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Performance Improvement of Bridgeless Cuk Converter Using Hysteresis Controller

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Abstract

The single-phase ac–dc rectifiers based on bridgeless Cuk topologies are proposed and analyzed using controller. The absence of an input diode bridge and the presence of only two semiconductor switches in the current flowing path during each interval of the switching cycle result in high output voltage with reduction in total harmonic distortion compared to the conventional Cuk converter . The proposed topologies are designed to work in both continuous and discontinuous conduction mode using hysteresis controller to achieve the low total harmonic distortion with achievable output voltage. This operation gives additional advantages such as zero-current turn-ON and turn-OFF in the power switches and output diode with simple control circuitry. Performance comparisons between the proposed and conventional Cuk Converter are performed based on circuit simulations. Simulation results for a 100 V_{rms} line input voltage to evaluate the performance of the proposed bridgeless PFC rectifiers are provided.

Index Terms—Bridgeless rectifier, Cuk converter, power factor correction (PFC) rectifier, total harmonic distortion (THD).

I. Introduction

Generally single switch is the most widely used topology for the PFC applications because of its simplicity and smaller EMI filter size. Due to the high conduction loss and switching loss, this circuit has a low efficiency at low input line. With respect to the usage of switches, the switching loss of the PFC circuit is dramatically improved. Meanwhile, the circuit still suffers from forward voltage drop of the rectifier bridge caused high conduction loss, especially at low input line. To reduce the rectifier bridge conduction loss, different topologies have been developed. Among these topologies, the bridgeless Cuk topologies doesn't require range switch, shows both the simplicity and high performance. Without the input rectifier bridge, bridgeless PFC generates less conduction loss comparing with the conventional PFC. Comparing with the conventional Cuk converter and bridgeless Cuk converter with hysteresis controller it gives more efficiency, reduces the switching losses and increased output voltage with low total harmonic distortion is obtained in the simulation results. In this paper, hysteresis technique is implemented in the bridgeless Cuk PFC controller. In the other hand the control techniques are developed to compare with the bridgeless cuk topologies and the simulation results shows the reduction in THD. The analysis is performed in the MATLAB/ Simulation.

II. Conventional Cuk Converter

In a conventional scheme has lower efficiency due to significant losses in the diode bridge. A conventional Cuk rectifier is shown in Fig. 1; the current flows through two rectifier bridge diodes and the power switch (*S*) during the switch ON-time, and through two rectifier bridge diodes and the output diode during the switch OFF-time. Thus, during each switching cycle, the current flows through three power semiconductor devices. As a result, a significant conduction loss, caused by the forward voltage drop across the bridge diode, would degrade the converter's efficiency, especially at a low line input voltage. An effort to maximize the power supply efficiency, considerable research efforts have been directed toward designing bridgeless circuits, where the number of semiconductors generating losses is reduced by essentially eliminating the full bridge input diode rectifier. A bridgeless PFC rectifier based Cuk allows the current to flow through a minimum number of switching devices compared to the conventional PFC rectifier. Accordingly, the converter conduction losses can be significantly reduced and higher efficiency can be obtained, as well as cost savings. Recently, several bridgeless PFC rectifiers have been introduced to improve the rectifier power density and/or reduce noise emissions via soft-switching techniques or coupled magnetic topologies [1]–[9].

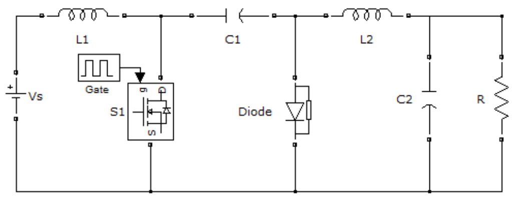

Fig.1. Conventional Cuk Converter

On the other hand, the bridgeless boost rectifier [10]–[17] has the same major practical drawbacks as the conventional boost converter such as the dc output voltage is higher than the peak input voltage, lack of galvanic isolation, and high start-up inrush currents. Therefore, for low-output voltage applications, such as telecommunication or computer industry, an additional converter or an isolation transformer is required to step-down the voltage.

However, the proposed topology in [18] still suffers from having three semiconductors in the current conduction path during each switching cycle. In [19]–[22], a bridgeless PFC rectifier based on the single ended primary-inductance converter (SEPIC) topology is presented. Similar to the boost converter, the SEPIC converter has the disadvantage of discontinuous output current resulting in a relatively high output ripple. A bridgeless buck PFC rectifier was recently proposed in [23], [24] for step-down applications. However, the input line current cannot follow the input voltage around the zero crossings of the input line voltage; besides, the output to input voltage ratio is limited to half. Also, buck PFC converter results in an increased total harmonic distortion (THD) and a reduced power factor [25].

III. Proposed System

The Cuk converter offers several advantages in PFC applications, such as easy implementation of transformer isolation, natural protection against inrush current occurring at start-up or overload current, lower input current ripple, and less electromagnetic interference (EMI) associated with the discontinuous conduction mode (DCM) topology [26], [27].In this paper, two topologies of bridgeless Cuk PFC rectifiers with implementation of hysteresis controller are implemented and evaluated the performance of bridgeless topologies using MATLAB tool. The proposed rectifiers are compared based on output voltage, components count, and total harmonic distortion.

The proposed bridgeless Cuk rectifiers are shown in Fig. 2. The proposed topologies are formed by connecting two dc–dc Cuk converters, one for each half-line period ($T/2$) of the input voltage. It should be mentioned here that the topology of Fig. 2 was listed in [20] as a new converter topology but not analyzed. The operational circuits during the positive and negative half-line period for the proposed bridgeless Cuk rectifiers are shown in Figs. 2–5, respectively. Note that by referring to Figs. 2–5, there are one or two semiconductor(s) in the current flowing path; hence, the current stresses in the active and passive switches are further reduced and the circuit efficiency is improved compared to the conventional Cuk rectifier. In addition, Fig. 4 and 5 shows that by using hysteresis controller the output voltage merely maintains same and the total harmonic distortion presented in the signal is reduced. Thus, the proposed topologies do not suffer from the high common-mode EMI noise emission problem and have common-mode EMI performance similar to the conventional PFC topologies.

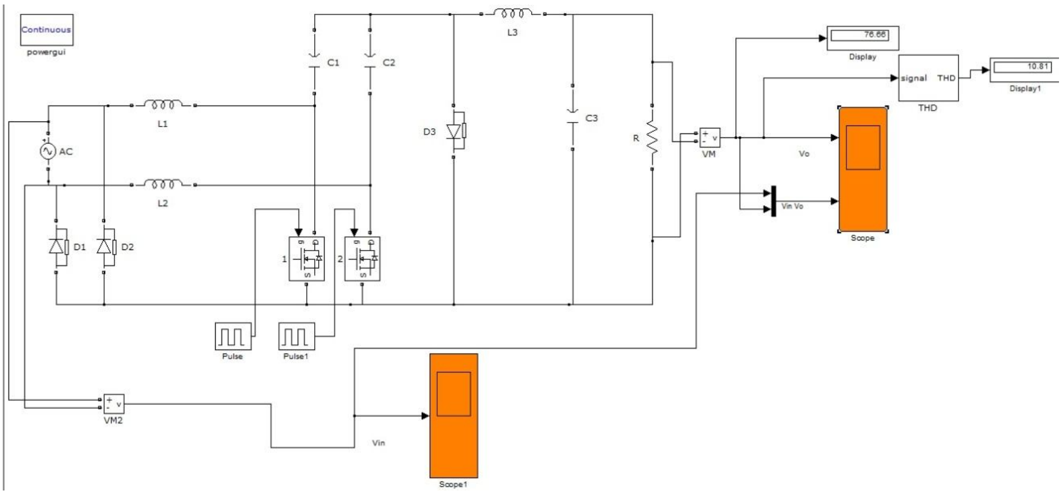

Fig.2. Type-I bridgeless Cuk rectifiers

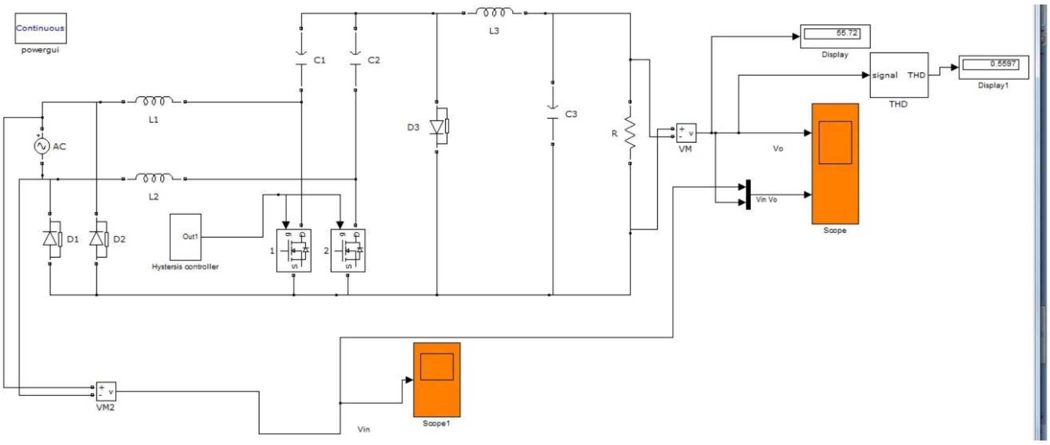

Fig.3. Type-I bridgeless Cuk rectifiers with hysteresis controller

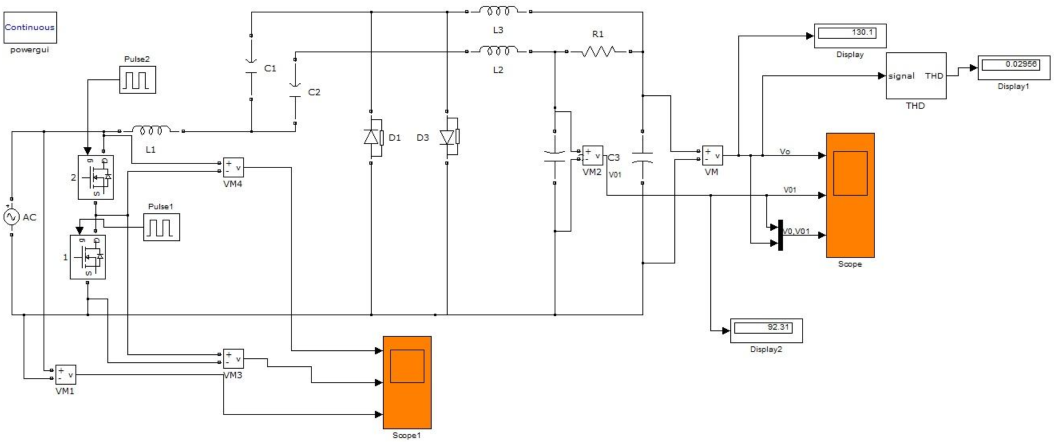

Fig.4. Type-II bridgeless Cuk rectifiers

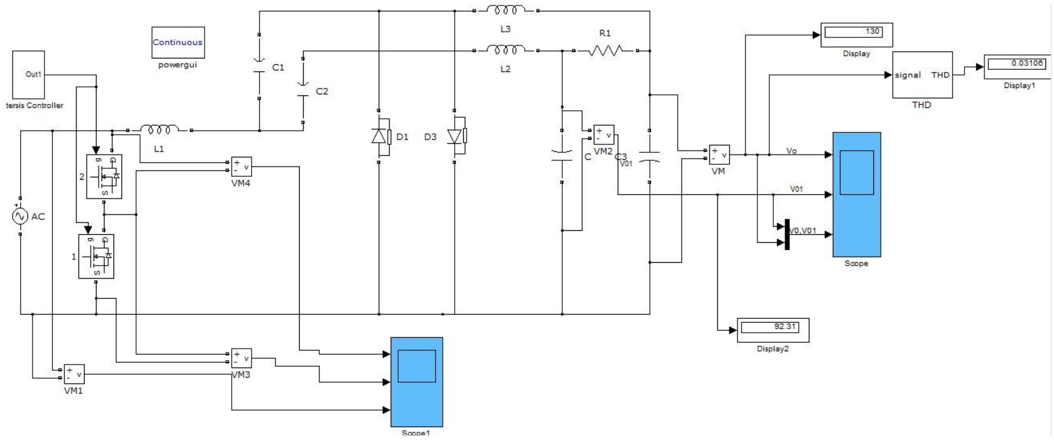

Fig.5. Type-II bridgeless Cuk rectifiers with hysteresis controller

Consequently, the proposed topologies appear to be promising candidates for commercial PFC products. The proposed bridgeless rectifiers of Fig. 2 utilize two power switches (*1* and *2*). However, the two power switches can be driven by the same control signal, which significantly simplifies the control circuitry. Compared to the conventional Cuk topology, the structure of the proposed topologies utilizes one additional inductor, which is often described as a disadvantage in terms of size and cost. However, a better thermal performance can be achieved with the two inductors compared to a single inductor. It should be mentioned here that the three inductors in the proposed topologies can be coupled on the same magnetic core allowing considerable size and cost reduction. Additionally, the "near zero-ripple-current" condition at the input or output port of the rectifier can be achieved without compromising performance.

IV. Comparison between the bridgeless Cuk PFC rectifier

The proposed topologies are compared with respect to their components count, efficiency, driver circuitry complexity, THD, and output voltage. And also we tabulated the performance analysis of these topologies.

Table 1. : Comparison of conventional and proposed Cuk rectifiers

S.No	Components	Conventional Cuk Converter	With Hysteresis controller	
			Type-1	Type-2
01	Diode	4 slow +1 fast	2 slow + 3 fast	2 fast
02	Switch	1	2	2
03	Component count	10	11	11
04	Number of	2	3	4

	Capacitors			
05	Switch Duty cycle	$M \times \sqrt{2Kc}$		
06	Integrated core	One core for 2 inductors	One core for 3 inductors	One core for 3 inductors

From table.1 shows the no of components used for the conventional and proposed conventional rectifiers with hysteresis controllers.

Table 2. : Various topologies simulated at 100Vrms input line voltage

S.No	Topology	Output Voltage	Total harmonic Distortion (THD)
01.	Type-1	76.66V	10.81
02.	Type-1 with hysteresis controller	55V	0.55
03.	Type-2	130V	0.029
04.	Type-2 with Hysteresis controller	130V	0.031

Table 2 represents the comparison between the simulated results of proposed topologies with hysteresis controller and also it shows the reduction in total harmonic distortion (THD) using the hysteresis controllers. A Cuk rectifier provides an output voltage that is less than or greater than the input voltage. In conclusion, the converter of choice is an application dependent.

Conditions for continuous inductor current and capacitor voltage is given by equ.1.

$$\frac{kV_s}{8C_2\ L_2 f^2} = 2V_a = \frac{2kV_s}{1-k} \quad --(1)$$

The voltage across the diode is calculated by using the equation 2.

$$V_{dm} = -kV_{C1} = -V_a k \frac{1}{-k} = V_a \quad ---(2)$$

As a result, the input current is continuous. The circuit has low switching losses and high frequency. Then the capacitors provide the energy transfer, the ripple current of the capacitor C_1 also high. This circuit also requires an additional capacitor and inductor for reducing the harmonic content from the output voltage.

V. Simulation Results

The type-I and type II converters of Fig. 2-5 has been simulated using MATLAB for the following input and output data specifications: *v*ac = 100 Vrms, 60 Hz and *fs* = 50 kHz. The circuit components used in the simulation is the same as those in Table 1. Fig. 6 shows the simulated voltage across the MOSFET and input waveforms for Type-I & II bridgeless Cuk converter. Fig. 7 shows the simulated voltage across the MOSFET and input waveforms for Type-I bridgeless Cuk converter with hysteresis controller. Fig. 8 shows that the comparison of output voltages obtained from various topologies under simulations.

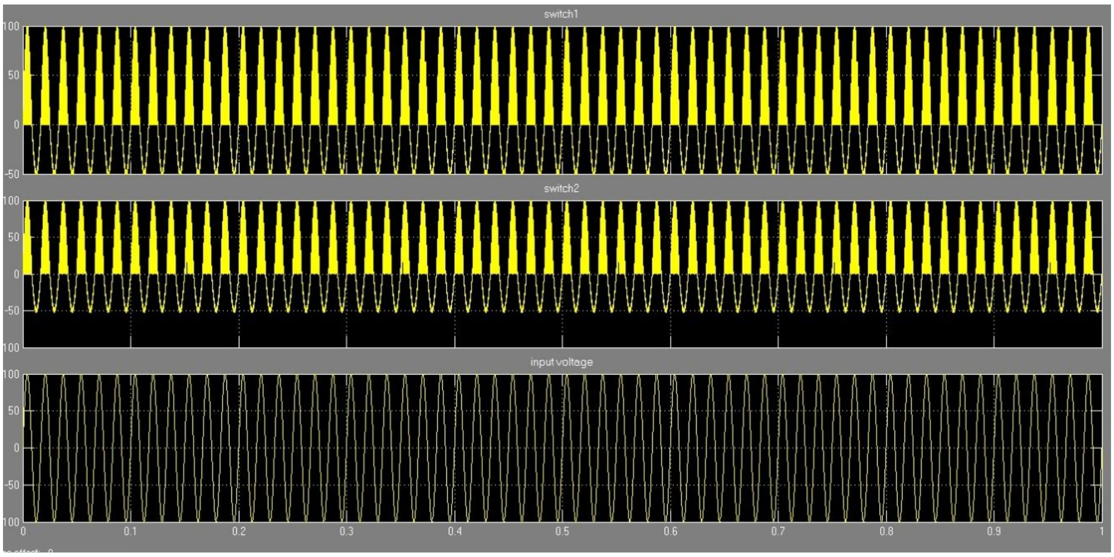

Fig.6. Voltage across the MOSFET switches and input voltage waveforms for Type-I & II bridgeless Cuk rectifiers

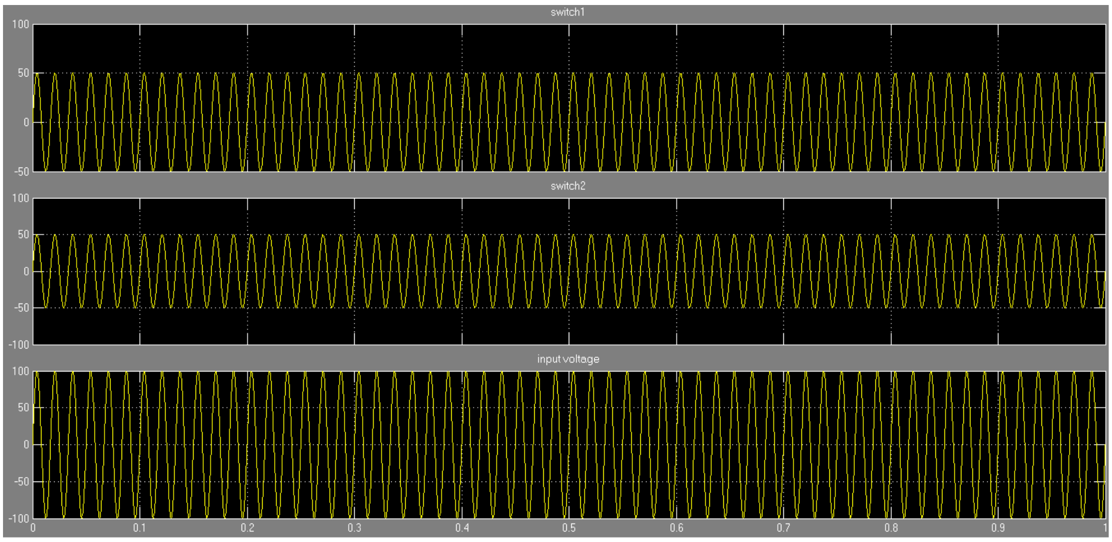

Fig.7. Voltage across the MOSFET switches and input voltage waveforms for Type-I & II bridgeless Cuk rectifiers with hysteresis controller

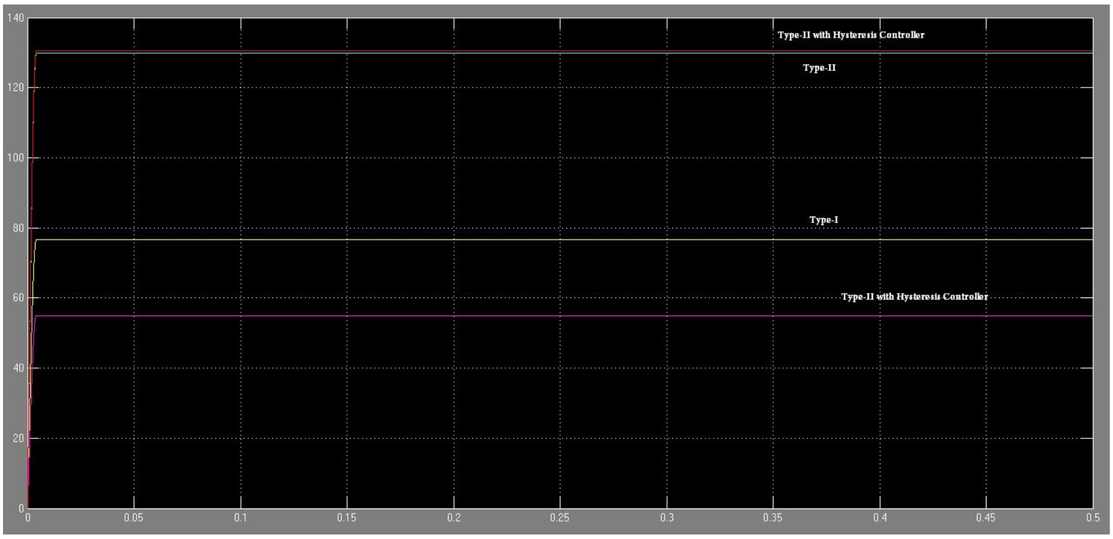

Fig.8. Comparison of output Voltages waveforms for Type-I & II bridgeless Cuk rectifiers with and without hysteresis controller

VI. Conclusions

Two single-phase ac–dc bridgeless rectifiers based on Cuk topology with hysteresis controller are presented and discussed in this paper. The validity and performance of the proposed topologies are verified by MATLAB simulation results. Due to the lower conduction and switching losses, the proposed topologies can further improve the conversion efficiency when compared with the conventional Cuk PFC rectifier. To maintain the same efficiency of output voltage, the proposed circuits can operate with a higher switching frequency. Thus, additional reduction in the size of the PFC inductor and EMI filter could be achieved. The proposed bridgeless topologies can improve the efficiency by using hysteresis controller. The performance of two types of the proposed topologies with hysteresis controller was measured and show in Table. I. The proposed bridgeless topologies are enhanced by using hysteresis controller to obtain the lower value of THD as 0.03% from Type-II Bridgeless Cuk rectifiers.

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