Input Current Shaping in BLDC Motor Drives Using a New Converter Topology

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Abstract - **A new converter topology is proposed for driving a Permanent Magnet Brushless DC (BLDC) Motor with unipolar currents. It is based on a Single-Ended Primary Inductance Converter (SEPIC) operating in the discontinuous conduction mode. 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 displacement 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.**

I. INTRODUCTION

The unipolar excitation of Brushless DC (BLDC) motors is of considerable interest to the industry because of the savings in converter cost. This opens up a lot of applications for variable speed drives (VSD) such as HVAC, fans, pumps and appliances, which have been dominated by constant speed drives. Recent papers [1,2,3] have introduced various converter topologies for the unipolar operation of BLDC motors. However, the improvement of the utility interface of BLDC drives has received little attention. A method of input current shaping utilizing inverter current control has been discussed in [4]. Harmonics standards such as the IEC 1000-3-2 limit the magnitude of current harmonics that can be injected into the utility. These standards are typically not satisfied by the conventional method of AC/DC conversion using a bridge rectifier followed by a large dc bus capacitor. Passive Power Factor Correction (PFC) circuits based on the use of reactive elements are impractical in 50-60Hz single-phase lines because of size, weight and cost [5]. Active PFC methods are becoming increasingly popular because of the availability of low-cost switches. They consist of a dc-dc converter between the diode bridge and the bulk capacitor which is controlled such that the input current is shaped to follow the input voltage. The frequency spectrum of the input current would then consist of the fundamental plus easily filtered higher order harmonics. The typical configuration of an ac motor drive with a power factor correction stage is shown in Fig. 1. Continuous Conduction Mode (CCM) is used for power levels exceeding a few hundred watts (eg. 300W). For lower power, Discontinuous Conduction Mode (DCM) is an attractive alternative [6]. At constant duty cycle, the average input current automatically tracks to some extent the sinusoidal shape of the input voltage. This is realized without the need of sensing and controlling the input current, thus simplifying the control circuit. Such a feature can be used to integrate the PFC stage with the output voltage regulation or inverter stage, which can lead to considerable cost reduction. The schematic of an ac motor drive with the PFC stage integrated with the inverter is shown in Fig. 2. The topology proposed in this paper makes use of a Single-Ended Primary Inductance Converter (SEPIC) operating in DCM to achieve a single-stage power factor improvement.

The unipolar excitation scheme of BLDC motors is discussed in Section 2. The proposed topology is introduced in Section 3. Simulation results are presented in Section 4, experimental results in Section 5 and the merits and demerits of the proposed scheme of operation are discussed in Section 6.

II. UNIPOLAR EXCITATION OF BLDC MOTORS

The back-emf and phase reference current waveforms for a three-phase BLDC motor with bipolar and unipolar excitations are illustrated in Fig. 3. Unipolar current conduction limits the phases to only one direction of current, and the commutation frequency is half that of a bipolar or full-wave drive. The motor windings can only be excited for

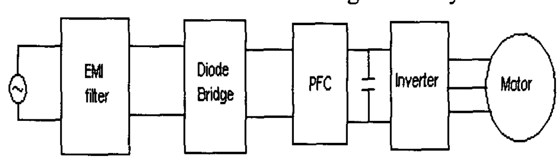

Fig. 1: AC motor drive with active Power Factor Correction stage

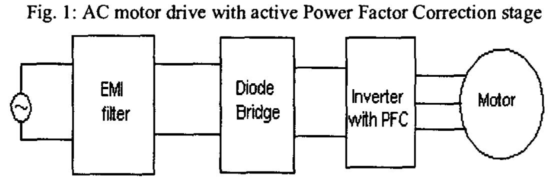

Fig. 2: AC motor drive with integrated PFC stage and inverter

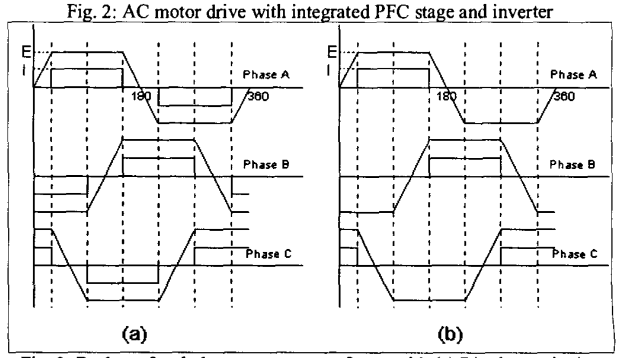

Fig. 3: Back-emf and phase current waveforms with (a) Bipolar excitation and (b) Unipolar excitation

a maximum of half of the total excitation cycle and therefore the windings are poorly utilized. However, it results in reduced parts count in the converter, because of which unipolar-driven motors are widely used in low-cost instruments.

III. PROPOSED CONVERTER TOPOLOGY

The schematic of a SEPIC converter [7] driving a BLDC motor is shown in Fig. 4. The output of the converter is used to energize the three phases of the motor, and the voltage of capacitor C_1 is used to demagnetize the phases during turn-off and for current control. A single controlled switch is used to control the current through each phase, and a freewheeling diode provides a path for turn-off. By operating the converter in DCM, the following desirable characteristics are obtained [8]: The converter works as a voltage follower, meaning that the input current naturally follows the input voltage profile (No current loop is needed) and the theoretical power factor is unity.

The operating modes of each motor phase are shown in Fig. 5. When the phase switch is on, the current through the phase is supplied by the output capacitor C_2 of the converter. When the switch is turned off, the current freewheels through the phase diode, capacitor C_1, and diode D_1. The capacitor voltage V_{c1} appears as a negative voltage across the phase winding. For proper demagnetization of the phase after each conduction interval and to prevent conduction during periods of negative back-emf, the instantaneous value of V_{c1} should be greater than the back-emf E. This is in opposition to the condition required for a voltage follower, namely that the capacitor voltage follow the half-sinusoidal input voltage. Hence a compromise is required in determining the voltage ripple in V_{c1} to achieve fast phase demagnetization and yet obtain a distortion-free input current.

In DCM, the circuit configurations are as shown in Fig. 6 [8]. The first stage is defined by the on time of the switch S_1. When S_1 is turned off, the circuit enters the second stage. This stage lasts until $i_1 = -i_2$. Then the diode D_1 turns off, and the third stage occurs till S_1 is turned on again.

IV. SIMULATION RESULTS

A block diagram of the drive system is shown in Fig. 7. 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. Hysteresis control is used to regulate the phase currents to the reference current waveforms of Fig. 3. The duty cycle is fixed at a value that results in DCM, or the output voltage could be controlled in a range that ensures operation in DCM.

The drive is rated 100W, the input voltage is 120V rms, the output is regulated to 100V by duty cycle control of S_1 at a switching frequency of 25KHz, and L_1 = 300μH, L_2 = 120μH, C_1 = 47μF and C_2 = 100μF.

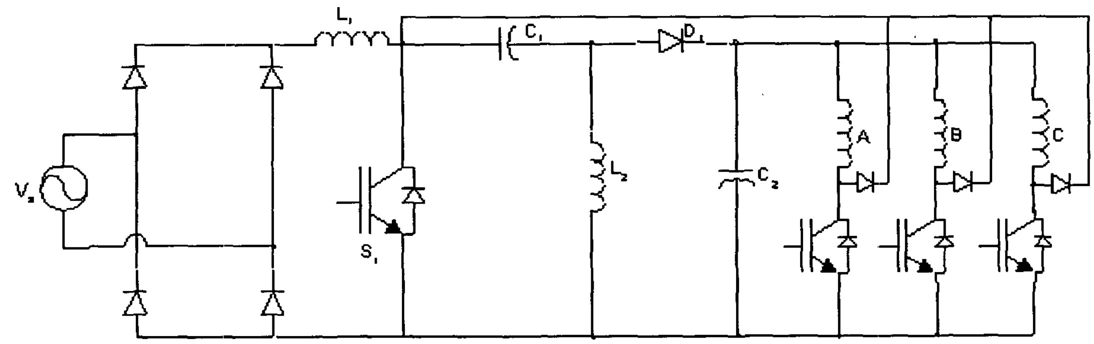

Fig. 4: Schematic of SEPIC converter based BLDC motor drive

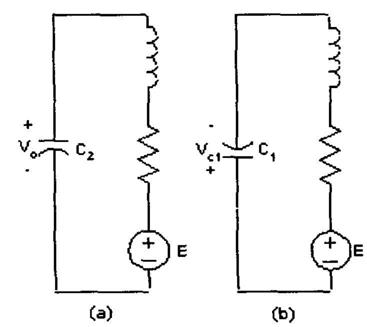

Fig. 5: Equivalent circuits of each machine phase when (a) the switch is on, and (b) when the diode is conducting.

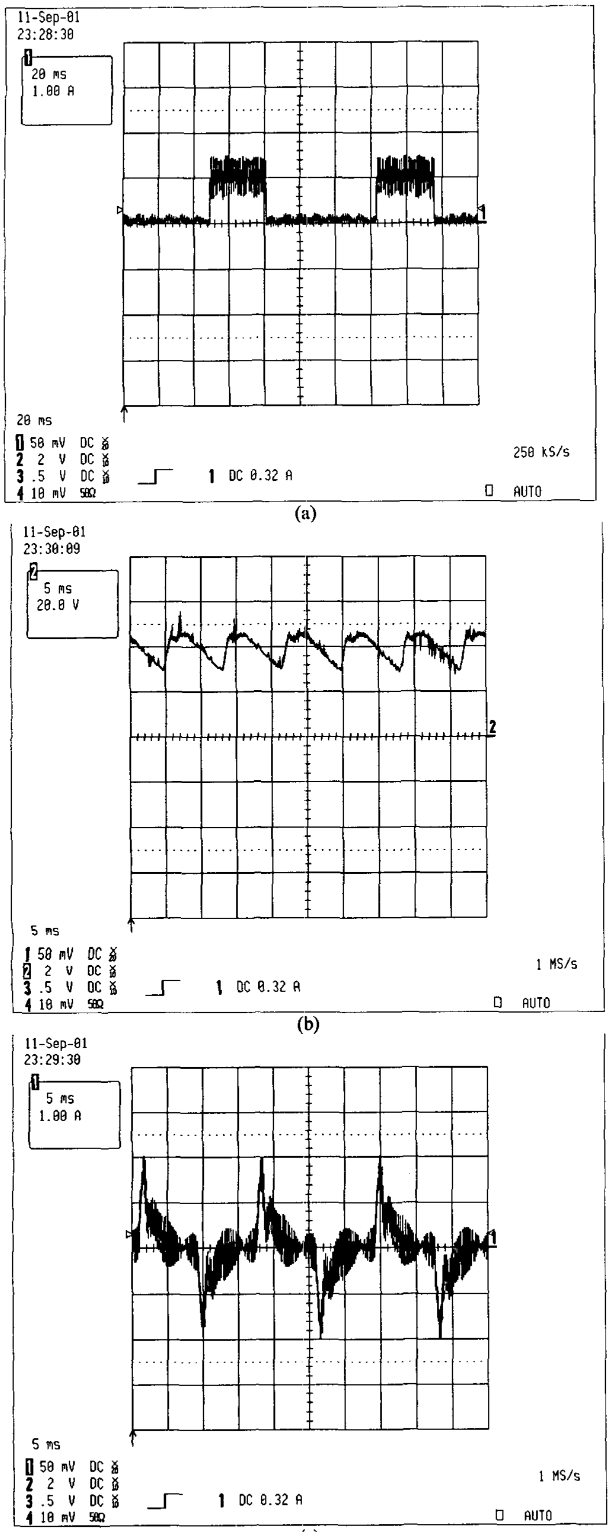

Fig. 9: (a) Phase current waveform, (b) Voltage across capacitor C_1, and (c) Input current waveform.

considerably simplifies their gate drive circuitry and results in low cost and compact packaging.

2. The input current naturally follows the input voltage to a certain extent, reducing the amount of low-order harmonics and resulting in a high displacement power factor.
3. Eliminates the possibility of shoot-through faults which could occur in bipolar converters.
4. 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.

Some of the disadvantages of this scheme are:

1. It results in current harmonics at multiples of the switching frequency, and an EMI filter may be required to achieve compliance with EMI standards.
2. Poor utilization of the machine windings because of halfwave excitation.

VII. CONCLUSION

A new converter topology based on a SEPIC converter operating in DCM has been proposed for unipolar excitation of Brushless DC motors. The proposed scheme has the advantage of reduced parts count, low cost, and input current shaping without the use of voltage or current sensors.

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