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BLDC Motor Driven By Power Factor Correction Based Cuk Converter

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***Abstract*: -- A Brushless dc motor (BLDC) drive fed by a Cuk converter with power factor correction at ac mains is a cost-effective solution for low-power applications. The speed of the BLDC motor is controlled by varying the dc-bus voltage of a voltage source inverter (VSI) which uses a low-frequency switching of VSI (electronic commutation of the BLDC motor) for low switching losses. Speed controllers for sensorless BLDC motor use the principle of Back EMF for finding out the commutation instance. A diode bridge rectifier followed by a Cuk converter working in a discontinuous conduction mode (DCM) is used for control of dc-link voltage with unity power factor at ac mains. Performance of the PFC Cuk converter is evaluated under four different operating conditions of discontinuous and continuous conduction modes (CCM) and a comparison is made to select a best-suited mode of operation. The performance of the proposed system is simulated in a MATLAB/ Simulink environment.**

***Keywords* — Cuk converter, BLDC motor, VSI, continuous conduction mode, discontinuous conduction mode.**

I. INTRODUCTION

BLDC motor is one of the types of synchronous motors. It means at the same frequency magnetic fields generated by both stator and rotor rotates. BLDC motors don't experience the "slip" that is normally seen in induction motors. BLDC motors have single-phase, 2-phase and 3-phase configurations. The stator has the same number of windings in all it's types. Out of these, the 3-phase motors are the most popular and widely used. Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. There is a requirement of an improved power quality (PQ) as per the international PQ standard IEC 61000-3-2 which recommends a high power factor (PF) and low total harmonic distortion (THD) of ac mains current for Class-A applications (<600 W, <16 A) which includes many household equipments. The conventional scheme of a BLDC motor fed by a diode bridge rectifier (DBR) and a high value of dc-link capacitor draws a non sinusoidal current, from ac mains which is rich in harmonics such that the THD of supply current is as high as 65%, which results in PF as low as 0.8 [15].

II. DESIGN AND OPERATION OF CUK CONVERTER

Two techniques used to control the cuk converter along with their circuits are discussed below

- Current multiplier approach
- Voltage follower approach

A.Current Multiplier Approach

Current multiplier approach is used for PFC converter operating in CCM. It offers low stresses on the PFC switch, but requires three sensors for PFC and dc-link voltage control. The circuit diagram is shown in below figure.

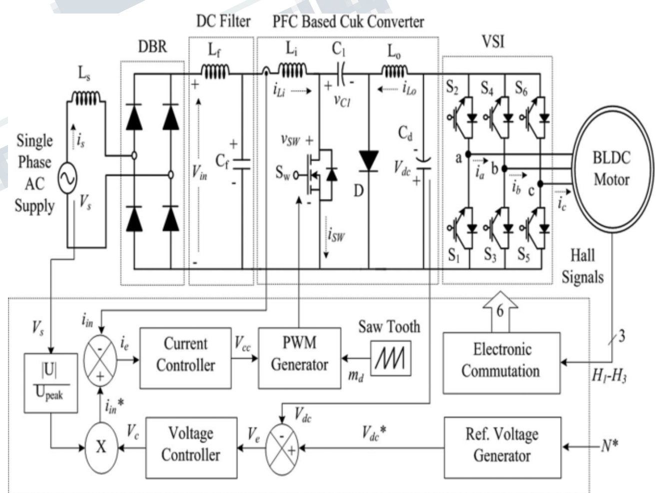

***Fig. 1 BLDC motor drive fed by a PFC Cuk converter using a current multiplier approach*.**

B. Voltage Follower Approach

This voltage follower technique requires a single voltage sensor for controlling the dc-link voltage with a unity PF. Therefore, voltage follower control has an advantage over a current multiplier control of requiring a single voltage sensor. Circuit diagram is shown in fig2. Depending on design parameters, either approach may force the converter to operate

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in the DCM or CCM. In this study, a BLDC motor drive fed by a PFC Cuk converter operating in four modes/control combinations is investigated for operation over a wide speed range with unity PF at ac mains. These include a CCM with current multiplier control, and three DCM techniques with voltage follower control. The PFC Cuk converter operating in the CCM using a current multiplier approach is shown in Fig. 1; i.e., the current flowing in the input and output inductors (*Li* and *Lo*), and the voltage across the intermediate capacitor (*C*1) remain continuous in a switching period, whereas Fig. 2 shows a Cuk converter-fed BLDC motor drive operating in the 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 (*C*1) becomes discontinuous in a switching period for a PFC Cuk converter operating in the DCM.

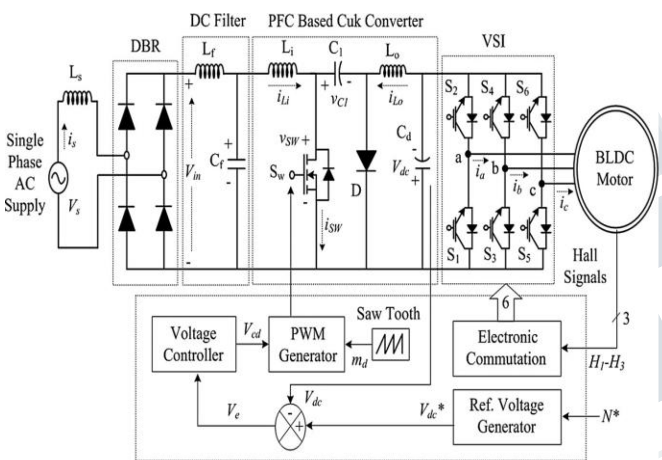

Fig.2 BLDC motor drive fed by a PFC Cuk converter using a voltage follower approach.

TABLE 1: SPECIFICATIONS OF A BLDC MOTOR

S. No.	Parameters	Values
1.	No. of Poles (P)	4 Poles
2.	Rated Power (P_{rated})	251.32W
3.	Rated DC link Voltage (V_{rated})	200V
4.	Rated Torque (T_{rated})	1.2Nm
5.	Rated Speed (ω_{rated})	2000rpm
6.	Back EMF Constant (K_b)	78V/krpm
7.	Torque Constant (K_t)	0.74Nm/A
8.	Phase Resistance (R_{ph})	14.56Ω,
9.	Phase Inductance (L_{ph})	25.71mH
10.	Moment of Inertia (J)	$1.3x10^{-4}Nm/s^2$

TABLE 2: DESIGN PARAMETERS IN DIFFERENT MODES OF OPERATION

Specifications ↓	Values			
Supply Voltage (V_s)	Rated: 220V, (Universal Mains: 85-270V)			
DC Link Voltage (V_{dc})	Rated: 200V, (40V-200V)			
Power (P)	Rated: 350W, (70W-350W)			
Switching Frequency (f_s)	20kHz			
Operation ↓	L_i	L_o	C_1	C_d
CCM	2.5mH	4.3mH	0.66μF	2200μF
DICM (L_i)	100μH	4.3mH	0.66μF	
DICM (L_o)	2.5mH	70μH	0.66μF	
DCVM (C_1)	2.5mH	4.3mH	9.1nF	

The two techniques which control the operation of cuk converter is explained below. The current multiplier approach is used to control the operation in continuous conduction mode where as voltage follower approach is used to control the operation in discontinuous conduction mode.

III. CONTROL OF CUK CONVERTER

A.Current Multiplier Approach for the Cuk Converter Operating in the CCM

An equivalent reference voltage (*V*dc*) corresponding to the reference speed (*N**) is generated by a "Reference Voltage Generator" as the speed of the BLDC motor is proportional to the dc-link voltage of the VSI. Fig. 3.1 shows the Cuk converter feeding BLDC motor drive using a current multiplier approach. The product of speed and the voltage constant (*Kb*) of the BLDC motor gives reference voltage and is given a

$$V^*dc = kbN^* \quad (1)$$

Now this reference voltage is compared with the sensed dc-link voltage (*V*dc) to generate a voltage error (*Ve*). The voltage error *Ve* at any instant "*k*" is given as

$$Ve\ (k) = V^*dc(k) - Vdc(k) \quad (2)$$

This voltage error is given to voltage proportional-integral (PI) controller for generation of a controlled output (*Vc*) as

$$Vc\ (k) = Vc\ (k - 1) + kpv\{Ve\ (k) - Ve\ (k - 1)\} + kivVe\ (k) \quad (3)$$

where *k*pv is the proportional gain and *k*iv is the integral gain of the voltage PI controller. By multiplying the controller output with the unit template of supply voltage the reference current (*i*in*) is generated and it given as

$$I^*in\ (k) = \{vs\ (k)/Vm\}Vc\ (k) \quad (4)$$

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where $vs\ (k)/Vm$ is the unit template of supply voltage vs and Vm represents the amplitude of supply voltage.

Now comparision is made between reference current and sensed input current to generate a current error given as

$$ie\ (k) = i^*in\ (k) - iin\ (k) \quad (5)$$

This current error is given to the current controller to generate a controlled output (Vcc) given as

$$Vcc(k) = Vcc(k-1)+kpi\{ie(k)-ie\ (k-1)\} + kii\ ie\ (k) \quad (6)$$

where $k$pi and $k$ii are the proportional and integral gain of the current PI controller.

Finally, the controller output (Vcc) is compared with the high frequency saw tooth waveform to generate the PWM signal to be given to the PFC converter switch as

$md(t)<Vcc(t)$ then

$$Sw = 1, \text{ else } Sw = 0 \quad (7)$$

where Sw denotes the switching signals as 1 and 0 for MOSFET to switch ON and OFF, respectively.

B. Voltage Follower Approach for the Cuk Converter Operating in the DCM

In this approach, a reference voltage (Vdc*) corresponding to the particular reference speed (N*) is generated similar to the current multiplier approach as

$$V^*dc=kbN^* \quad (8)$$

where kb represents the BLDC motor's voltage constant and$N$* is the reference speed.

Now, this reference voltage is compared with sensed dc-link voltage (Vdc) to generate a voltage error (Ve). The voltage error

Ve at any instant "k" is given as

$$Ve\ (k) = V^*dc(k) - Vdc(k) \quad (9)$$

This voltage error is given to the voltage PI controller to generate a controlled output (Vcd) given as

$$Vcd\ (k) = Vcd\ (k-1) + kpv\{Ve\ (k) - Ve\ (k-1)\} + kivVe\ (k) \quad (10)$$

where kpv and kiv are the proportional and integral gain of the voltage PI controller.

Finally, the controller output (Vcd) is compared with the high frequency saw tooth waveform to generate the PWM signal to be given to PFC converter switch as

$md(t)<Vcd(t)$then

$$Sw = 1, \text{ else } Sw = 0 \quad (11)$$

where Sw denotes the switching signals as 1 and 0 for MOSFET to switch ON and OFF, respectively conduction and supplies energy to the dc-link capacitor.

IV. SIMULATION RESULTS

From the comparison of operating modes based on the peak voltage across the switch and current stress through the switch shows the peak voltage and current stress variation with the load on the BLDC motor.

TABLE 3: COMPARATIVE ANALYSIS OF VARIOUS MODES OF OPERATION

Attributes	*CCM*	*DCM (L_i)*	*DCM (L_o)*	*DCM (C_1)*
Sensor's Requirement	3 (2V, 1C)	1 (V)	**1 (V)**	1 (V)
Control	Complex	Easy	**Easy**	Easy
Filter Requirement	No	Yes	**No**	No
Voltage Stress	Low	Low	**Low**	Very High
Current Stress	Low	High	**Medium**	Low
Cost of PFC system	High	Low	**Low**	Low
Inductor Rating	Low	High (L_i)	**High (L_o)**	Low
Capacitor Rating	Low	Low	**Low**	Very High

the voltage stress of the DCVM ($C1$) is very high and cannot be recommended because of higher switch rating requirement, whereas the voltage stress for the remaining three modes is of the order of 560 V which is acceptable. Now lower current stress in the DICM (Lo) is obtained which makes it suitable for the particular application. Moreover, EMI problems in the DICM (Li) configuration are high because of the input side inductor which in series with the supply operating in discontinuous mode. From this analysis DCIM (Lo) is stated as the best suited mode.

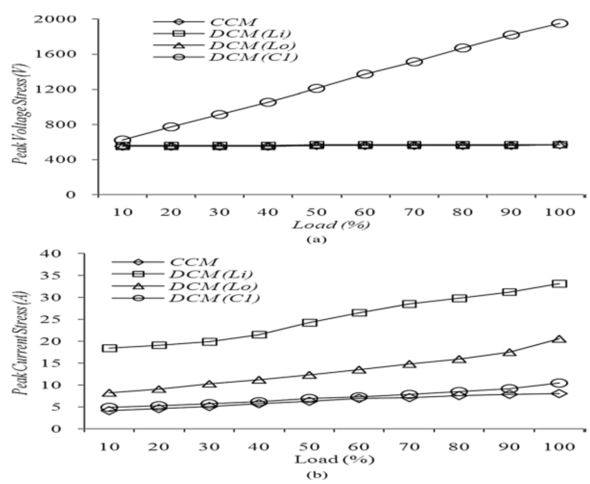

Fig. 4 Variation of (a) THD of supply current and (b) PF with dc-link voltage

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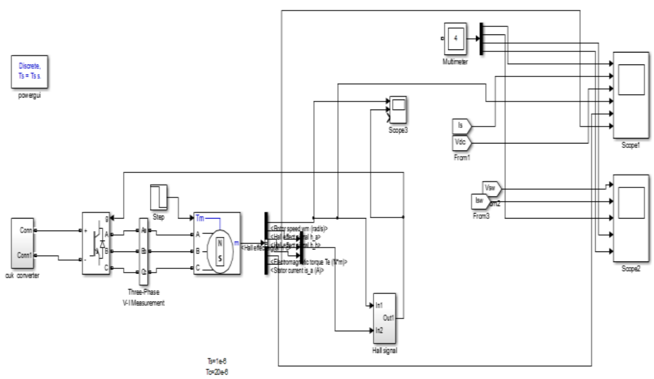


Fig.14. cuk converter fed bldc motor drive with sensor signals operating in DCIM(Lo) mode

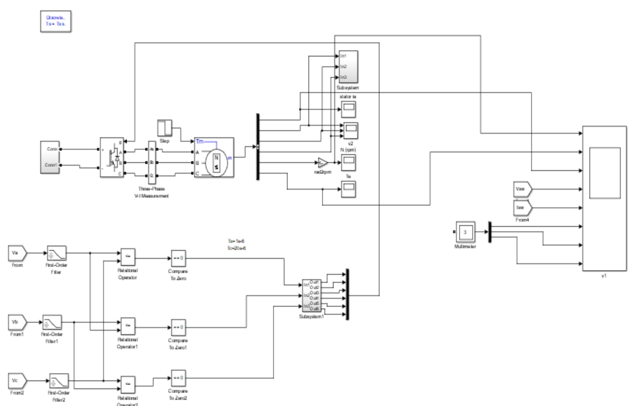
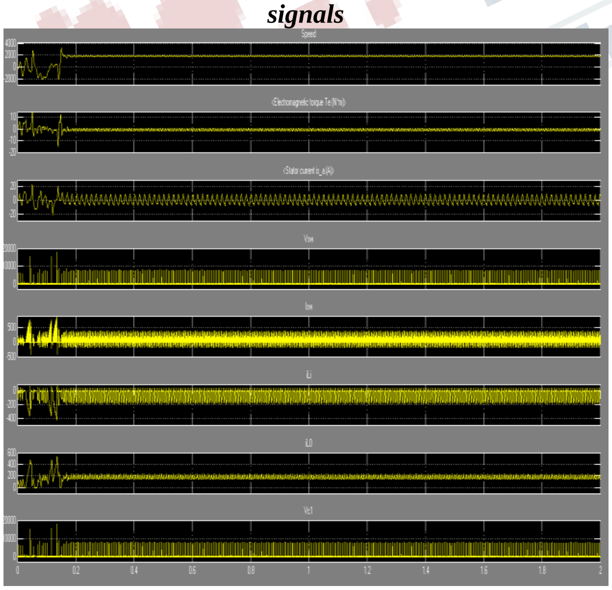


Fig.15. cuk converter fed bldc motor drive with sensorless signals



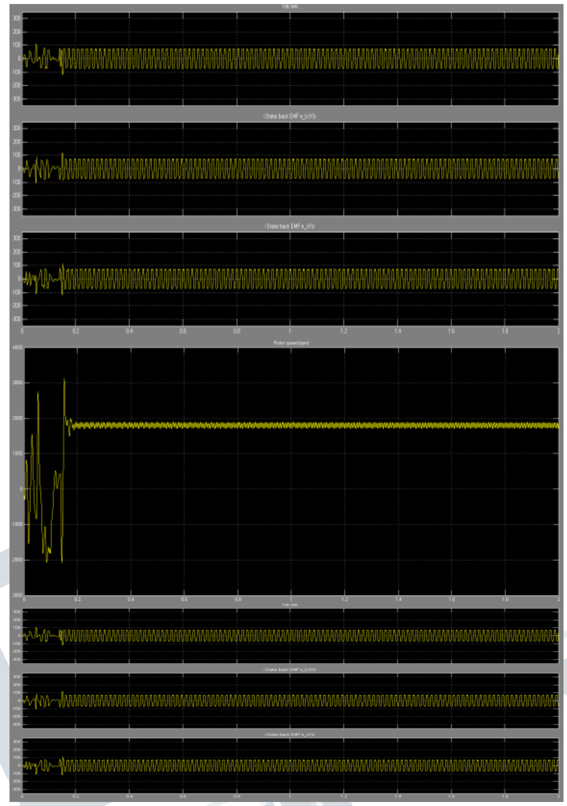


Fig 4. Simulation results

V. CONCLUSION AND FUTURE SCOPE

Power factor correction has become one of the most important issue due to the increased integration of sensitive loads in the AC mains. This proposed cuk converter model employs only ten utility devices rather than 15 electronic utility devices used.. The PFC analysis of the proposed cuk converter fed VSI operated BLDC motor under different speed variation conditions has been analyzed in these studies. The proposed converter model with BLDC motor attains almost unity power factor through the electronic commutation. The firing pulse generation of the proposed cuk converter is done by means of PI controller which is based on the control of the DC-link voltage reference as an equivalent to the reference speed of the BLDC motor. The highly developed graphic facilities available in the MATLAB/Simulink are used to conduct all aspects of model implementation and to carry out the extensive simulation studies. Five case studies are made on rise time deviations and in settling time difference in DC-link voltage and in motor speed. The simulation results validate the performance of the proposed cuk converter fed BLDC motor with PI control for varying speed and dynamic load condition. The performance of the present research work may further be enhanced by implementing different intelligent controllers like neuro-fuzzy, BELBIC, etc in order to minimize the peak overshoot both in DC-link voltage and in motor speed.

REFERENCES

1. J. F. Gieras and M.Wing, Permanent Magnet Motor Technology—Design and Application. New York, NY, USA: Marcel Dekker, Inc, 2002.

2. C. L. Xia, Permanent Magnet Brushless DC Motor Drives and Controls Beijing, China: Wiley, 2012.

3. Y. Chen, C. Chiu, Y. Jhang, Z. Tang, and R. Liang, "A driver for the singlephase brushless DC fan motor with hybrid winding structure," IEEE Trans. Ind. Electron., vol. 60, no. 10, pp. 4369–4375, Oct. 2013.

4. S. Nikam, V. Rallabandi, and B. Fernandes, "A high torque density permanent magnet free motor for in-wheel electric vehicle application," IEEE Trans. Ind. Appl., vol. 48, no. 6, pp. 2287–2295, Nov./Dec. 2012.

5. X. Huang, A. Goodman, C. Gerada, Y. Fang, and Q. Lu, "A single sided matrix converter drive for a brushlessDCmotor in aerospace applications," IEEE Trans. Ind. Electron., vol. 59, no. 9, pp. 3542–3552, Sep. 2012.

6. W. Cui, Y. Gong, and M. H. Xu, "A permanent magnet brushless DC motor with bifilar winding for automotive engine cooling application," IEEE Trans. Magn., vol. 48, no. 11, pp. 3348–3351, Nov. 2012.

7. C. C. Hwang, P. L. Li, C. T. Liu, and C. Chen, "Design and analysis of a brushless DC motor for applications in robotics," IET Elect. Power Appl., vol. 6, no. 7, pp. 385–389, Aug. 2012.

8. T. K. A. Brekken, H. M. Hapke, C. Stillinger, and J. Prudell, "Machines and drives comparison for low-power renewable energy and oscillating applications," IEEE Trans. Energy Convers., vol. 25, no. 4, pp. 1162– 1170, Dec. 2010.

9. N. Milivojevic, M. Krishnamurthy, A. Emadi, and I. Stamenkovic, "Theory and implementation of a simple digital control strategy for brushless DC generators," IEEE Trans. Power Electron., vol. 26, no. 11, pp. 3345– 3356, Nov. 2011.

10. T. Kenjo and S. Nagamori, Permanent Magnet Brushless DC Motors. Oxford, U.K.: Clarendon Press, 1985.

11. J. R. Handershot and T. J. E Miller, Design of Brushless Permanent Magnet Motors. Oxford, U.K.: Clarendon Press, 2010.

12. T. J. Sokira andW. Jaffe, Brushless DCMotors: Electronics Commutation and Controls. Blue Ridge Summit, PA, USA: Tab Books, 1989.

13. H. A. Toliyat and S. Campbell, DSP-Based Electromechanical Motion Control. New York, NY, USA: CRC Press, 2004.

14. "Limits for harmonic current emissions (equipment input current ≤16 A per phase)," International Standard IEC 61000-3-2, 2000

15. N. Mohan, T. M. Undeland, and W. P. Robbins, Power Electronics: Converters, Applications and Design. New York, NY, USA: Wiley, 2009.