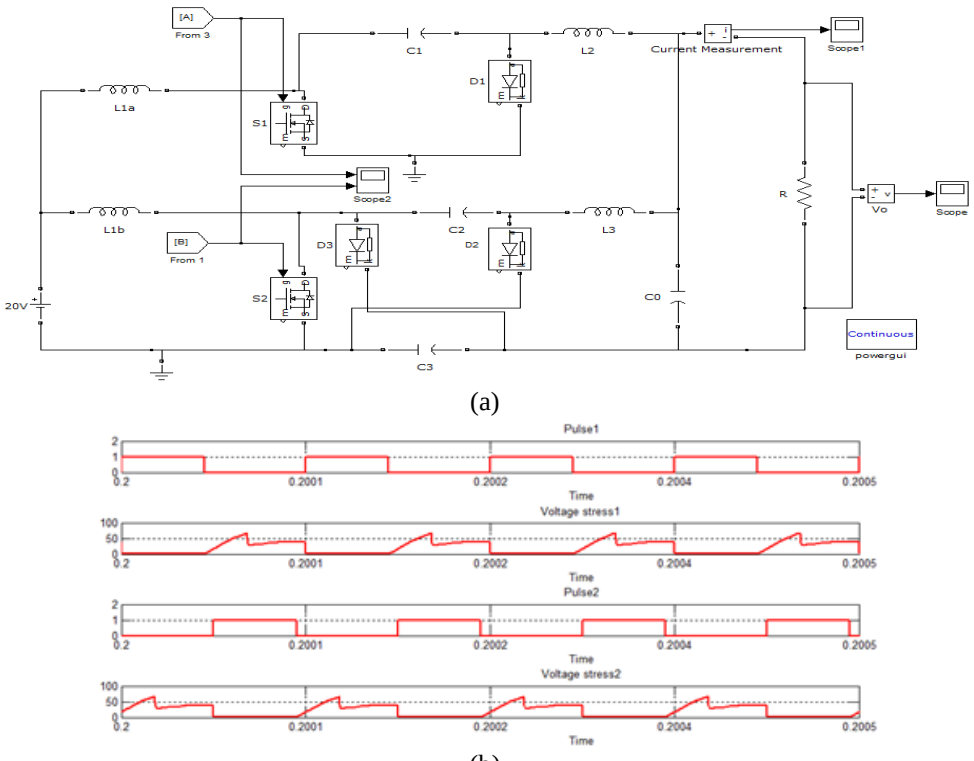
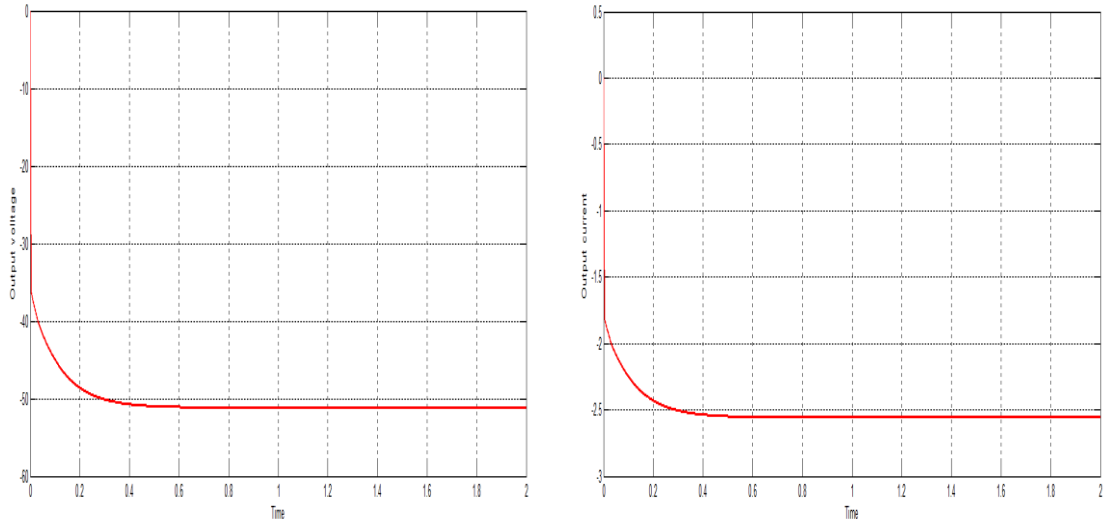


Fig.6. a) Simulink model b) Pulses and voltage stresses c) Output current d) Output voltage

Figure shows the gate pulse for interleaved cuk converter. The output feedback voltage is compared in an error detector with set value of 40V. A DC signal compared with sawtooth waveform and generated PWM is used to trigger the switch. The switching frequency is kept to a nominal value of 10 kHz. The signal from PSPWM is applied to turn ON the switches of ICC hence the switching stress is reduced to 70V.The output current is also ripple free and it is equal to 2A. The interleaved cuk converter provides negative output current.

4.2. High Gain Interleaved Cuk Converter





(c) (d)

Fig.6. a) Simulink model b) Pulses and voltage stresses c) Output current d) Output voltage

Figure shows the gate pulse for interleaved cuk converter. The output feedback voltage is compared in an error detector with set value of 40V. A DC signal compared with sawtooth waveform and generated PWM is used to trigger the switch. The switching frequency is kept to a nominal value of 10 kHz. The signal from PSPWM is applied to turn ON the switches of ICC hence the switching stress is reduced to 60V.

4.3. Comparative Study

By modifying ICC to high gain interleaved topology, the voltage stress has reduced to 60V which is a remarkable advantage compared to existing conventional cuk converters (100V). Further the efficiency is not sacrificed in order to reduce input current ripple. The developed high gain interleaved cuk converter has an efficiency of 96.4 percent.

Table 1: Comparative Study

Parameter	Conventional cuk converter	Interleaved cuk converter	High gain ICC
Input voltage	20V	20V	20V
Output voltage	40V	40V	52V
Output current	2A	2A	2.6A
Voltage stress	100V	70V	60V
Output power	80W	80W	135W
Efficiency	94.11	95.23	96.4

V. CONCLUSIONS

Cuk converter provide reduction in the ripple of input and output current compared to other traditional converters. A conventional cuk converter in continuous conduction mode brings in large current ripple on input side which in turn injects harmonics to the source. This undesirable input current ripple is mitigated by employing the interleaved cuk converter (ICC). Simulation results of modified interleaved cuk converter shows that the input ripple is reduced by 73 percent of conventional cuk converter, the voltage stress is reduced by 14 percent and voltage gain is improved by 30 percent of ICC. The efficiency really matters when ripple reduction takes place, but here the efficiency is not sacrificed and kept remarkably greater than 95 percent.

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