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Efficiency and Power Factor improvement of Bridgeless Soft-switched PWM Cuk Converter using Multiplier control approach

Anjan Kumar Sahoo[1], Sarika Kalra[2], Nitin Singh[3]
Department of Electrical Engineering,
Motilal Nehru National Institute of Technology, Allahabad, India

Abstract :*For the improvement of efficiency and power factor, a bridgeless single-phase ac-dc soft switched PWM cuk converter with multiplier control technique is proposed. This paper emphasizes more on the converter efficiency and power factor. The conduction losses and input current harmonics of the proposed converter is very less due to the absence of the input diode bridge and also during each switching cycle, only two semiconductor switches are present in the current path unlike other conventional Cuk converters. Soft switching (ZVS) technique is applied by using an auxiliary circuit to improve the efficiency of the proposed converter. Multiplier control technique is provided to regulate the output which also ultimately improves the efficiency. Power factor is almost unity due to less input current harmonics. The circuit configuration, principle of operation, design procedure and simulation results are presented.*
Keywords - *Bridgeless, Cuk converter, Multiplier control, Power factor correction (PFC), Rectifier, Soft switching.*

I. INTRODUCTION

Switch mode power supplies are widely used in the power electronics & telecommunication applications. Nevertheless the converters with hard switching technique suffer from switching losses, very low efficiency and substantial amount of EMI. There are two ways to improve the efficiency [1] of the converter either by reducing the energy loss of each component or by introducing the soft switching technique [9]. The cuk converter based on soft switching technique is presented in [10-13].In [13] an attractive comparison between four different types of zero voltage transition cuk converters is made. In all these papers [10-13] soft switching is done in different ways but the presence of input diode bridge rectifier makes the conduction losses more. Fig.1 shows conventional input diode bridge rectifier cuk converter. The numbers of elements used in each switching cycle are more. This results more conduction losses and less efficiency, although it is of low cost and simple in construction. As we are more interested in the improvement of efficiency, we have to design a bridgeless converter with soft switching technique.

These days the bridgeless converter has obtained its popularity in designing switch mode power supplies.Fig.2 shows the bridgeless boost converter with soft switching technique [15].Due to the bridgeless structure and soft switching technique, the efficiency of the converter is very high but this boost type converter suffers from many drawbacks like (1) the dc output voltage is always higher than the peak input voltage, (2) implementation of input-output isolation is difficult, (3) the startup inrush current is high and there is lack of current limiting during overload condition [3].To overcome the problems associated with boost converter, a bridgeless step down cuk converter with soft switching technique is proposed in this paper.

Soft switching condition is achieved for all semiconductor elements without any significant additional voltage or current stresses. To reduce the voltage and current stresses on the switching devices and improve the converter efficiency, soft switching technique for the proposed converter is applied by providing the auxiliary circuit. The auxiliary circuit consists of one switch, one resonant inductor and two resonant capacitors. The zero voltage switching (ZVS) turn on or zero current switching (ZCS) turn off is achieved by using resonant converter [4-7] based on resonant inductor and resonant capacitor. The control signal obtained by taking a portion of the output voltage is provided to the gate drive. This is done to regulate the output voltage and hence improve the efficiency.

The analysis on the efficiency of different switching devices with respect to output power is made in [3]. It says that efficiency improvement is more articulated when an IGBT is used as the switching device. The proposed converter follows the same for efficiency improvement. All switches are PWM controlled and operate in soft switching mode. The converter has high efficiency and produces little electromagnetic interference.

The circuit configuration, principle of operation, control scheme, design procedure and simulation results are presented. First the circuit configuration of the proposed converter is discussed. In section III, principle of operation and in section IV, control scheme is presented. Section V and section VI deals with design procedure and simulation results respectively.

II. CIRCUIT CONFIGURATION

The circuit configuration of the proposed converter is presented in fig.3.Dp, Dn are two low recovery diodes.D3 is a fast recovery diode.S1,S2 are two main power switches and S_a is the auxiliary switch.

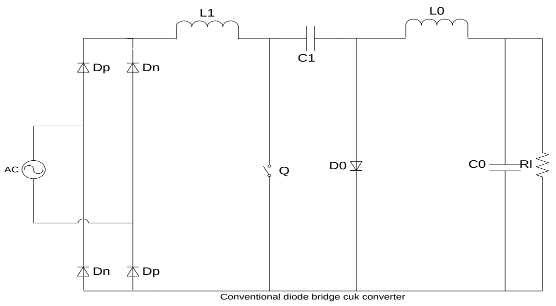


Fig. 1. Conventional diode bridge cuk converter.

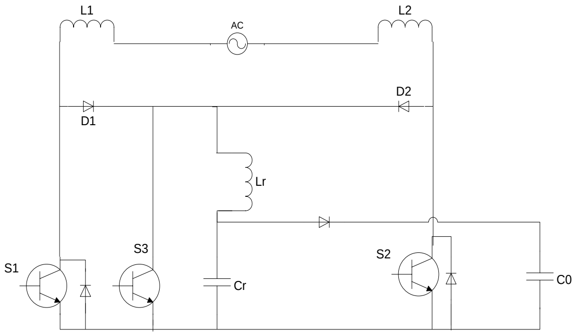


Fig. 2. Conventional bridgeless boost converter with soft switching technique [15]

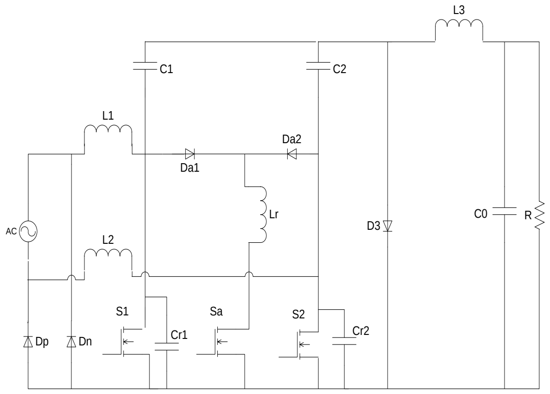


Fig. 3. Proposed ZVS bridgeless PWM cuk converter

L1, L2 are the input inductors and L3 is the output inductor. The capacitors C1, C2 are the medium for transferring energy from source to load. The output capacitor C0 is made very large to reduce the output ripple. The auxiliary circuit consists of two auxiliary diodes Da1, Da2 facing each other, one resonant inductor Lr, two resonant capacitors Cr1,Cr2 and one auxiliary switch Sa. The resonant inductance and resonant capacitance are resonant to achieve zero voltage switching (ZVS) of the auxiliary switch. At the same time the resonance between the resonant inductance and output capacitance of the main switches will achieve ZVS of the main switch. One of the main switches and auxiliary switch are all turned on at ZVS which enables the converter to operate with higher switching frequency and reduction in the size of the reactive components.

III. PRINCIPLE OF OPERATION

Some assumptions of the proposed converter is made for the analysis: (1) All circuit elements are ideal;(2) the converter is operating at steady state condition;(3) the converter operates in continuous conduction mode (CCM);(4) the output capacitor value is very large to act as an ideal dc voltage source (V0);(5) input voltage, input current and output inductor current are constant in a switching cycle. The operation of the converter is symmetrical in two half line cycles of the input voltage. So the converter operation is explained during positive half line cycle of the input voltage. There are six operating modes of the proposed converter in a switching period. The current path in all six modes is represented by bold line. The key waveform is also represented in fig. 4.The converter is assumed to operate in power transferring mode and $i_{Lr}=0$, $V_{Cr}=V_0+V_{ac}(t_1)$.

Mode 1 ($t_1 < t < t_2$ Fig. 5a):The first mode starts by turning Sa on to provide ZCS condition for the main switch S1.So the L_r current increases linearly with slope of $(V_0+V_{ac}(t_1))/L_r$. This mode lasts until the L_r current reaches $i_{in}+i_{L3}$.The duration of this mode is obtained by the equation given below.

$$t_2 - t_1 = \frac{\left(V_0 + V_{ac}\left(t_1\right)\right)}{L_r(i_{in} + i_{L3})} \tag{1}$$

Mode 2 ($t2 < t < t3$, Fig. 5b): The diode D_3 is turned off under zero current condition, when i_{Lr} reaches $i_{in}+i_{L3}$.Then resonance between L_r and Cr1takes place. This mode continues until L_r current becomes zero. The switch S1 can be turned on during this interval. Due to the sinusoidal shape of auxiliary switch S_a, this switch turns on and off under ZCS condition in this mode. To provide soft switching condition i_{Lr} should become zero and below equation need to be satisfied.

$$Z_r \leq \frac{\left(V_0 + V_{in}\left(t_1\right)\right)}{i_{in} + i_{L3}} \tag{2}$$

Mode 3 ($t3 < t < t4$, Fig. 5c): In this mode,C_r1 is charged by $I_{in}+I_{L3}$ linearly. This mode is finished when the voltage of C_r1 reaches zero. So the main switch turns on at ZVS condition. The duration of this mode can be determined from the below equation.

$$t_4 - t_3 = \frac{C_r * V_{cr1}(t_3)}{I_{in} + I_0} \tag{3}$$

Mode 4 ($t4 < t < t5$, Fig. 5d):This mode deals with the conducting of main switch and charging of input inductor which is similar to the on time of the main switch of the conventional hard switching of the cuk converter. This mode lasts until the switch S_1 is turned off.

Mode 5 ($t5 < t < t6$, Fig. 5e): This mode starts by turning off the switch S_1.The C_{r1} is charged linearly by the $i_{L3}+i_{in}$ current. Thus the main switch voltage increases linearly to $V_0+V_{in}(t_1)$.At the same time the main switch is turned off under ZVS condition. The following equation describes the duration of this mode.

$$t_6 - t_5 = \frac{C_r\left(V_0 + V_{in}\left(t_1\right)\right)}{I_{in} + I_0} \tag{4}$$

Mode 6 ($t6 < t < T_s$, Fig. 5f): In this mode the diode D_3 is turned on under ZVS condition and the $i_{in}+i_{L3}$ is transferred to the output. This mode continues until the end of the switching cycle T_s

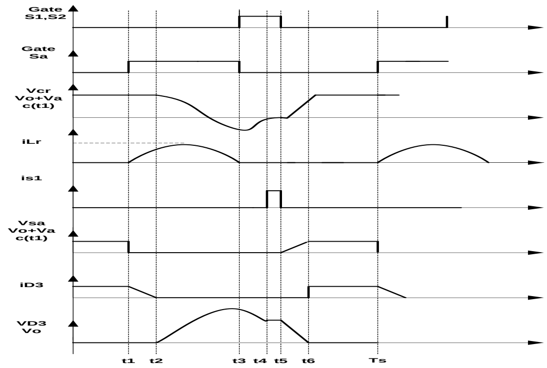


Fig. 4. Key waveform of the proposed converter in CCM.

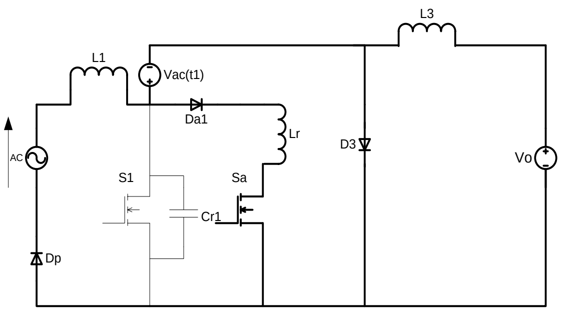


Fig. 5(a) Mode 1 [$t_1 < t < t_2$]

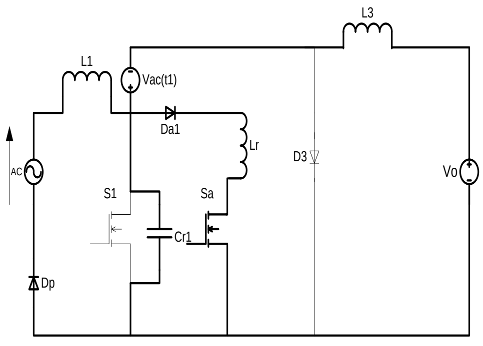


Fig. 5(b) Mode 2 [$t2 < t < t3$]

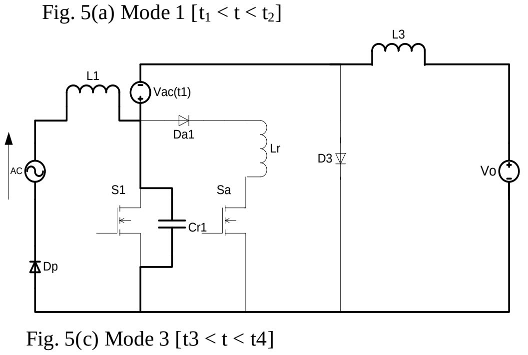


Fig. 5(c) Mode 3 [$t3 < t < t4$]

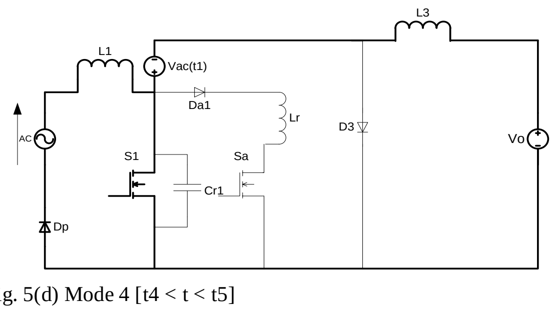


Fig. 5(d) Mode 4 [$t4 < t < t5$]

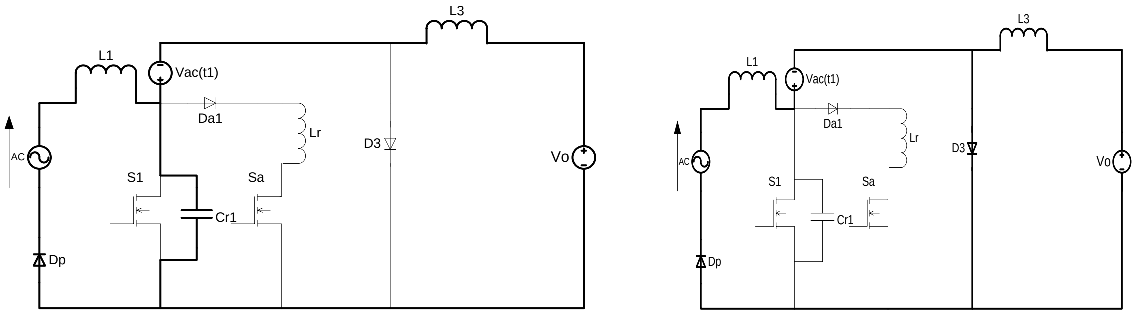


Fig. 5(e) Mode 5 [t5 < t < t6]

Fig. 5(f) Mode 6 [t6 < t < T_s]

Fig. 5. Operation modes of proposed converter.

IV. CONTROL SCHEME

There are two types of the control schemes used in the response improvement of cuk converter .One is input current control and another is output voltage control. Both types of control schemes can be used when the converter is operating in CCM. Depending upon the requirement any of the two can be used. If we are interested for regulating the output voltage for efficiency improvement and also improving the input power factor, then we should go for the combination. This combined control circuit is known as multiplier control circuit. This control technique is applied to the converters operating in CCM. The proposed converter deals with this multiplier control approach [16].

As shown in fig. 6 a proportion of output voltage (V'_{out}) is compared with reference voltage and the error signal thus generated is multiplied with the magnitude of a proportion of input voltage with the help of a multiplier. The output of the multiplier is again compared with input current sensed with the help of a current sensor. The error signal thus generated is used to drive the gate of the main switches. As a result of which the main switches are controlled with respect to desired output voltage and required high switching frequency. Due to the use of multiplier control approach technique, the output voltage is regulated and thus efficiency is improved. Along with that the input current harmonics are reduced, the input voltage and current waveforms are well shaped and thus power factor is improved.

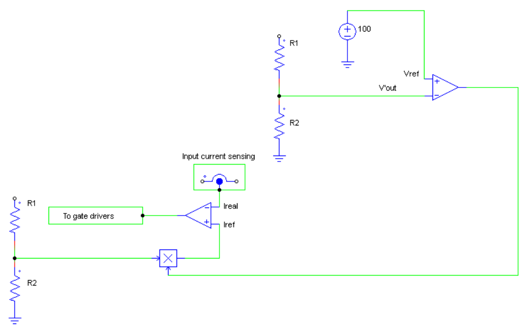


Fig. 6. Control circuit for the proposed converter.

V. DESIGN CONSIDERATION

Except at the switching instants the operation of the proposed converter is like conventional cuk converter. The switching transients can be neglected in comparison with the rest of switching time. So the resonant frequency of the auxiliary circuit is selected ten times greater than the switching frequency. The relation between resonant frequency and switching frequency is represented in (5).

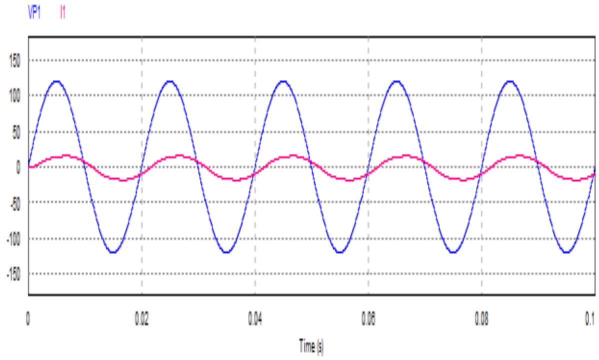
The value of R1=1.2kΩ.The value of R2 is determined from (6).The value of V_{ref} is normally less than desired output. This value is fixed depending on the output voltage obtained. The phase shift fixed PWM control is provided for auxiliary switch. The operation and design procedure for the main converter elements are provided in the [2, 14].So the design guidelines for designing the auxiliary circuit are discussed.

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}} = 0.1 f_{sw} \qquad (5)$$

$$R_2 = \frac{R_1 * V_{ref}}{V_0 - V_{ref}} \qquad (6)$$

VI. SIMULATION RESULTS

The proposed high efficiency bridgeless PWM cuk converter with soft switching technique is simulated by PSIM when V_{AC} =85V_{rms},V_0 =80±5 V_{DC}, f_{SW}=100KHz and 380W output power. By using design procedure formula the main circuit element values obtained are C_1=C_2=3.7µF, L1=L_2=2.8mH, L3=60µH, C_0=1000µF. The resonant elements, Cr1=C_r2=10nF and L_r=5µH.If we are interested to make the switching transient times observable in the waveforms, then its better to select resonant frequency 5times greater than the switching frequency rather following (5).



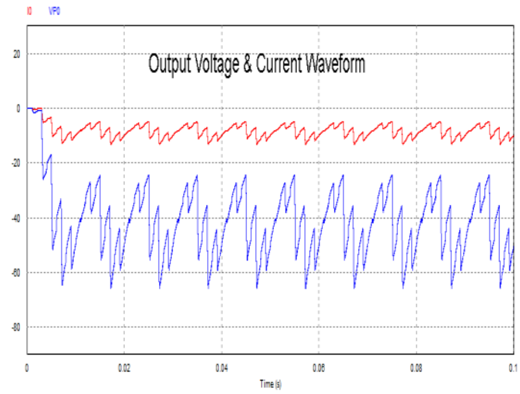
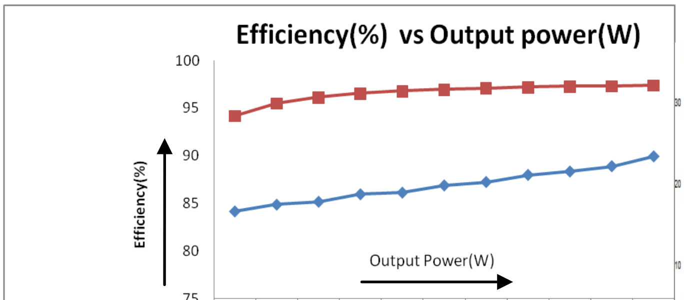


Fig. 7. Input voltage & current waveform of the proposed converter. Fig. 8. Output voltage & current waveform of the proposed converter.



	100	150	200	250	300	350	400	450	500	550	600
HARD SWITCHING	84.1	84.8	85.1	85.9	86.1	86.8	87.2	87.9	88.3	88.8	89.9
SOFT SWITCHING	94.1	95.4	96.1	96.5	96.7	96.9	97.0	97.1	97.2	97.3	97.3

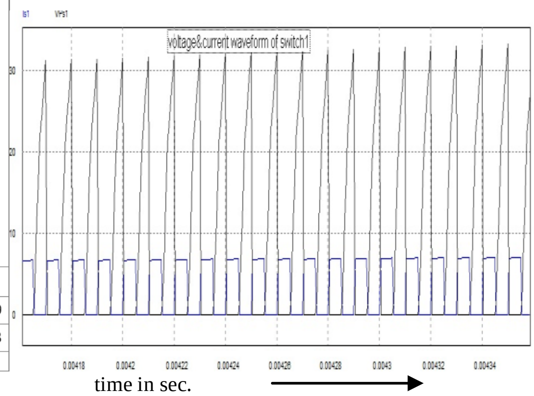


Fig. 9. Efficiency comparison between hard switching & soft switching in proposed converter.

Fig. 10. Voltage and current waveform of switch1 in the proposed converter.

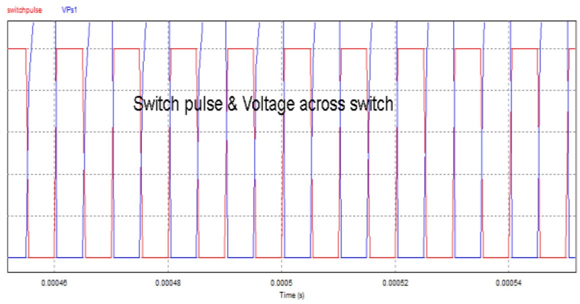


Fig. 11. Switching pulse and voltage across switch S1

Fig. 7 shows the combined waveform of input current and input voltage. From this waveform it is observed that the input current and input voltages both are almost in phase. It gives almost unity power factor. Fig. 8 gives the combined waveform of the output voltage and current waveform. As the proposed converter is based on soft switching technique, our main attention is on the efficiency improvement. Efficiency comparison between hard switched and soft switched proposed cuk converter obtained from simulation results is presented in fig. 9. As discussed in the previous section the use of IGBT as switching device, auxiliary circuit, resonant elements and control circuit enhances the efficiency to a very high value of more than 96%.From the combined waveform of the voltage across and current through the switches in fig. 10 it is observed that there is no common area between the voltage and current waveform and hence switching loss is also very less. Fig. 11

shows the waveform of switching pulse and voltage across switch. As we know zero voltage switching is the technique in which the switch turns on at zero voltage, the sudden rise and fall of the voltage during turn off and turn on of the main switch says about perfect ZVS of the main switch in the proposed converter.

VII. CONCLUSION

A new highly efficient bridgeless PWM cuk converter with soft switching technique is introduced in this paper. The main goal of the converter design is efficiency improvement and loss minimization which is verified clearly from the simulation results. Efficiency of more than 96% is obtained. The power factor obtained satisfies the IEC6100-3-2 standard. The input current harmonics is very less. The multiplier control approach helps in getting desired response. The main applications of this circuit are in regulated dc power supplies, where a negative polarity output may be desired with respect to the common terminals of the input voltage like control section of the telecommunication system which requires -58vDC as its input supply.

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