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An Approach of Power Factor Correction in BLDC Motor Drives Using Cuk Derived Converters

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Abstract

This paper deals with a comparative analysis of various converter topologies for Power Factor Correction (PFC) in BLDC motor drives. A power factor corrected converter is required for improving power quality at the AC mains of an inverter fed BLDC motor drive. Conventionally, the BLDC motor is fed by a diode bridge rectifier (DBR) which results in highly distorted supply current and a poor power factor. A new bridgeless single-phase ac–dc Cuk derived topology has been introduced for power factor correction. This bridgeless topology uses minimum number of switches and thus reduces the less conduction losses compared with the conventional PFC rectifier. There are three Cuk derived configurations for power factor correction. In this paper, all the Cuk derived topologies are investigated and compared. The best topology is identified and recommended for PFC in BLDC motor drive.

***Keywords**: power factor correction (PFC), bridgeless cuk converters, total harmonic distortion, BLDC drives, power quality*

1. Introduction

The BLDC motors are becoming popular in many low and medium power applications. It is used in many household types of equipment like fans, air conditioners, water pumps, refrigerators, washing machines etc. [1-3]. It also finds application in many industrial tools, medical equipment's, heating, ventilation and air conditioning, robotics and precise motion control systems. As the name indicates it has no brushes for commutation. Based on the rotor position the power electronic switches are commutated. Hence it is also known as an electronically commutated motor [4-5].

Power quality problems have become important issues in these motors due to the recommended limits of harmonics in supply current by various international power quality standards such as the International Electrotechnical Commission (IEC) 61000-3-2 [6]. So the power factor correction has led the circuit designers to look closely at all sections of the circuit and develop possible lower loss alternatives. One section that contributes significantly to the losses is the input bridge rectifier. As a result, the alternatives to eliminate the diode bridge or convert it into a dual-use circuit have been explored for many years. This elimination/conversion of Diode Bridge brings about its own set of challenges.

Bridgeless converters are becoming more popular in order to increase the power factor at the ac mains. The distinguishing characteristic of a bridgeless PFC converter is that it eliminates the need for a diode bridge at the input. This reduces power losses that normally occur in a diode bridge and, as a result, improves overall system efficiency with comparable cost savings. Power Factor Correction rectifiers are used to improve the rectifier power density and to reduce noise emissions via soft switching techniques or coupled magnetic topologies [7-9].

2. PFC Converters

A conventional PFC scheme has lower efficiency due to significant losses in the diode bridge. Conventionally boost converters are used as front end rectifiers [10-11]. For low voltage applications such as telecommunication or computer industry an additional converter or isolation transformer is required to step down the voltage. Bridgeless PFC buck converters

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are limited for step down applications [12-13]. Input line current cannot follow the input voltage around zero crossings of the input line voltage. Output to input voltage ratio is limited to half resulting in increased THD and reduced PF. A brief comparison of various configurations reported in the literature is tabulated in Table 1.

Table 1. Comparative Analysis of the Bridgeless PFC Converter Topologies

Converter Topology	Component Count					Half Period	Stability
	S_W	D	L	C	Total		
BL-BUCK [8]	2	4	2	2	10	5	NO
BL-BOOST [10]	2	2	1	1	6	4	NO
BL-BUCK BOOST [14]	3	4	1	3	11	8	YES
BL-CUK T-1 [16,17]	2	3	3	3	11	7	YES
BL-CUK T-2 [16,17]	2	2	3	4	11	11	YES
BL-CUK T-3 [16,17]	2	3	3	2	10	7	YES

To overcome these drawbacks several bridgeless topologies suitable for step up or step down applications have been proposed. Bridgeless buck-boost converter is one of them which has both step up and step down operation in a single circuit [15-16]. It has the disadvantages: Discontinuous input current, high peak current in power components, poor transient response make it less efficient.

3. Cuk Derived PFC Converters

Bridgeless Cuk converter has the following advantages:

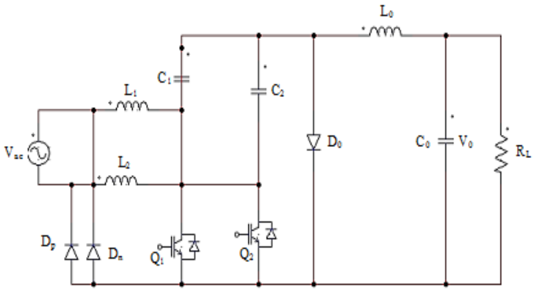
a) Easy implementation of transformer isolation.
b) Natural protection against inrush current occurring at start up or overload current, lower input current ripple.
c) Less electromagnetic interference associated with discontinuous conduction mode (DCM) topology.
d) Cuk converter has both input and output currents with a low current ripple.

For applications, which require a low current ripple at the input and output ports of the converter, the Cuk converter seems to be a potential candidate in the basic converter topologies.

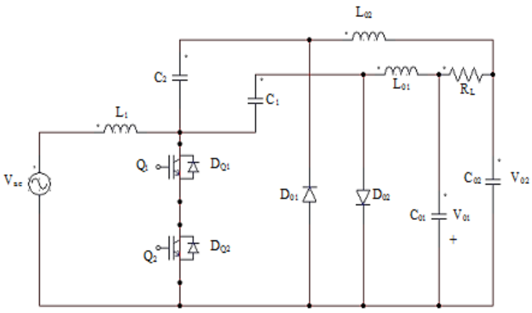
The three new Cuk derived topologies are derived from the conventional PFC Cuk rectifiers [17-19]. The bridgeless Cuk derived converter is a combination of two dc-dc converters. This converter operates for each half line period (T/2) of the input voltage.

There are one or two semiconductor switches in the current flowing path. Current stresses in the active and passive switches are further reduced. Circuit efficiency is improved as compared to conventional Cuk rectifier. They do not suffer from high common mode noise problem and common mode emission performance is similar to the conventional PFC topologies.

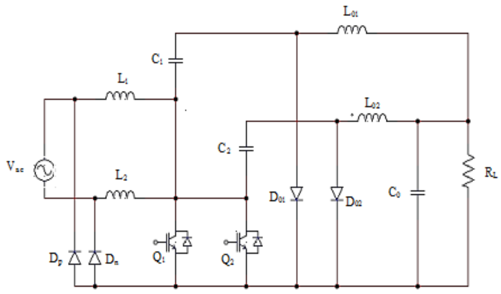
The three new Cuk rectifiers are compared based on components count, mode of operation in DCM and driver circuit complexity as tabulated in Table 2. The bridgeless PFC Cuk rectifiers of Figure 1 utilize two power switches (*Q*1 and *Q*2). However, the two power switches can be driven by the same control signal, which significantly simplifies the control circuitry.



(a) Type I



(b) Type II



(c) Type III

Figure 1. CUK Derived Converter Topologies

Table 2. Cuk Converter Topologies in DCM Mode

Item	Conv. Cuk	Type-I	Type-II	Type-III
Diode	4 slow+1 fast	2 slow+3 fast	2 fast	2 slow+2 fast
Switch	1	2(with unidirectional current capabilities)	2	2
Current Conduction Path when S_W on	2 slow diodes and 1 switch	1 slow diode and 1 switch with series diode	1 body diode and 1 switch	1 slow diode and 1 switch
Current Conduction Path when S_W on	3 diodes(2 slow and 1 fast)	2 diodes(1 slow and 1 fast)	1 fast diode	2 diodes(1 slow and 1 fast)
Current Conduction Path in DCM	2 slow diodes	1 slow diode	-	1 slow diode
Component Count	10	11	11	13
Number of Capacitors	2	3	4	3
Driver circuit Complexity	1 non-floating	2 non-floating	1 floating + 1 non-floating	2 non-floating

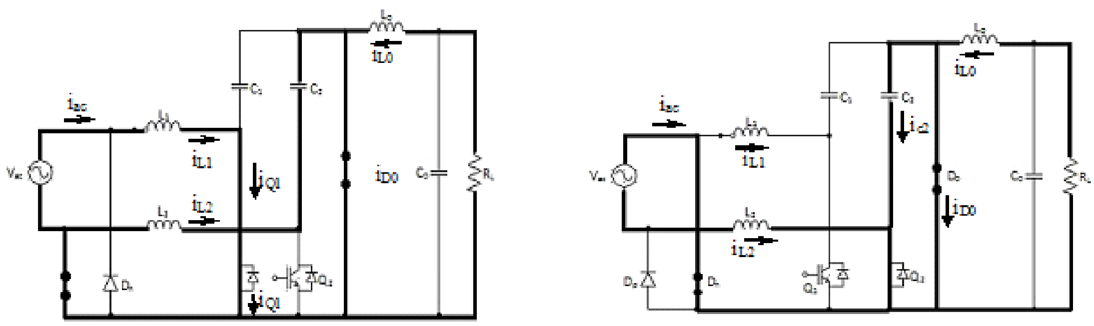
In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2, 5]. The discussion can be made in several sub-chapters.

4. Operation of Bridgeless Cuk Converters

The choice of mode of operation of a PFC converter is a critical issue because it directly affects the cost and rating of the components used in the PFC converter [20-22]. Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM) are widely used in practice. In CCM or DCM, the inductor's current or the voltage across intermediate capacitor in a PFC converter remains continuous or discontinuous in a switching period respectively. To operate a PFC converter in CCM, one requires three sensors (two voltage, one current) while a DCM operation can be achieved using a single voltage sensor. The stresses on PFC converter switch operating in DCM are comparatively higher as compared with its operation in CCM.

By operating the rectifier in DCM, several advantages can be gained such as:

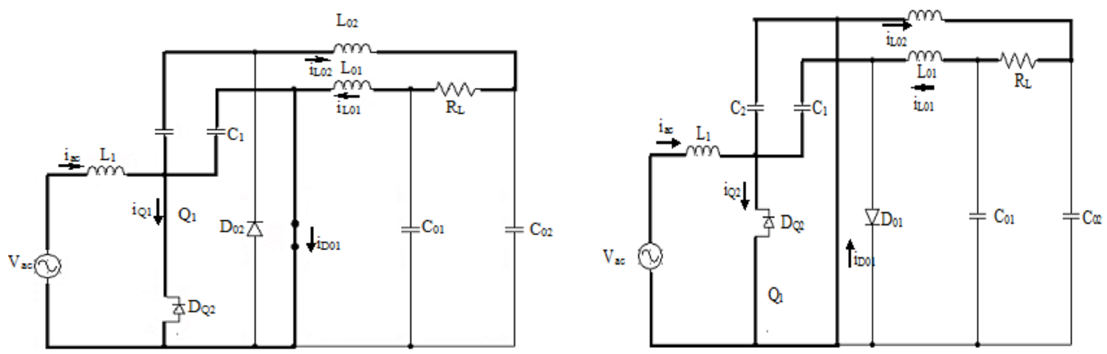
a) Natural near-unity power factor.
b) The power switches are turned ON at zero current and the output diodes are turned OFF at zero current.



(a) During positive half cycle (b) During negative half cycle

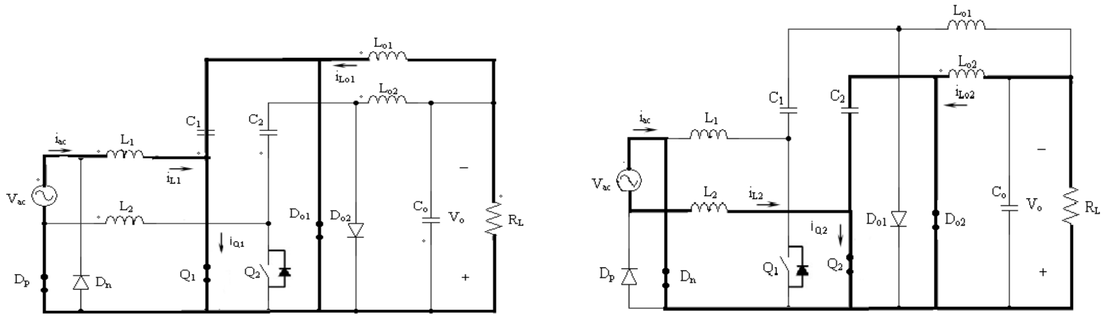
Figure 2. Circuits of Type I Cuk rectifier

Thus, the losses due to the turn-on switching and the reverse recovery of the output diodes are considerably reduced. Conversely, DCM operation significantly increases the conduction losses due to the increased current stress through circuit components. As a result, this leads to one disadvantage of the DCM operation, which limits its use to low-power applications (less than 300W). Hence, DCM is preferred for low-power applications.



(a)During positive half cycle (b) During negative half cycle

Figure 3. Circuits of Type II Cuk rectifier



(a) During positive half cycle (b) During negative half cycle

Figure 4. Circuits of Type III Cuk rectifier

5. Conclusion

A comparative analysis of different types of converter topologies for power factor correction in BLDC motors have been discussed. A suitable Type III Cuk Converter seems to be a potential candidate for PFC. The bridgeless Type III PFC Cuk converter fed BLDC motor drive can be used to achieve almost near unity power at the AC mains with low THD. Hence the overall system can be implemented in Air-conditioning System.

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