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A New Topology for Speed control of Sensor less BLDC Motor with Reduced Commutator Switches and Improved Input Power Factor

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Abstract: **The Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. BLDC motors are used in aerospace applications, medical field, industrial automation equipment and instrumentation. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. This paper proposes a new optimized drive for speed control of BLDC motor, In this operation mode, it approximates a voltage follower and the line current follows the line voltage waveform to a certain extent. The reduction in low-order harmonics and improved power factor is achieved without the use of any voltage or current sensors. The simplicity and reduced parts count of the proposed topology make it an attractive low-cost choice for many variable speed drive applications.**

Keywords: about four key words separated by commas.

I. INTRODUCTION

Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. BLDC motor has been used extensively in industrial automation, aerospace, instrumentation and automotive industries since 1970's. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated.

BLDC motors have many advantages over brushed DC motors and induction motors. A few of these are:

- Better speed versus torque characteristics
- High dynamic response
- High efficiency
- Long operating life
- Noiseless operation
- Higher speed ranges

In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors.

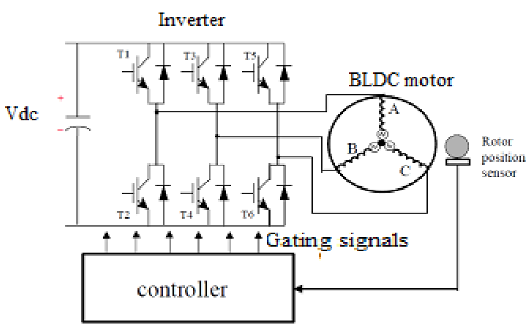

Fig. 1.Basic BLDC motor control system with position sensors.

These BLDC motors are generally controlled using a three-phase inverter, requiring a rotor position sensor for starting [1]. The three phase inverter provides proper commutation sequence for the speed control of BLDC motor. The position sensors will increase the cost and the size of the motor, and a special mechanical arrangement needs to be made for mounting the sensors. They could reduce the system reliability due to increased number of the components and hardware interfacing. The position sensors can be Hall sensors, resolvers or absolute position sensors. Hall sensors are particularly temperature sensitive, limiting the operation of the motor to below 75˚C. In some applications, it even may not be possible to mount any position sensor on the motor. Therefore, sensorless control of BLDC motor has been receiving great interest in recent years.

Typically, a Brushless dc motor is driven by a three-phase inverter with six-step commutation. The conducting interval for each phase is 120˚ by electrical angle. The commutation phase sequence is AB-AC-BC-BA-CA-CB. Each conducting stage is called one step. Therefore, only two phases conduct current at any time, leaving the third phase floating. In order to produce maximum torque, the inverter should be commutated every 60˚ so that current is in phase with the back EMF. The commutation timing is determined by the rotor position, which can be detected by Hall sensors or estimated from motor parameters, i.e., the back EMF on the floating coil of the motor if it is sensor less system.

The simplest unipolar drive consists of a single switch in series with each winding and a zener diode or dump resistor in the freewheeling path as shown in Fig. 2 [2]. This drive is inefficient because the stored energy in the phases is dissipated. Better performance can be obtained by using topologies that have previously been used for driving switched reluctance motors (SRM). An example is the C-dump converter shown in Fig. 3 [3], which offers full regenerative control. However, it has the disadvantage of requiring a complicated control for the dump capacitor voltage, the failure of which couldbe catastrophic

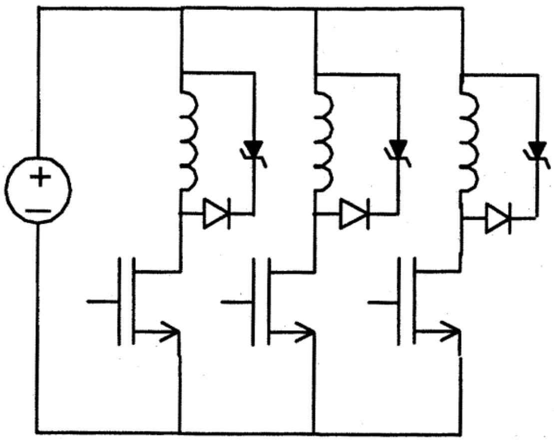

Fig. 2. Simple unipolar converter for three-phase BLDC motor.

A buck converter- based drive for the unipolar BLDC motor was proposed in [4]. Both these topologies require a higher voltage on the dump capacitors than what is applied to the motor phases during turn-on. While this is a requirement for the SRM motor in order to achieve a fast turn-off of the phase current to avoid negative torque spikes, it is not so for the BLDC motor. In fact, by allowing the phase currents to overlap during the commutation intervals, the commutation torque pulsations can be reduced. The topology proposed in this paper takes advantage of this fact to use a smaller voltage on the dump capacitor. A three-switch converter for the unipolar BLDC motor for ac supply operation was investigated in [5], but it requires a modification in the machine windings and a split-capacitor voltage balancing control scheme.

II.PROPOSED CONTROL STRATEGY

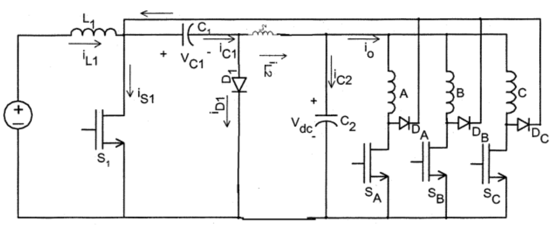

Fig. 3. Schematic of CUK converter based BLDC motor drive.

The proposed converter with four controlled switches and diodes is shown in Fig. 3. The front-end consists of a SEPIC dc/dc converter comprised of inductors L_1 and L_2, switch S_1 , intermediate capacitor C_1,diode D_1 and output capacitor C_2. A, B, and C are the three machine windings, and the currents through them are controlled by turn-on and turn-off of the switches S_a,S_b,S_c, and , respectively. Since there is only one switch per phase, the currents through them are unidirectional. The diodes D_a, D_b, and D_c serve to free wheel the winding currents when the switches are turned off during current regulation and phase commutation. The output of the converter is used to energize the three phases of the motor, and the voltage of capacitor C1 is used to demagnetize the phases during turn-off and for current control. Each phase is energized by turning on the corresponding switch in series with it. The equivalent circuit of phase A when switch Sa is turned on is shown in Fig. 4(a). To regulate the current, Sa is turned off, which forces the turn-on of diode Da, and the flow of current through as shown in the equivalent circuit of Fig. 4(b). This applies a voltage of -VC1 across the machine winding, enabling a fast decay of the phase current. For proper demagnetization of the phase after each conduction interval and to prevent conduction during periods of negative back-emf, the instantaneous value of VC1 should be greater than the peak value of the back-emf E, or

$$V_{C1}>E \tag{1}$$

By applying Kirchoff's voltage law to the CUK front-end, we obtain

$$V_{in}=V_{L1}+ V_{C1}+ V_{D1} \tag{2}$$

Since the average voltages in the inductor is zero, and as when diode is in conduction we get

$$V_{in}= V_{C1} \tag{3}$$

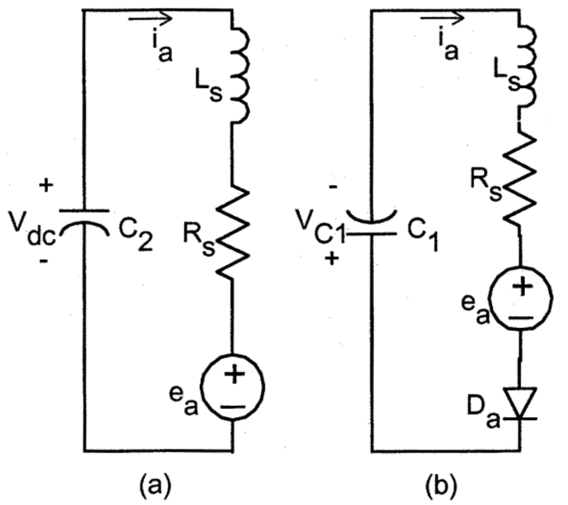

Fig. 4. Equivalent circuits of each machine phase when (a) the switch is on and (b) when the diode is conducting

From (1) and (2), we obtain the peak back-emf at the maximum speed of the motor, which is given by $E_{max}=V_{in}$, assuming that the ripple in the intermediate capacitor voltage is negligible. The maximum operating speed is then given by $N_{max}=V_{in}/K_e$ Where K_e is the phase back-emf constant of the motor. If the motor is operated beyond this speed, it would result in negative torque spikes because of conduction during periods of negative back-emf.

The minimum voltage V_{dc} required is V_{dc}=E+IR+Ldi/dt where R and L are the phase resistance and inductance, and I is the phase current. At low speeds, when the back-emf is low, the switching frequency of the phase switches increases in order to regulate the phase current. The switching frequency and hence the losses at low speeds can be minimized by bucking the input voltage to lower levels at the output. At higher speeds, the current regulator loses its ability to force current into the phases especially during turn-on because of the high back-emf voltage. The ability of the CUK front-end to boost the available input voltage makes it possible to maintain current-regulated operation of the drive at higher speeds. This feature makes the proposed topology particularly suitable for low voltage dc applications such as automotive circuits.

III.MODELLING OF CUK CONVERTER

A non-isolated Ćuk converter comprises two inductors, two capacitors, a switch (usually a transistor), and a diode. Its schematic can be seen in figure 5. It is an inverting converter, so the output voltage is negative with respect to the input voltage.

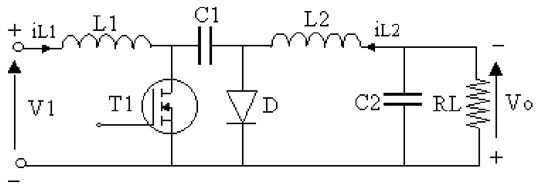

Fig. 5. Circuit diagram of CUK converter

The two inductors L_1 and L_2 are used to convert respectively the input voltage source (V_i) and the output voltage source (C_o) into current sources. At a short time scale an inductor can be considered as a current source as it maintains a constant current. This conversion is necessary because if the capacitor were connected directly to the voltage source, the current would be limited only by the parasitic resistance, resulting in high energy loss. Charging a capacitor with a current source (the inductor) prevents resistive current limiting and its associated energy loss.

As with other converters (buck converter, boost converter, buck-boost converter) the Ćuk converter can either operate in continuous or discontinuous current mode. However, unlike these converters, it can also operate in discontinuous voltage mode (i.e., the voltage across the capacitor drops to zero during the commutation cycle).

In steady state, the energy stored in the inductors has to remain the same at the beginning and at the end of a commutation cycle. The energy in an inductor is given by:

$$E=1/2\ ^{x}LI^{2} \qquad (4)$$

This implies that the current through the inductors has to be the same at the beginning and the end of the commutation cycle. As the evolution of the current through an inductor is related to the voltage across it

$$V_L=Ldi/dt \qquad (5)$$

1) In the off-state, inductor L_1 is connected in series with V_i and C Therefore $V_{L1}=V_1- V_{C1}$. As the diode D is forward biased (we consider zero voltage drop), L_2 is directly connected to the output capacitor. Therefore $V_{L2}= V_0$
2) In the on-state, inductor L_1 is directly connected to the input source. Therefore V_{L1}=Vi. Inductor L_2 is connected in series with C and the output capacitor, so

$$V_{L2}=V_0+ V_{C1} \qquad (6)$$

3) The converter operates in on-state from t=0 to t=D·T (D is the duty cycle), and in off state from D·T to T (that is, during a period equal to (1-D)·T). The average values of V_{L1} and $V_{L2}$are therefore:

$$V_{L1}=DV_i+(1-D)*(V_i-V_C)=(V_i-+(1-D)*V_C \qquad (7)$$

$$V_{L2}=D(V_0+V_C)+(1-D)*V_O=V_O+DV_C \qquad (8)$$

As both average voltage have to be zero to satisfy the steady-state conditions we can write, using the last equation:

$$V_C=-V_O/D \qquad (9)$$

So the average voltage across L_1 becomes:

$$V_{L1}=(V_i+(1-D)*V_O/D)=0 \qquad (10)$$

Which can be written as

$$V_0/Vi=--D/-1-D \qquad (11)$$

IV. SENSORLESS CONTROL

V_a, V_b, V_c are referred to the terminal voltages of BLDC motor, V_N is the neutral point voltage and VDC is the DC bus voltage of inverter. R and L are resistance and inductance of stator windings which is assumed to be constant for all phases. The magnetic circuit saturation and losses in motor are also ignored. At each instant of time only two phases out of three phases of stator are conducting. Therefore back-EMF can be detected from the floating terminal voltage. Consider phase B and phase C are conducting and phase A is floating phase (ib = -ic and ia = 0). Then voltage terminal equations can be written as,

$$V_a = E_a + V_n \qquad (12)$$
$$V_b = RI_b + Ldi/dt + E_b + V_n \qquad (13)$$
$$V_c = RI_c+ Ldi/dt+ E_c + V_n \qquad (14)$$

Where $i_b = -i_c$, $E_b = -E_c$ and $V_b + V_c$ = VDC Therefore by adding (12) and (13) neutral point voltage is,

$$V_n = V_{dc} /2 \qquad (15)$$

Substituting (14) in (10) floating point terminal voltage can be written as,

$$V_a = E_a + V_{dc} /2 \qquad (16)$$

If $E_a = 0$ then condition of back-EMF zero crossing detection from the floating terminal voltage is

$$V_a = V_{dc} /2 \qquad (17)$$

In this technique voltage of only one phase regarding DC bus voltage is sensed instead of all three terminal voltages. Zero crossing signals are generated anytime line voltage reaches to half of DC bus voltage. Commutation signal is set to logic one at the ZCD points of rising edge of the line voltage and it is set to logic zero at ZCD points of falling edge of line voltage. Commutation instants must be generated 30 electrical degrees after ZCD points. Other two commutation signals are generated by 120 electrical degrees delay respectively to the first signal.

V. SPEED CONTROL

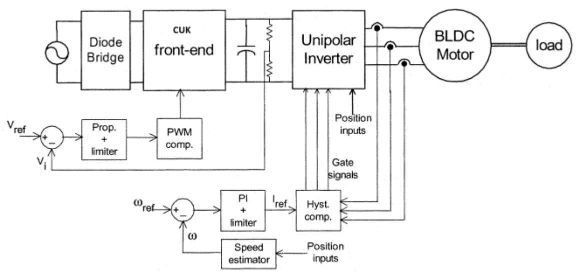

Fig. 6. Block diagram of the drive system.

A block diagram of the drive system implementation is shown in Fig.6. The rotor position is sensed by means of three hall sensors, and the position information is used to determine the phase winding to be excited. The motor speed is derived from the position inputs and is compared with the speed reference to generate the current references. The dc bus voltage is regulated by PWM control of the switch S_1.

VI. SIMULATION RESULTS

A PI controller (K_p=0.001andK_i=0.01) is used to compare the reference and actual speed and generate the current reference. The resulting speed response is shown in Fig.7 and the torque response to a step change in load torque in Fig. 8.

Fig.9 shows When a BLDC motor rotates, each winding generates back electromotive Force or back EMF, which opposes the main voltage supplied to the windings according to Lenz's Law. The polarity of this back EMF is in opposite direction of the energized voltage. Back EMF depends mainly on three factors:

• Angular velocity of the rotor
• Magnetic field generated by rotor magnets
• The number of turns in the stator windings.

Shows the intermediate capacitor voltage waveform. In an ideal PFP, this would go to zero in each half-cycle of the input voltage, but in this case, its minimum value is limited to the peak phase back-emf. This results in some distortion of the input current around the zero-crossing of the input voltage. The phase currents at 500 rpm are shown.

The operation of the proposed topology has been verified for simulation

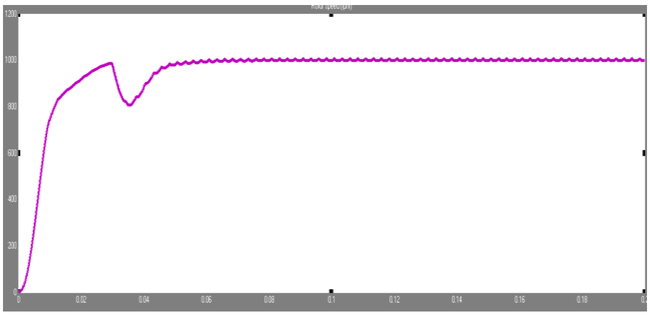

Fig. 7. rotor speed waveform.

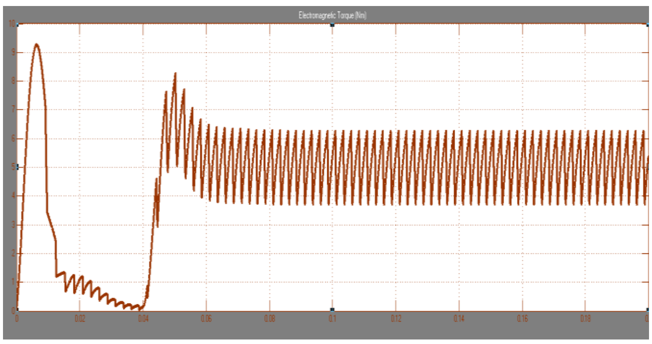

Fig. 8. Electromagnetic torque

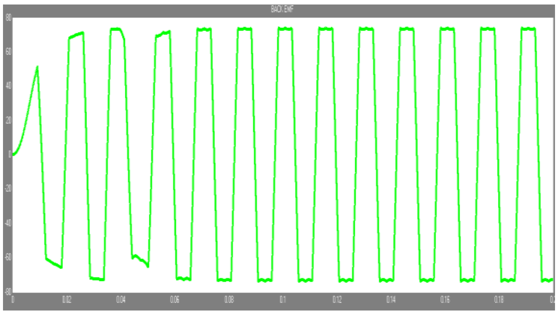

Fig. 9. Back emf waveform of one phases

For ideal voltage follower operation, the intermediate capacitor voltage should follow the half-sinusoidal input voltage, and goes to zero in each half-cycle. This is illustrated for the case of a
resistive load. However, with a unipolar BLDC motor load, the intermediate capacitor voltage has to be greater than the phase back-emf for proper demagnetization of the phases. This causes a distortion of the input current waveform around the zero-crossings of the input voltage. This is acceptable because the input current shaping is achieved at no cost to the drive, and as will be seen, the resulting power factor is better than with the conventional circuit configuration.

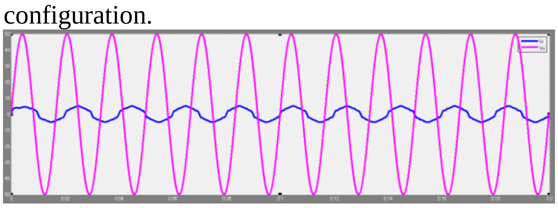

Fig. 10 input voltage and current

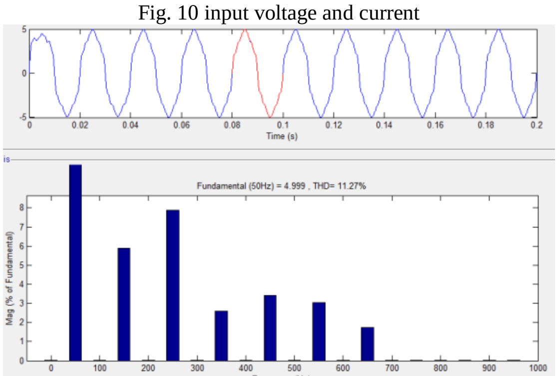

Fig. 11 shows input current THD

VII. CONCLUSION

A new converter topology based on a CUK converter operating in DCM has been proposed for unipolar excitation of brushless dc motors. The proposed scheme has the following advantages.

1) The proposed converter uses only four controlled switches, all of which are referenced to ground. This considerably simplifies their gate drive circuitry and results in low cost and compact packaging.

2) It is capable of bucking or boosting the available input dc voltage to maximize the current-regulated operation of the drive.

3) The input current naturally follows the input voltage to a certain extent, reducing the amount of low-order harmonics and resulting in a high power factor.

4) Eliminates the possibility of shoot-through faults which could occur in bipolar converters.

5) Lower conduction and switching losses because of the presence of only one switch and diode per phase as opposed to two in the bipolar case.

VIII. REFERENCES

[1] T. Kenjo and S. Nagamori, *Permanent-Magnet and Brushless DC Motors*. Oxford, U.K.: Clarendon Press, 1985.

[2] J. R. Hendershot Jr. and T. J. E. Miller, *Design of Brushless Permanent Magnet Motors*. Hillsboro, OR: Magna Physics Publishing, 1994

[3] R. Krishnan and S. Lee, "PM Brushless dc motor drive with new powerconverter topology," in *Proc. IEEE IAS Annu. Meeting*, Oct. 1995, pp. 380–387.

[4] R. Krishnan and P. Vijayraghavan, "A new power converter topology for PM Brushless dc motor drives," in *Proc. IEEE IECON'98 Conf.*, vol. 2, 1998, pp. 709–714.

[5] R. Krishnan, "A novel single switch per phase converter topology for four-quadrant PM Brushless dc motor drive," in *Proc. IEEE IAS Annu. Meeting*, vol. 1, Oct. 1996, pp. 311–318

6] J. Sebastián, M. Jaureguizar, and J. Uceda, "An overviewof power factor correction in single-phase off-line power supply systems," in *Proc. IEEEIECON'94 Conf.*, vol. 3, 1994, pp. 1688–1693.

[7] J. Skinner and T. A. Lipo, "Input current shaping in Brushless dc motor drives utilizing inverter current control," in *Proc. 5th Intl. Conf. Elect. Mach. Drives*, 1991, pp. 121–125.

[8] R. P. Massey and E. C. Snyder, "High voltage single-ended dc-dc converter," in *Proc. IEEE PESC'77 Conf.*, 1977, pp. 156–159.

[9] D. S. L. Simonetti, J. Sebastián, and J. Uceda, "The discontinuous conduction mode SEPIC and Cuk power factor preregulators: analysis and design," *IEEE Trans. Ind. Electron.*, vol. 44, pp. 630–637, Oct. 1997.

[10] T. Gopalarathnam, S. Waikar, H. A. Toliyat, M. S. Arefeen, and J. C. Moreira, "Development of low-cost multi-phase Brushless dc (BLDC) motors with unipolar current excitations," in *Proc. IEEE IAS Annu. Meeting*, Oct. 1999, pp. 173–179.

[11] J. Sebastián, J. Uceda, J. A. Cobos, J. Arau, and F. Aldana, "Improving power factor correction in distributed power supply system's usingPWM and ZCS-QR SEPIC topologies," in *Proc. IEEE PESC'91 Conf.*, 1991, pp. 780–791.

[12] F. S. Dos Reis, F. Antunes, J. Sebastián, and J. Uceda, "Influence of the control method in the PFP converter size," in *Proc. ISIE'97 Conf.*, 1997,pp. 36