Close Loop Analysis of a Single Phase High-Efficiency AC-DC CUK Converter with Low Input Current THD and Improved Power Factor

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Close Loop Analysis of a Single Phase High-Efficiency AC-DC CUK Converter with Low Input Current THD and Improved Power Factor

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Abstract— **In this paper, design and analysis of a novel single phase AC-DC converter based on Ćuk topology is proposed. Performance comparisons are shown between open loop and closed loop configurations of the proposed converter which reveals that the inconsistencies arising in open loop connection can be mitigated sufficiently by adding PFC controller to it. The closed loop technique applied to the proposed bridgeless converter results in low input current THD at input AC mains along with near unity (0.99) power factor. Thus, significant improvements in overall power quality of the system is achieved despite the absence of input side filtering. The proposed circuit is also non-burdensome as it gets rid of bulky filtering capacitors. The aforementioned circuit performances are observed based on software simulations using PSIM 9.1 professional environment.**

Index Terms- **AC-DC Ćuk Converter, THD, PFC.**

I. Introduction

Switched mode power supply AC-DC converters are required to serve innumerable applications since a variety of DC operating applications has increased in number such as inverters, battery chargers, DC power supplies, LED drive, motor control, home appliances, renewable energy applications as solar photovoltaic and maximum power point tracking and so on [1]-[4]. Conventional AC-DC converters suffer from low fluctuating input currents, escalating total harmonic distortion (THD), hiked electromagnetic interference (EMI) and poor power factor [5], [6]. Passive filtering improves the THD, but it has low input power factor and involves bulky capacitor and inductor [7], [8]. Active filtering requires smaller sized filter than passive filtering, but a DC-DC converter must follow after a rectifier [9].

On the other hand, Ćuk converter in PFC applications has lower current ripple, less EMI and higher protection against inrush current at startup; thus, becoming suitable for low power applications [10]. Ćuk is preferable than buck or boost because rather than only step up or step down, both mechanisms are facilitated in this configuration [11]. Although Ćuk converter has inverting polarity output, it has become a good choice for converter applications as it has continuous input-output current. Also, Ćuk circuit has reduced circuit parameters than SEPIC converter, hence the cost is also reduced [12]. Ref. [13], [14] discusses several integrated topologies, but this paper discusses about basic Ćuk circuit topology which can potentially be used as a basic building block in these hybrid techniques also.

This paper is organized as follows. Section II presents the proposed AC-DC bridgeless Ćuk converter. Close loop analysis of converter circuit operation has been presented in section III and simulation works are represented both in tabular and graphical forms in section IV. Section V concludes the paper along with future work directions.

The circuit diagram of the proposed converter as shown in Fig. 1 is comprised of fifteen components i.e. six diodes, three capacitors, four inductors, one switch, one resistor and AC input voltage. Though the conventional converters as shown in Fig. 7 can be constructed with lesser components, but it is not preferred due to the use of bridge rectifier. The output of the bridge rectifier which is given as input to the switch contains harmonics in the form of pulsating dc. Although conventional circuit 2 and 3 are bridgeless, but the uses of multiple switches cause higher switching loss. On the other hand, the proposed AC-DC Ćuk converter circuit achieves superior power quality by resolving these drawbacks.

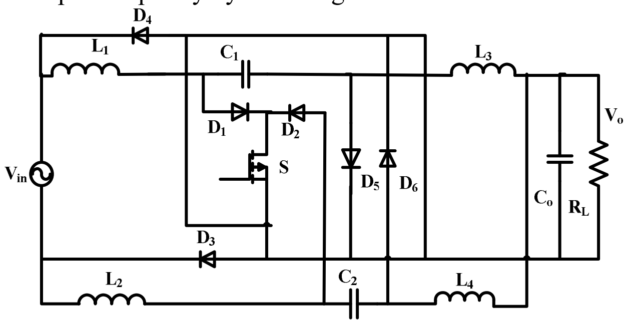

Fig. 1 Proposed Ćuk Converter Circuit.

II. Principle of Operation

A. Single Phase Ćuk Converter

The four steps of operation of the proposed converter are shown in Fig. 2, 3, 4, and 5 respectively.

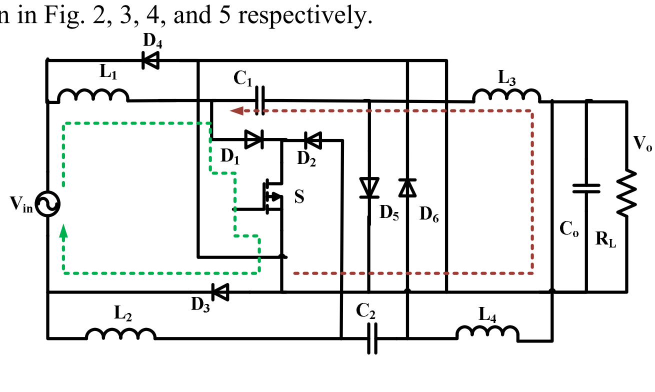

Fig. 2 State 1: Positive half cycle during ON state of switch S.

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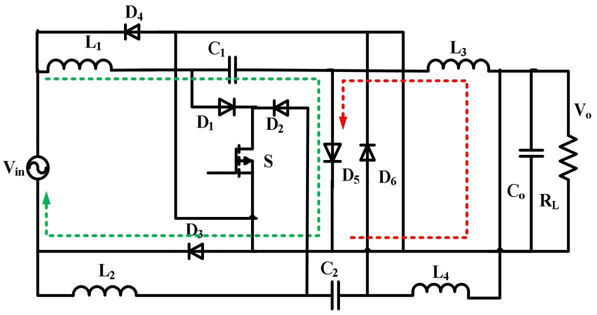

Fig. 3 State 2: Positive half cycle during OFF state of switch S.

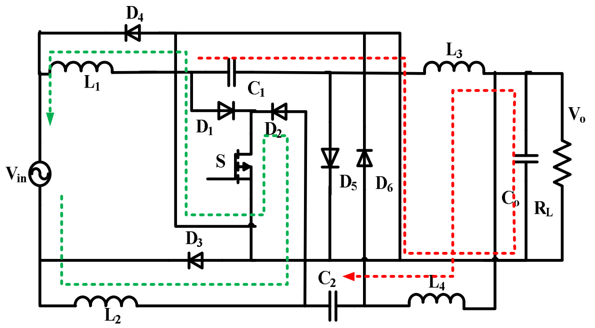

Fig. 4 State 3: Negative half cycle during ON state of switch S.

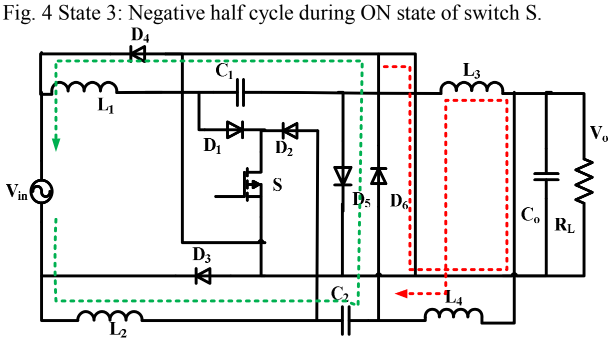

Fig. 5 State 4: Negative half cycle during OFF state of switch S.

III. Feedback Control to Improve Power Factor

Power quality in an electrical system is determined by its power factor. Open loop operation of conventional AC-DC converters suffer from very low power factor which causes several problems in overall power system. To resolve this issue, proper feedback controller design is required.

The PFC circuit for the proposed Ćuk converter along with its control circuit has been shown in Fig. 6. The main objective of PFC circuit is to minimize the angle between supply voltage and current. As the reference inductor current is of the full-wave rectified form thus the amplitude of the inductor current causes inner current control loop and an outer voltage loop, to provide the required PWM signal to drive the switch of the proposed Ćuk converter.

The internal current loop as appeared in Fig. 6 confirms the type of inductor current based on the template $sin|\omega t|$ acquired by estimating the absolute value of the input voltage. On the basis of the output voltage, feedback voltage control loop determines the amplitude of inductor current. Due to insufficient inductor current supplied by PFC the output voltage will fall down from pre-selected reference value V_{Ref}.

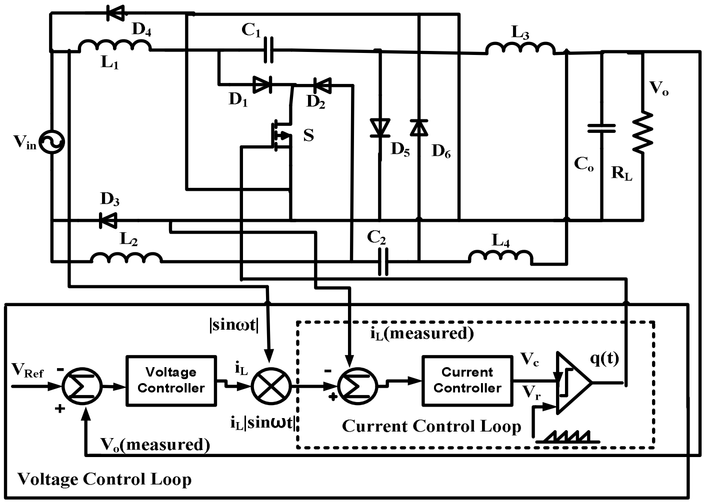

Fig. 6 Proposed Ćuk converter with feedback control to improve power factor and to reduce input current THD.

By estimating the output voltage and utilizing it as the feedback signal, the voltage control loop alters the inductor current amplitude to convey the measured output voltage to its reference value [15].

IV. Simulation and Results

The simulation of the three conventional and the proposed Ćuk AC-DC converters were performed using PSIM 9.1 professional version and also with MATLAB Simulink.

Proposed Ćuk configuration has been compared with three advanced conventional design of Ćuk converters. Conventional circuit topologies 1, 2 and 3 are given in Fig. 7, 8 and 9 respectively.

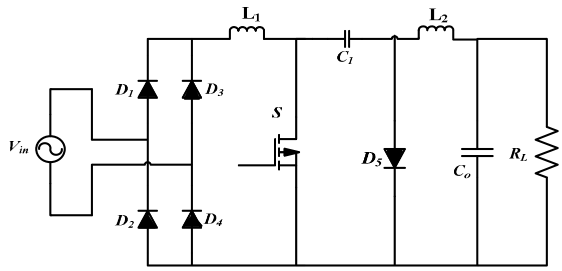

Fig. 7 Conventional circuit 1.

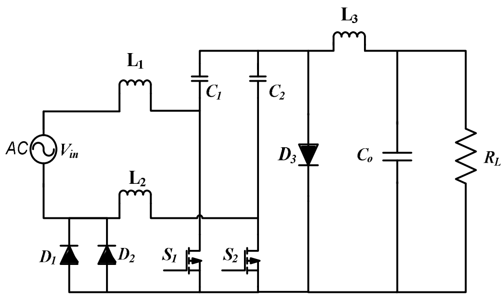

Fig. 8 Conventional circuit 2.

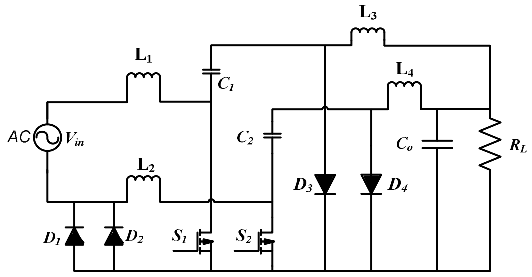

Fig. 9 Conventional circuit 3.

A. *Values of Elements of Proposed and Conventional Converters*

Simulation results for the proposed and conventional converters are given below to justify the feasibility of the proposed circuit. Following values have been used for the proposed converters in open loop operation.

Input voltage, V_{in}=220V, 50Hz. Switching frequency, Fs= 8kHz, Inductor, L_1=L_2= 1mH, L_3=L_4= 1.5mH, Capacitor, C_1=C_2= 1µF, C_0= 220µF, Load resistor, R_L= 100Ω

To obtain the simulation result from the conventional circuit of Fig. 7 we have used same values as mentioned above. In the conventional circuit 2 and 3 the values of inductors have been changed to get maximum performance. Values of inductors of conventional circuit 2 and 3 are, L_1=L_2= 2.2mH, L_3=L_4=68µH.

B. *Open and Close Loop Simulation Result*

Simulation results of the proposed and conventional circuit 1 in open loop operation are given in Fig. 10 and 11. It is evident from the following diagrams that the proposed circuit offers better performance than conventional circuit 1 in terms of THD and power factor. Although, conventional circuit 2 and 3 exhibit good performance in terms of THD and power factor but they show very poor performance in case of efficiency. As shown by bar diagram in Fig. 12, the proposed converter has higher efficiency and outperforms all the three conventional converters as per simulation results.

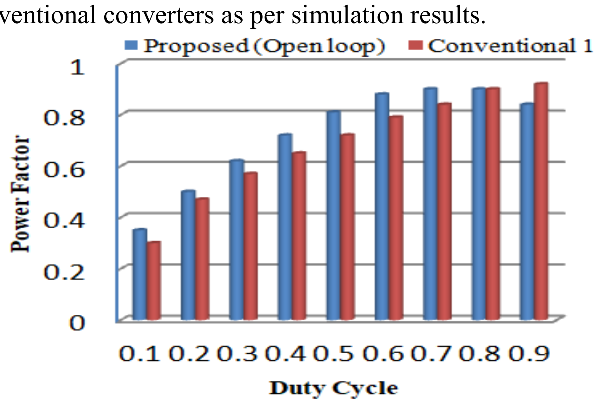

Fig.10 Comparison of the performance between proposed and conventional converters in terms of power factor by varying duty cycle.

The input current wave form of the proposed input switched Ćuk converter in open loop configuration is given in Fig. 13.

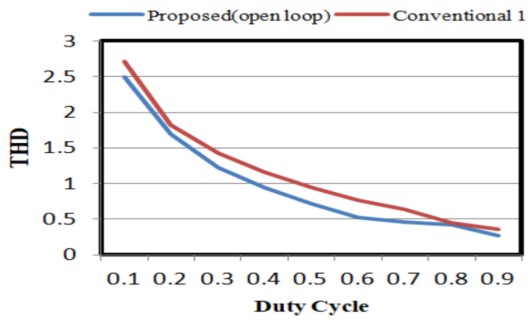

Fig. 11 Performance analysis of THD between conventional and proposed converters by varying duty cycle.

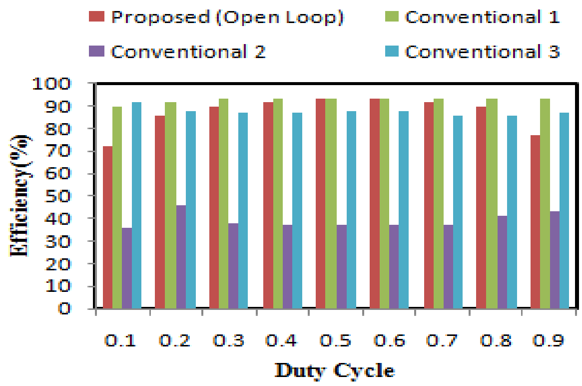

Fig. 12 Comparison of the performance of Efficiency between proposed and three conventional converters by varying duty cycle.

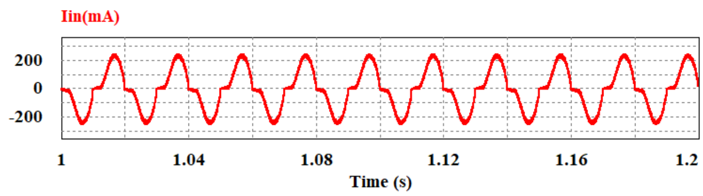

Fig. 13 Input current waveform in open loop operation.

Fig. 14 shows the voltage-current waveforms obtained in close loop operation. It is seen that, the current waveform is enhanced in the latter case, thus mitigating the short comings of open loop output. The output voltage of the proposed circuit in closed loop operation is a considerably smooth dc signal as shown in Fig. 15. Simulation of the proposed converter with feedback controller is performed by the parameters given in Table I. The PFC controller is designed to obtain an average output voltage of 646V_{dc}. The simulation result of the designed controller is given in Table II.

TABLE I
PARAMETER TABLE FOR CLOSE LOOP CONTROLLER

Parameters	Value
Nominal Input AC Source Voltage (V_1)	220V, 50 Hz
Switching Frequency (F_s)	30kHz
Inductors (L_1, L_2; L_3, L_4)	1mH; 1.5mH
Capacitor, (C_1,C_2)	1µF
Resistor (R_L)	100Ω
Gain of Voltage Sensor (V_{SEN1}, V_{SEN2})	0.015, - 0.036
Gain of Current Sensor (I_{SEN1})	1

TABLE II
COMPARISON BETWEEN THE CONVENTIONAL AND PROPOSED AC-DC ĆUK CONVERTER FOR BOTH WITH AND WITHOUT FEEDBACK CONTROLLER

Performance Parameters	**Conventional Ćuk**	**Proposed Ćuk Without Feedback**	**Proposed Ćuk With Feedback**
Input Current THD	.95	.71	0.04
Input Power Factor	.72	.81	.99
Efficiency (%)	93	93	93

From the above table it is observed that, the total harmonic distortion of the input ac mains reduces very much significantly when a PFC has been added with the proposed Ćuk converter. Also, the power factor reaches almost unity which is a highly desired circuit performance. The efficiency exhibited by all the three configurations is also very high. All these mentioned parameters of Table II show satisfactory simulated performance values for the proposed Ćuk converter with a feedback controller. This performance analysis of Table II is shown graphically in Fig. 16 also.

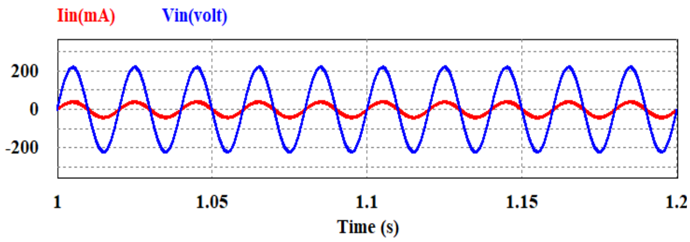

Fig. 14 Waveforms of input voltage and current showing in phase operation in closed loop configuration.

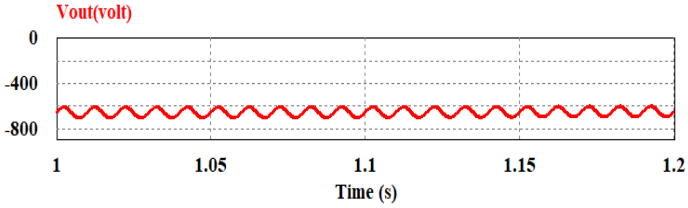

Fig. 15 Output voltage signal of the proposed Ćuk converter in closed loop operation.

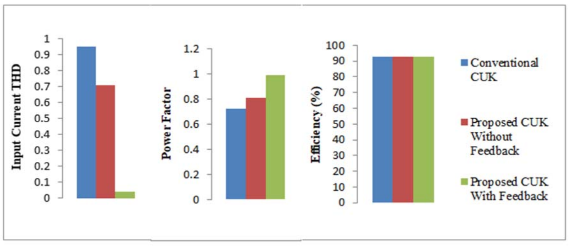

Fig. 16 Comparison between conventional and proposed Ćuk converter in open and close loop operation.

V. CONCLUSION

Here a novel AC-DC Ćuk converter circuit has been presented where PFC controller scheme has been added to obtain satisfactory result without using filter circuit in the input side. It is evident from the performance analysis that amongst all given configurations, the proposed Ćuk with feedback controller scheme outperforms all the other converter circuits based on the individual simulation results and achieves superior power quality not only in terms of power factor and efficiency, but also the input current THD value has been brought to below 4% which is within IEEE prescribed limit. Thus, this converter circuit holds promise for future which can be practically realized through hardware implementations. Moreover, the proposed converter circuit's feasibility can be further analysed by integrating this basic building block with solar photovoltaic cells and various drives applications also.

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