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A Power Factor Corrected Bridgeless Type III Cuk Derived Converter fed BLDC Motor Drive

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Abstract

This paper deals with the power factor correction in BLDC motor drive with different cuk derived converter topologies and the best one is simulated for power factor correction operation. Power quality issue is the major concern in the BLDC motor drive due to recommended limits of harmonics in the supply current. Conventionally the BLDC motors are powered with the help of diode bridge rectifiers which results in highly distorted supply current and poor power factor. So modification in converter topology is the research hotspot in recent years. Alternatively bridgeless converter topologies are used in place of diode bridge rectifiers (DBR). Among the bridgeless topologies cuk derived converters suited well for power factor correction. In this paper the different cuk topologies are investigated and the best one is simulated with the help of neuro-fuzzy controller in MATLAB/Simulink platform.

***Keywords**: power factor correction (PFC), bridgeless Cuk converters, total harmonic distortions (THD), power quality, diode bridge rectifier (DBR), BLDC motor drive*

1. Introduction

The BLDC motors are becoming more popular in many low and medium power applications. They are widely used in 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. A conventional PFC scheme has lower efficiency due to significant losses in the diode bridge. One section that contributes significantly to reduce the losses in the input bridge rectifier. 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. As a result, the alternatives to eliminate the diode bridge or convert it into a dual-use circuit have been explored for many years. The elimination/conversion of Diode Bridge brings about its own set of challenges.

To overcome these drawbacks several bridgeless topologies suitable for step up or step down applications in order to increase the power factor at the ac mains. The distinguishing characteristic of a bridgeless PFC converter is that the partial elimination of diodes in the diode bridge at the input. This reduces power losses that normally occur in a diode bridge; hence the overall system efficiency is improved with comparable cost savings. Bridgeless PFC buck converters 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. Bridgeless buck-boost converter 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

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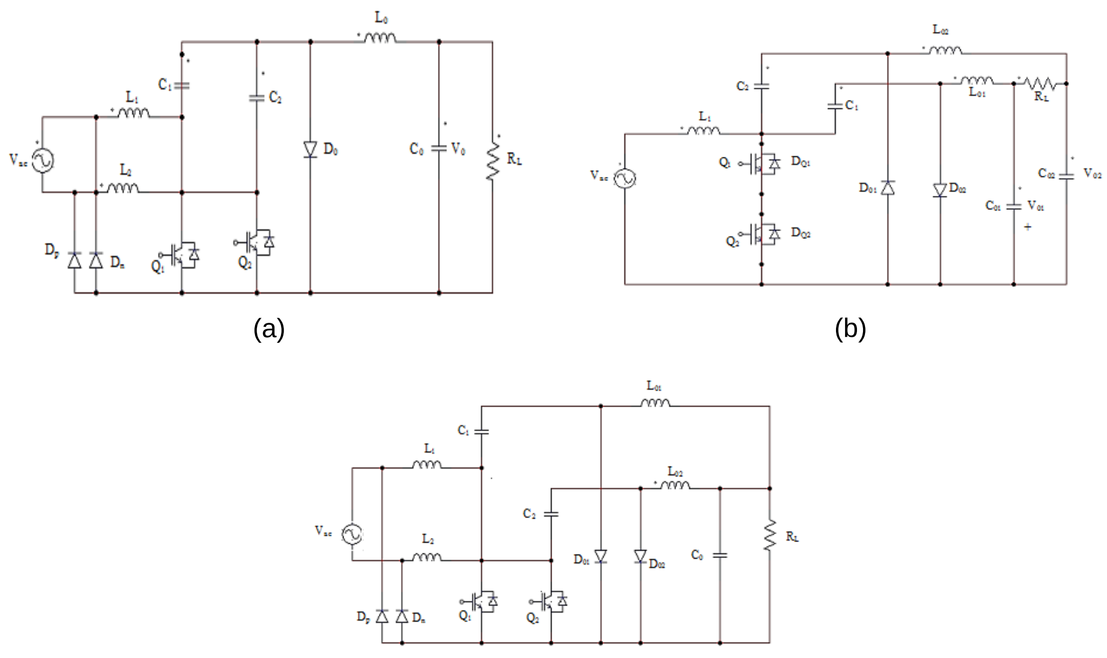
make it less efficient. Power Factor Correction rectifiers are used to improve the rectifier power density and to reduce noise emissions via soft switching techniques or coupled magnetic topologies [7-9].

2. Cuk Derived PFC Converters

Power Factor Converters used for both step-up and step down applications are analyzed Cuk converter has both input and output currents with a low current ripple, the Cuk converter seems to be a potential candidate in the basic converter topologies. Hence it can be used for applications resulting in lower input and output current ripple.

The three new Cuk derived topologies are derived from the conventional PFC Cuk rectifiers [17-19] as shown in Figure 1. The bridgeless Cuk derived converter is a combination of two dc-dc converters. One for each half line period (T/2) is the input voltage. The number of semiconductor switches in the current flowing path is reduced. 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.



(a) (b)

(c)

Figure 1. CUK Derived Converter Topologies
(a) Type I, (b) Type II, (c) Type III

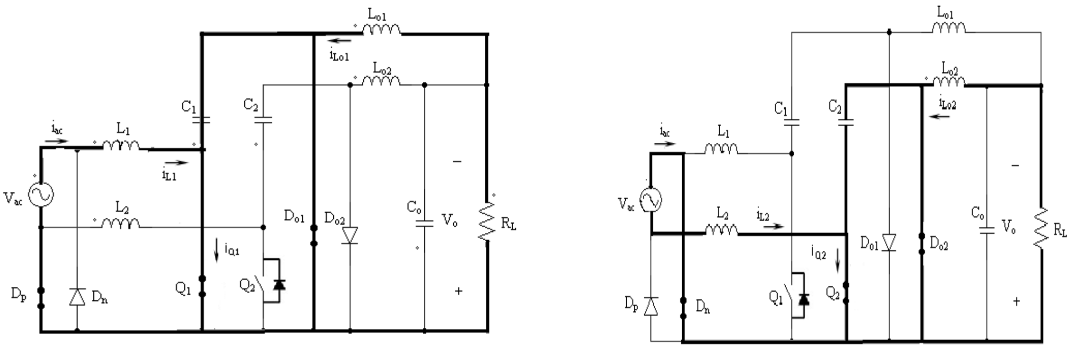
The three new Cuk rectifiers are compared based on components count, mode of operation in DCM and driver circuit complexity. From the comparison results the type III cuk converter provides less component count and switches conducted in current flowing path is minimum. It utilizes two power switches (*Q*1 and *Q*2 and the two power switches can be driven by the same control signal, which significantly simplifies the control circuitry.

3. Operation of Type III BL Cuk Converter

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 [20-21]. 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:

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

The mode of operation is an application dependent. CCM is suitable for high power applications and DCM for low power applications. 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 300 W). Hence, DCM is preferred for low-power applications [22].



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

Figure 2. Circuits of Type III Cuk rectifier

4. Design of Neuro-Fuzzy Controller

The cost of a BLDCM drive has two main components; one is the motor and other is the controller. The cost of the controller and complexity of control become the key factor for the commercialization of these drives. Therefore, the controller design for a particular application plays a major role in the performance and efficiency of the drive. Hence the acceptability of BLDC motors in a variety of applications solely depends upon the research in the area of simplified and low cost controller design having improved power quality at the input mains of the drive.

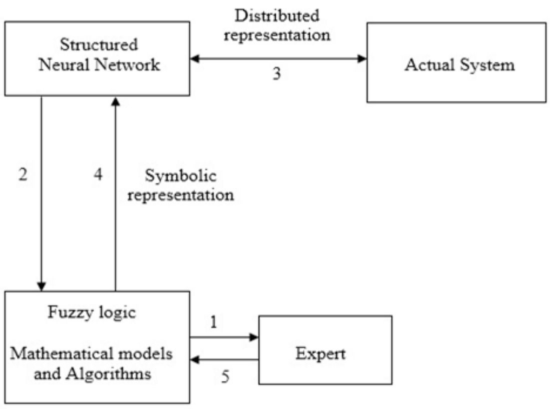


Figure 3. Neuro-fuzzy Logic Controller

Neural networks are used to design membership functions of fuzzy systems that are employed as decision-making systems for controlling equipment as shown in Figure 3. Although fuzzy logic can encode expert knowledge directly using rules with linguistic labels, it usually takes a lot of time to design and tune the membership functions which quantitatively define these linguistic labels. Neural network learning techniques can automate this process and substantially reduce development time and cost while improving performance.

A fuzzy neural system combines the advantages of fuzzy systems and neural networks. As a fuzzy system, it does not require a large data set and it provides transparency, smoothness, and representation of prior knowledge. As a neural system, it provides parametric adaptability.

5. Simulation Circuits

A computer simulation model for PFC Cuk converter fed BLDC motor drive is developed using the MATLAB/SIMULINK software is shown in Figure 4. The switching pulse for Cuk converter is generated with the help of hall signals obtained from hall sensors. The speed of the motor is controlled by controlling the DC link voltage of the inverter with the help of Neuro fuzzy logic controller. Single phase ac voltage is given as input to the Cuk rectifier. The voltage source inverter boost the DC voltage of the rectifier and is fed to the BLDC Motor.

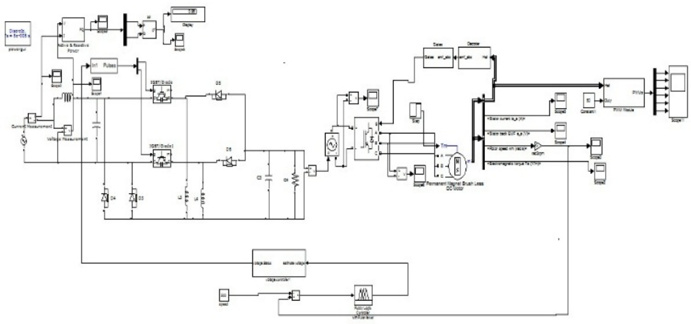


Figure 4. Simulink block of BLDC motor drive with Neuro-Fuzzy logic controller

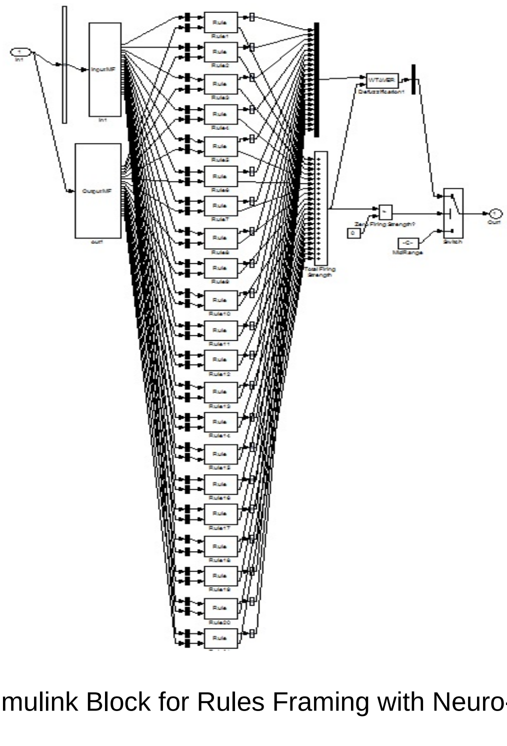


Figure 5. Simulink Block for Rules Framing with Neuro-Fuzzy Algorithm

Input and output parameters are chosen as two membership functions as speed error and change in speed error are designed with the help of neural network. Rules for controlling of switches are framed with the knowledge of fuzzy logic as shown in Table 1. These two combinations are implemented in neuro-fuzzy controller as shown in Figure 5. The two inputs are taken as speed error and change in speed error for fuzzy logic controller. Thus the decision making rules for FLC for obtaining controlled signal comprises of 11x3 matrices. Based upon these rules the switching pulse for cuk converter is generated corresponding to speed variation. The cuk converter regulates the supply given to the inverter, so that the speed should be maintained at the reference value.

Table 1. Rules table for FLC

u		ce		
		NS	Z	PS
e	NVB	NVB	NVB	NB
	NB	NB	NVB	NB
	NM2	NM2	NVB	NB
	NM1	NM1	NM2	NM1
	NS	NS	NM1	NS
	Z	Z	PS	PM1
	PS	PS	PM1	PM2
	PM1	PM1	PM2	PB
	PM2	PM2	PVB	PVB
	PB	PB	PVB	PVB
	PVB	PVB	PVB	PVB

The simulation block for AC mains power factor calculation block is shown in Figure 6. The display shows the AC mains power factor which could be affected when the motor is connected to the mains. With the help of cuk converter with neuro-fuzzy logic switching pulse, the power factor has been improved to 0.98 which is nearer to unity.

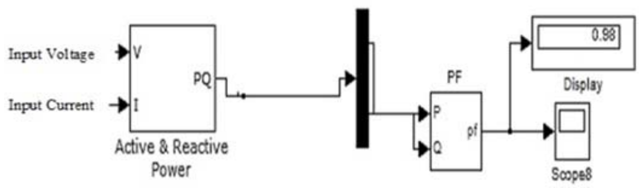


Figure 6. Power Factor Calculation Block

The sub block of power factor calculation is shown in Figure 7. The line side voltage and current is taken as input and it is converted into corresponding real and reactive power using real and reactive power Simulink block. The power factor of the AC mains is calculated with the help of math operator blocks.

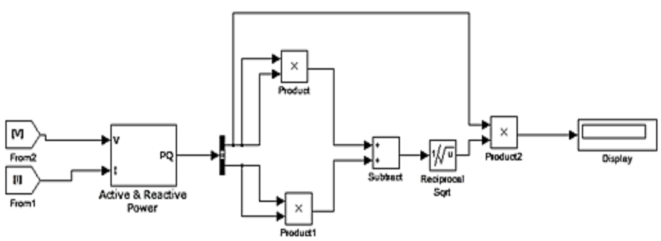


Figure 7. Sub block for power factor calculation

6. Results and Discussions

As said earlier compared to other bridgeless converters, the type III cuk converter effectively regulates the inverter supply and improves the power factor at AC mains near to unity. The ac-dc bridgeless converter thus reduces the conduction losses and the use of PWM inverter makes it possible to operate at the fundamental switching frequency. The artificial intelligent fuzzy logic controller generates the switching pulses for the Cuk converter.

The speed is controlled effectively by controlling the DC link voltage. For the performance evaluation of the proposed drive under input ac voltage variation, the DC link voltage is kept constant.

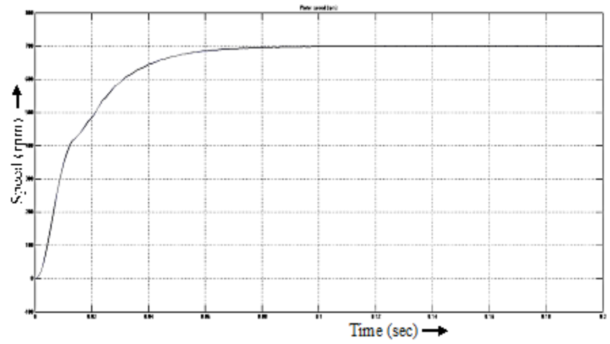


Figure 8. Speed Response

The speed should be linearly varied and settled to the reference value at 0.056s. Compared to other controllers, the settling time of the artificial intelligent controllers is minimum. The speed variation is also smoother. There is no dip and rise in the speed waveform.

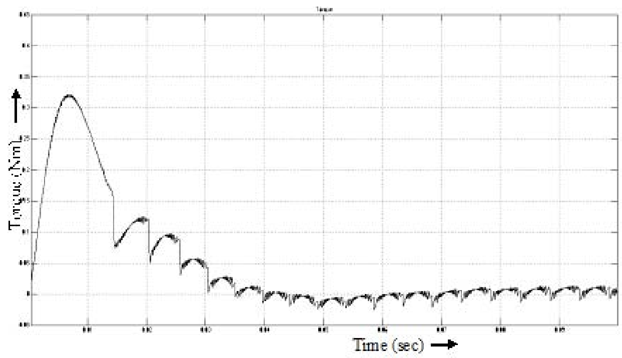


Figure 9. Electromagnetic Torque waveform

The electromagnetic torque waveform is shown in Figure 9. The peak overshoot of the torque is 0.32 Nm at 0.008s. The generated electromagnetic torque contains ripples in its waveform. The torque attain its nominal value at 0.03ms. Due to torque ripple, the BLDC motor produce EMI and performance of the motor is degraded due to noise.

The trapezoidal shape back EMF waveform is shown in Figure 10. The shape of the back EMF waveform gets collapsed at the time of starting. Up to 0.1s the back EMF waveform is ideal and after that there should be some distortions in the waveform.

The stator current waveform is shown in Figure 11 Compared to other controllers, the distortion in in the waveform is minimum. The peak overshoot of the current is 2.3A at 0.007s. Due to the less distortions in the waveform, the heating of the phase winding is minimum. The current should attain the nominal value at 0.017ms.

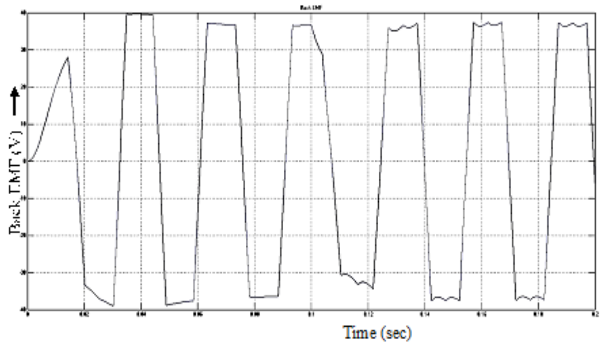


Figure 10. Back EMF Waveform

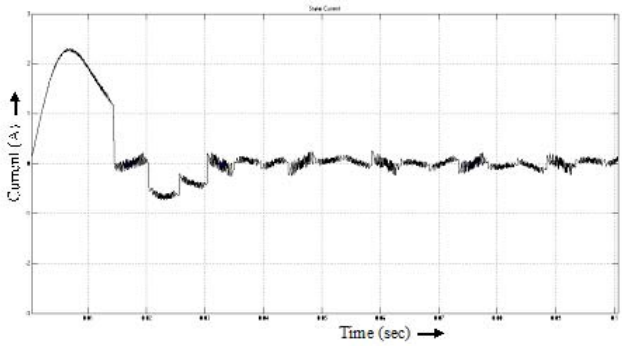


Figure 11. Stator Current Waveform

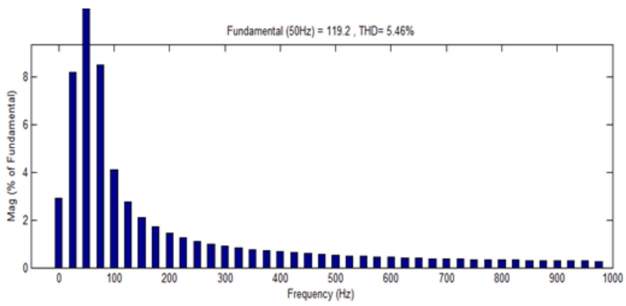


Figure 12. Total Harmonic Distortion

The Total Harmonic Distortion (THD) is achieved as 5.46% is represented in Figure 12. For any type of load the harmonic level is almost constant.

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