AN ANALYTICAL STUDY ON POWER FACTOR RECTIFICATION BY USING CUK CONVERTER-FED BLDC MOTOR

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ABSTRACT
Because of its attributes of great efficiency, a broad speed range, and cheap maintenance, brushless dc motors (BLDC) are increasingly being used in low-power appliances. As a practical option for low power applications, this study discusses a power factor correction (PFC) based Cuk converter fed brushless DC motor or (BLDC) drive. By altering the DC bus voltage of the voltage source inverter (VSI), which uses low frequency switching of VSI (electronic commutation of BLDC motor) for reduced switching losses, the speed of the BLDC motor can be regulated. By electronically commutating the BLDC motor, fundamental frequency switching has been used to lower the switching losses in the VSI. Two BLDC motor drive control methods have been implemented, one of the control strategies is based on PFC-CUK converter fed BLDCM drive and another one is Hysteresis current controller converter fed BLDC motor drive. Comparison has been made between the two control strategies is PI and HCC in terms of minimize Torque ripple, Power factor for different operating speeds. T he proposed work has been implemented under M AT LAB/Simulink environment.
Keywords: BLDC motor, BLDCM drive, PFC-CUK converters, fed brushless DC motor, power factor correlation

I. INTRODUCTION

A three-phase AC motor with electronic commutation and feedback on the rotor position is a BLDC motor. Typically, a three phase inverter with six switches is used to implement a BLDC motor. The data pertaining to rotor position is provided by the Hall Effect sensors. Due to the widespread use of BLDC motors and their inherent benefits, such as high efficiency, high flux density, and optimal cost, there are fewer switches and sensors [1]. For BLDC drive systems, a new architecture known as Six Switches, Three Phase Inverter (SSTPI) is being studied [2, 3]. This architecture lowers the need for power electronic switches, which lowers total costs and losses [4, 5]. PWM with uneven voltage makes it difficult to minimize conducting currents. The existing PWM schemes cannot be used for SSTPI.

Therefore, a new converter topology for three phase BLDC motor drive is to be developed. The Back EMF wave form of BLDC motor is trapezoidal in shape. And the stator current wave form is rectangular in shape. Hysteresis current control is employ to maintain the actual motor currents close to rectangular reference values [6, 7].All through steady state analysis SSTPI fed BLDC motor is studied, the modeling, simulation and practical realization is to be explored. PI control is method of speed control of BLDC motor which reduces the steady state error to zero [8], PI controller does not respond to quick variation of speed and reaches the set point slowly. The PI controller can be easily implemented because simplicity and most common usage since long time [9]. In this paper, two control strategies for BLDC motor drive have been implemented. One of the control strategies is based on PFC-CUK converter fed BLDCM drive and another one is Hysteresis current controller converter fed BLDC motor drive and comparison is made between this two control strategies for different operating speeds. The performance of the BLDC motor with CUK converter for four switch VSI fed BLDCM motor is found to be quite effective due to improve power quality, less torque ripple and smooth control of speed of BLDC motor[10-

12]. The CUK converter for six switches VSI fed BLDC motor drive system. The control scheme employs hysteresis current control. For each phase of 3-hystersis current controller, six power electronic switches are used and hence low cost and less switching losses and also reductions in torque ripple, as well as voltage stress and improved dynamic response. The variable DC output of bridge rectifier is fed to CUK converter. The output of the CUK converter is fed three leg VSI inverter which drives BLDC motor [13-14]. The power factor correction control scheme is based on the principle of current multiplier approach. This involves the presence of current loop inside speed control loop, in case of continuous conduction of the converter. The control loop starts with processing of speed obtained by comparing the actual, speed with the desired reference speed. The error is fed to the PI controller to obtain the reference torque and compared with actual torque of BLDC motor. The resultant torque error is multiplied with suitable constant and amplified is order to provide input to reference current block. The reference current is compared with phase a current which is gives to hysteresis current control. The hysteresis current controller generates pluses for operation of three leg inverter and a rate limiter is introduced, which limits the current within specified limits [15].

II. SYSTEM CONFIGURATION

Figs.1 and .2 shows the PFC Cuk converter based VSI fed BLDC motor drive using a current multiplier and a voltage follower approach respectively.

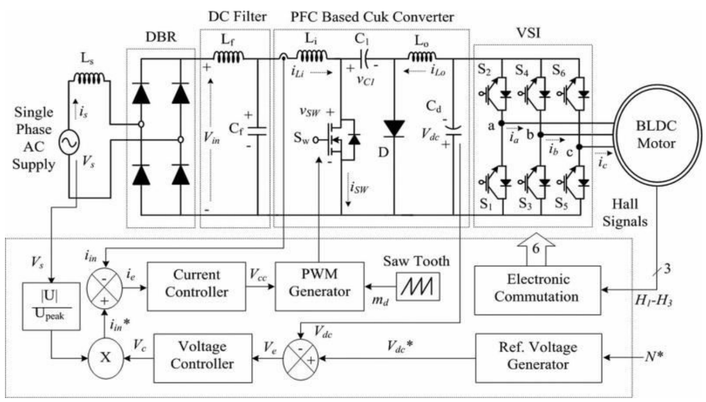

Fig.1. BLDC motor drive fed by a PFC Cuk converter using a current multiplier approach

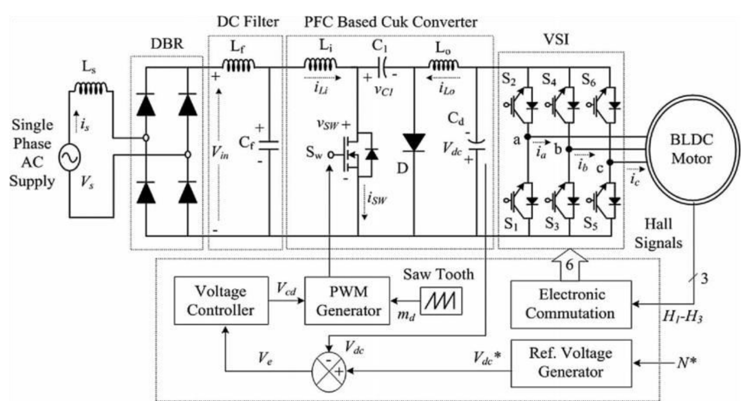

Fig.2.A BLDC motor drive fed by a PFC Cuk converter using a voltage follower approach.

A high frequency metal oxide semiconductor field effect transistor (MOSFET) is used in Cuk converter for PFC and voltage control whereas insulated gate bipolar transistor's (IGBT) are used in the VSI for its low frequency operation .BLDC motor is commutated electronically to operate the IGBT's of VSI in fundamental frequency switching mode to reduce its switching losses [13-14]. The PFC Cuk converter operating in CCM using a current multiplier approach is shown in Fig.1 i.e. the current flowing in the input and output inductors (L Lo), and the voltage across the intermediate capacitor (C1) remains continuous in a switching period. Whereas, Fig.2 shows a Cuk converter fed BLDC motor drive operating in DCM using a voltage follower Approach. The current flowing in either of the input or output inductor (Li and Lo) or the voltage across the intermediate capacitor (C1) become discontinuous in a switching period for a PFC Cuk converter operating inDCM. A Cuk converter is designed to operate in all three discontinuous conduction modes and a continuous conduction mode of operation and its performance is evaluated for a wide voltage control with unity power factor at AC mains [15].

III.OPERATION OF CUK CONVERTER IN DIFFERENT MODES

The operation of Cuk converter is studied in four different modes of CCM and DCM. In CCM, the current in inductors (Li and Lo) and voltage across intermediate capacitor C1 remain continuous in a switching period. Moreover, the DCM operation is further classified into two broad categories of discontinuous inductor current mode (DICM) and discontinuous capacitor voltage mode (DCVM). In DICM, the current flowing in inductor Lior Lo becomes discontinuous in their respective modes of operation. While in DCVM operation, the voltage appearing across the intermediate capacitor C1becomes discontinuous in a switching period. Different modes for operation of CCM and DCM are discussed as follows.

CCM Operation:

The operation of Cuk converter in CCM is described as follows. Figs.3(a) and (b) show the operation of Cuk Converter in two different intervals of a switching period and Fig.3(c) shows the associated waveforms in a complete switching period.

Interval I: When switch Swim turned on, inductor LI stores energy while capacitor C1discharges and transfers its energy to DC link capacitor C d as shown in Fig.3(a). Input inductor current iLi increases while the voltage across the intermediate capacitor VC1 decreases as shown in Fig3(c).

Interval II: When switch Swiss turned off, then the energy stored in inductor Lo is transferred to DC link capacitor Cd, and inductor Li transfers its stored energy to the intermediate capacitor C1 as shown in Fig.3(b). The designed values of Li, Lo and C1are large enough such that a finite amount of energy is always stored in these components in a switching period

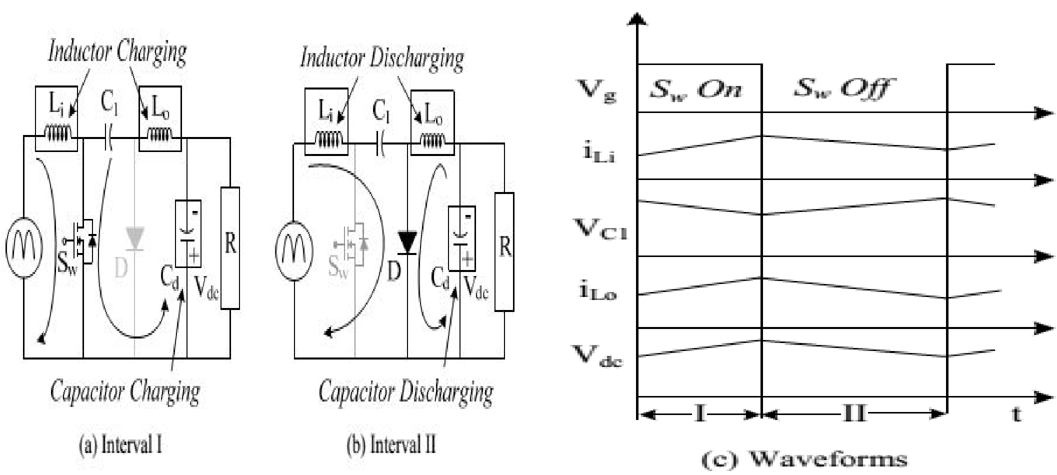

Fig.3. Operation of Cuk converter in CCM during (a-b) different intervals of switching period and (c) theassociated waveforms

IV. DESIGN OF A PFC CUK CONVERTER

A PFC based Cuk converter fed BLDC motor drive is designed for DC link voltage control of VSI with power factor correction at the AC mains. The Cuk converter is designed for a CCM and three different DCMs. In DCM, any one of the energy storing elements Li, Lo or C1are allowed to operate in discontinuous mode whereas in CCM, all these three parameters operate in continuous conduction. The design and selection criterion of these three parameters is discussed in the following section. The input voltage Vs applied to the DBR is given as,

$$Vs\ (t)=|Vm\text{Sin}\ (2\pi f Lt)|=|220\sqrt{2}\ \text{Sin}\ (314t)\ |V\ (1)$$

Where Vm is the peak input voltage (i.e. √2Vs, Vs is the rms value of supply voltage), fL is the line frequency i.e. 50 Hz. The instantaneous voltage appearing after the DBR is as,

$$(t) = |Vm\text{Sin}\ (wt)| = |220\sqrt{2}\ \text{Sin}\ (314t)\ |V \quad (2)$$

Here represents the modulus function. The output voltage, Vdc of Cuk converter is given as

$$Vdc= D\ (1-D)\ /\ (t)\ (3)$$

Here D represents the duty ratio. The instantaneous value of duty ratio, D(t) depends on the Input voltage appearing after DBR, Vin (t) and the required DC link voltage, Vdc.

Hence the instantaneous duty ratio, D (t) is obtained by substituting (2) in (3) and rearranging it as,

$(t) = Vdc/\ (t)+Vdc = Vdc/|Vmsin(\omega t)|+Vdc(4)$

The Cuk converter is designed to operate from a minimum DC voltage of 40V (Vdc min) to a maximum DC link voltage of 200V (Vdc max). The PFC converter of maximum power rating of 350W (P max) is designed for a BLDC motor of 251W (Pm) (full specifications given in Table I) and the switching frequency (fS) is taken as 20kHz. Since the speed of the BLDC motor is controlled by varying the DC link voltage of the VSI, hence the instantaneous power, Piatt any DC link voltage (Vdc) can be taken as linear function of Vdc. Hence for a minimum value of DC link voltage as 40V, the minimum power is calculated as 70W.

TABLE I

SPECIFICATIONS OF A BLDC MOTOR

S.NO	**PASRAMETERS**	**VALUES**
1	No. of poles (P)	4 POLES
2	Rated power (PRATED)	251.3 W
3	Rated DC link voltage (VRSATED)	200V
4	Rated torque (TRATED)	1.2 N-M
5	Rated speed (NRATED)	2000 RPM
6	Back Emf constant (Kb)	78 V/KRPM
7	Torque constant (Kt)	0.74 N-M/A
8	Phase resistance (RPH)	14.56 Ω
9	Phase inductance (LPH)	25.71 mH
10	Moment of inertia (J)	$1.3\times10{-}4$ N-M/-S^2

TABLE II

ELECTRONIC OUTPUT BASED ON THE HALL EFFECT SIGNAL

HALL SIGNALS			**SWITCHING SIGNALS**					
H1	H2	H3	Sa1	Sa2	Sb1	Sb2	Sc1	Sc2
0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	1	0
0	1	0	0	1	1	0	0	0
0	1	1	0	1	0	0	1	0
1	0	0	1	0	0	0	0	1
1	0	1	1	0	0	1	0	0

1	1	0	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0

TABLE III

DESIGN PARAMETERS IN DIFFERENT MODES OF OPERATION

S.NO	SPECIFICATIONS	VALUES			
1	Supply voltage(Vs)	Rated:220v ,(Universal Mains:85-270v)			
2	DC Link Voltage(Vcd)	Rated:220v,(40v-200v)			
3	Power (P)	Rated:350w,(70w-350w)			
4	Switching frequency(fs)	20khz			
5	Operation	Li	Lo	C1	Cd
6	CCM	2.5Mh	4.3mH	0.66μF	220μF
7	DICM(Li)	100μH	4.3MH	0.66μF	220μF
8	DICM(Lo)	2.5Mh	70μH	0.66μF	220μF
9	DCVM(C1)	2.5mH	4.3mH	9.1nF	220μF

V.MATLAB/SIMULATION RESULTS

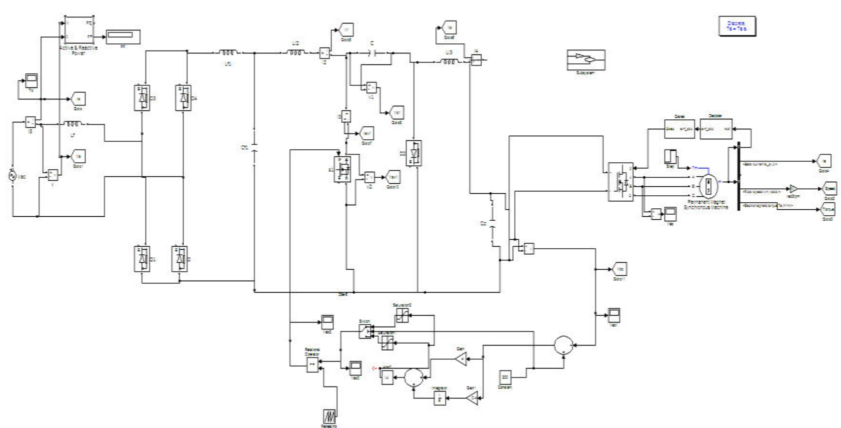

Fig.4. Simulation model of BLDC motor drive fed by a PFC Cuk converter using a multiplier approach

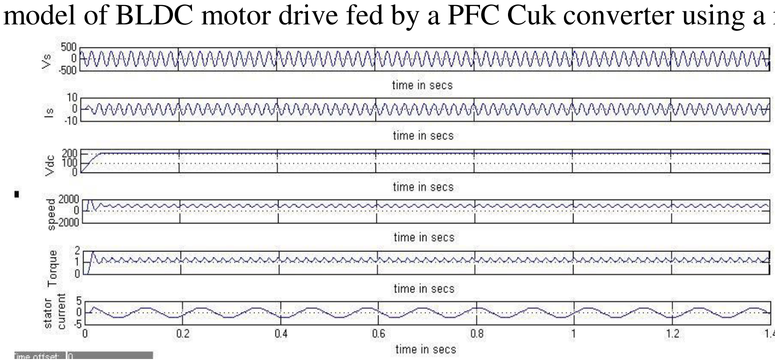

Fig.5.Simulation waveform for source voltage and current, dc voltage, speed, torque and armature current of the BLDC motor drive with the Cuk converter operating in the CCM

Performance of BLDC Motor Fed Cuk Converter Operating in the CCM:

The circuit configuration and control of the PFC Cuk converter operating in the CCM. The parameters selected for this converter to operate in the CCM are as follows: Input inductor Li = 2.5 mH, output inductor Lo = 4.3 mH, intermediate capacitor C1 = 0.66 μF and dc-link capacitor Cd = 2200 μF.

The performance of the proposed BLDC motor drive fed by a PFC Cuk converter operating in the CCM The input inductor current iLi, output inductor current iLo, and intermediate capacitor's voltage VC1 are continuous in operation while the supply current Is is sinusoidal and in phase with the supply voltage vs. which shows a 0.9306 PF at ac mains.

Simulation model of CUK-converter fed HCC BLDCM drive by using HCC:

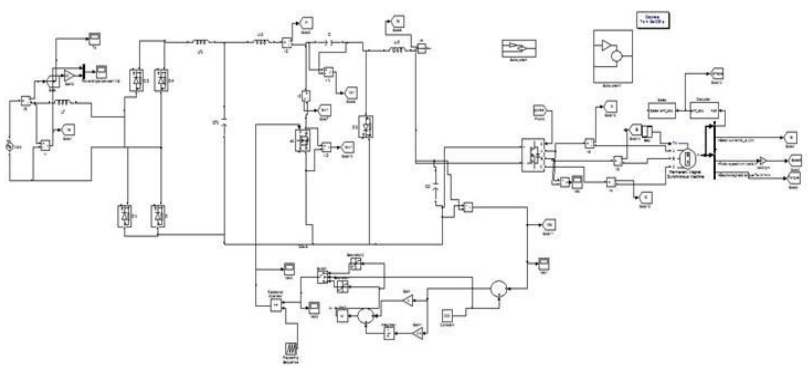

Fig.6. Simulation model of HCC based BLDC motor drive fed by a PFC Cuk converter.

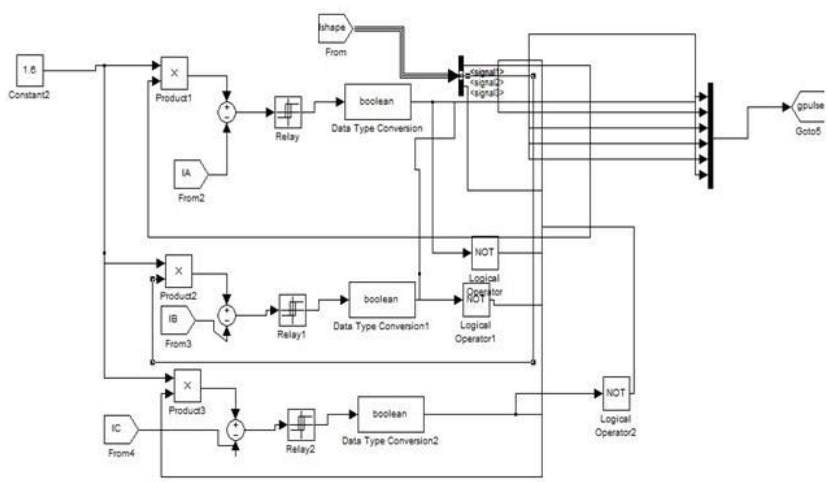

Fig.7.Control strategies for hysteresis current control

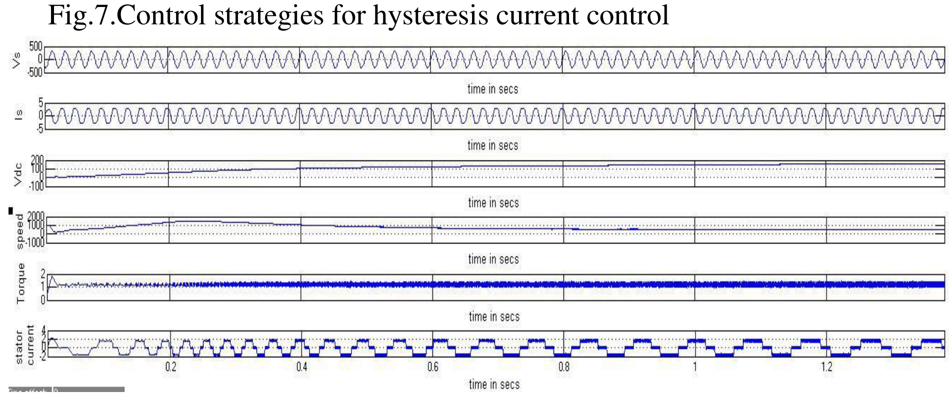

Fig.8.Siumulation results for source voltage, current, dc link voltage, and speed, torque, stator Currentof BLDC motor under hysteresis current control

Performance of HCC based BLDC Motor Fed Cuk Converter:

Finally, a best suited mode of Cuk converter operating in CCM has been selected for experimental verifications. By using HCC the power factor is improved from 0.9306 to 0.9994.The simulation model which is implemented in a modular manner with HCC under MATLAB environment allows dynamic characteristics such as phase currents, rotor speed, and mechanical torque ripple has been effectively reduced.

Performance details:

S.NO	BLDC MOTOR	POWER FACTOR
1	Fed CUK-converter	0.9306
2	fed CUK-Converter along with HCC	0.9994

VI.CONCLUSION

For the creation of cheap cost PFC motors for multiple low power equipment's such as fans, blowers, water pumps, etc., a Cuk converter for VSI fed BLDC motor driving has been developed. By adjusting the DC link voltage of the VSI, it is possible to regulate the speed of the BLDC motor drive and reduce switching losses by operating the VSI in fundamental frequency switching mode. For the creation of a BLDC motor drive with a unity power factor at the AC mains, four distinct modes of the Cuk converter running in CCM and DCM have been investigated. When the system is disturbed, the proposed hysteresis current controller system has great robustness and good adaptability. HCC increases the power factor is improved from 0.9306 to 0.9994. The simulation model which is implemented in a modular manner with HCC under MATLAB environment allows dynamic characteristics such as phase currents, rotor speed, and mechanical torque ripple has been effectively reduced.

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