Single Current Sensor based Speed Controller for PMBLDC Motor Drive in Pumping Application

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***Abstract*— This paper presents a single current sensor based speed controller for permanent magnet brushless DC motor (PMBLDCM) in pumping application. The pump considered in this work is a positive displacement pump working at constant flow rate and variable head. The PMBLDCM is fed from a single phase AC supply mains using diode bridge rectifier (DBR). So a single switch power factor correction (PFC) Cuk converter is used to control the power quality at AC mains along with voltage regulation at the input of voltage source inverter (VSI) feeding the PMBLDCM. The design and performance evaluation of the complete drive is carried out in MATLAB-SIMULINK environment for 1 KW, PMBLDCM used for pumping at variable speeds of 1000rpm, 750rpm and 500rpm. The performance results obtained on the hardware test setup are also presented for validation of proposed concepts. The performance results demonstrate speed control with improved power quality (PQ) for the proposed single sensor speed controller based PMDLDCM drive.**

Keywords*— Cuk converter, PMBLDC motor, pumping application, power quality.

I. INTRODUCTION

Pumping applications are most common application of motors and consume a large fraction of overall power generation. Most of the water pumping systems employ induction motors which run at approximately 0.8 PF and 85% efficiency, hence, draw the focus for energy conservation. A permanent magnet brushless direct current motor (PMBLDCM) can be a better option for pumps due to its high efficiency, low maintenance and soundless running [1-3]. A PMBLDCM is a three phase synchronous motor having permanent magnet on the rotor and three phase armature winding on the stator [4-9]. It requires a three phase voltage source inverter (VSI) for control of winding currents as per position of the rotor magnets as given by Hall sensors. It requires two current sensors for control of winding currents to control the torque of the motor. The complete control scheme is shown in Fig 1. Since the current drawn from the DC link is same as sensed by the two current sensors after VSI, these two current sensors can be replaced by a single sensor ad DC link without affecting the control of drive. Fig 2 represents the proposed single current sensor based controller for PMBLDC motor.

For low power applications, PMBLDC motors are powered by single phase AC mains followed by a diode bridge rectifier (DBR) with a smoothening DC capacitor [4-5, 7-8]. Uncontrolled charging of DC link capacitor cause pulsating current waveform drawn from AC mains and its magnitude is higher than the fundamental input current. Therefore many power quality (PQ) problems arise at AC supply mains including poor power factor (PF), high crest factor (CF), increased total harmonic distortion (THD) of AC mains current. These power quality indices must remain within the specified limits as mentioned in international standard IEC 61000-3-2 [10], especially in low power applications when many such drives are connected simultaneously.

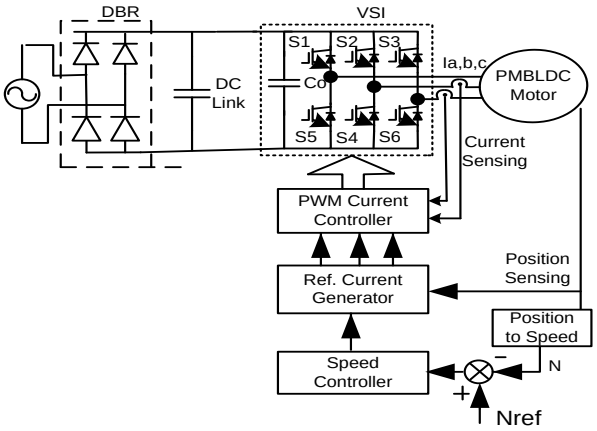

Fig.1: Conventional speed and current control scheme for PMBLDC motor

Therefore, PMBLDCM drives with power factor correction (PFC) converters are being preferred in small powered applications for reliability and conservation of energy. A DC-DC converter topology available in several configurations [11-15] e.g. boost, buck-boost, Cuk, SEPIC, zeta etc. can be used as a PFC converter to draw current from supply mains in phase with its voltage. These PFC converters result in improved PQ indices with voltage control at DC link.

This paper presents a Cuk converter based PFC converter to feed PMBLDCM drive, as it has inherited advantages of low current and voltage ripples in output, low EMI due to capacitive energy transfer and simple control [12]. The complete control schematic of the proposed PMBLDCM drive is shown in Fig. 2. The load considered for this work is Positive displacement pump which moves liquid by displacing it with a solid volume such as a piston. Piston pumps, diaphragm pumps, gear pumps and all other types of positive displacement pumps are constant torque loads. Positive displacement blowers and compressors are also constant torque loads. Accordingly, design and performance evaluation of the proposed PFC converter for pumping application is presented. The paper is

composed in six main sections, namely introduction, working and control of Cuk converter fed PMBLDCM, design and modeling of PMBLDCM drive, evaluation of performance and conclusion.

II. CUK PFC CONVERTER FOR PMBLDC MOTOR DRIVE

Figure 2 shows the proposed topology of Cuk PFC converter fed PMBLDCM drive for speed control as well as PFC with DC link voltage regulation. For the speed control of the PMBLDCM, regulation of DC link voltage is used to drive a variable head constant flow pumping system. Hall Effect sensor is used to sense rotor position of PMBLDCM and transformed to speed signal, which is compared with a desired speed.

The speed error signal is used to generate reference current of motor by passing through the speed controller and multiplied with a rectangular unit template in phase with back EMF of the PMBLDCM. The actual three phase currents for the PMBLDC motor are obtained using sensed DC link current (single sensor) and multiplied by rectangular unit template of the hall sensors. The error between the reference and actual currents of the motor are compared with the saw-tooth carrier wave to produce PWM pulses for VSI switches. The PMBLDCM needs a simple controller for commutation and current control as the rotor position information is required only at commutation points, i.e. at every 60^0 electrical of three phases [4-7, 9]. The DC-DC converter regulates the output voltage of DBR by changing the duty ratio (D) and improves the power factor through high frequency switching. In this work insulated gate bipolar transistors (IGBTs) are used as switches because IGBTs can operate in wide range of frequency.

This work uses current multiplier approach with average current control in continuous conduction mode (CCM) for power quality control. To perform control action, the voltage at dc link is sensed and compared with reference voltage. The obtained voltage error generated modulated current signal using a PI controller which is multiplied with unit template of input AC voltage to get reference input current. This reference current is compared with DC current sensed after DBR to get current error which is amplified and compared with sawtooth carrier wave to generate PWM signals for Cuk PFC converter.

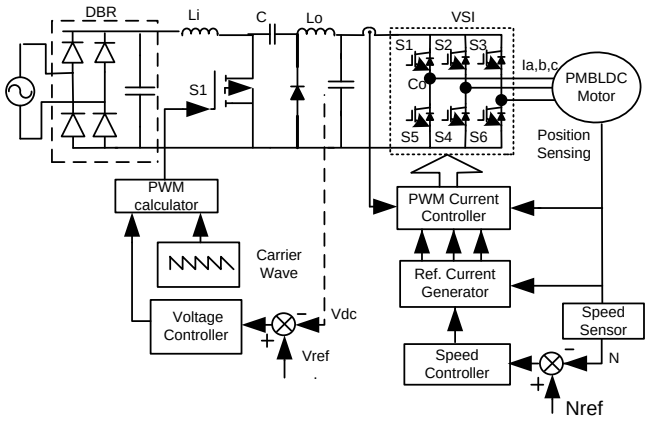

Fig.2: Proposed Control Scheme for PMBLDC Motor

III. DESIGN OF PFC CUK CONVERTER FOR PMBLDCM DRIVE

In the topology shown in the Fig.2, the inductance, Lo, is used as a output filter to reduce the magnitude of current variations, ΔI_{LO}, within specified limit for a given switching frequency, f_s. The output voltage magnitude variation is restricted by Co, within a specified limit ΔV_o.

The Cuk converter regulates DC output voltage for wide range of input AC voltage and designed for constant voltage across the intermediate capacitor, C, as it follows the principle of capacitive energy transfer. The boost inductor L_i is used to transfer the maximum power output of the Cuk converter. The components are designed using equations given in reference [14-15].

IV. MODELLING OF PROPOSED PMBLDCM DRIVE

The modeling of proposed PMBLDCM drive consists of modeling of a PFC converter and modeling of PMBLDCM drive as given in reference [14-15]. The MATLAB model of the proposed drive is shown in Fig 3.

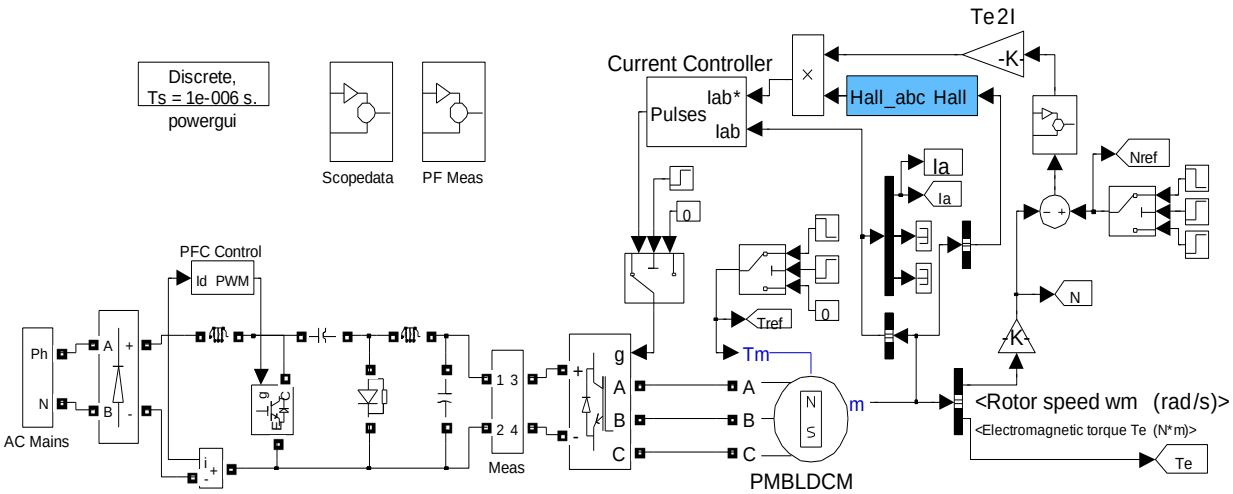

Fig.3: MATLAB Model of Proposed Control Scheme for PMBLDC Motor Drive

V. PERFORMANCE EVALUATION

The performance of proposed PMBLDC motor drive is evaluated for a pumping load at constant torque and variable speed. The PMBLDC motor considered for this application has Rated Power: 1 KW, rated speed: 4600 rpm, rated torque: 2.2 Nm, number of poles: 4, stator resistance: 1.535 Ω/ph, inductance: 3.285 mH/ph, Voltage constant (Kb): 51V/krpm, Torque Constant (Kt): 0.49 Nm/A. Since the hardware setup for the proposed drive has PMBLDC motor coupled with a DC generator having maximum speed of 1500 rpm, the simulation is limited to 1200 rpm speed only.

A. Simulation Performance under variable speed and constant torque

Fig. 4 (a-d) presents the simulation results of proposed PMBLDCM drive under variable speed and at a rated torque (2.2Nm). The obtained results show a smooth operation of the PMBLDCM drive as desired.

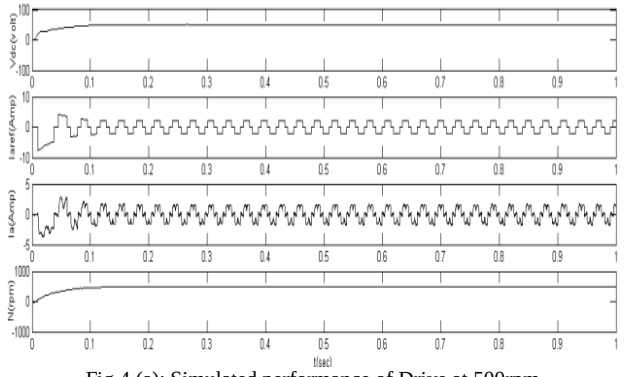

Fig.4 (a): Simulated performance of Drive at 500rpm

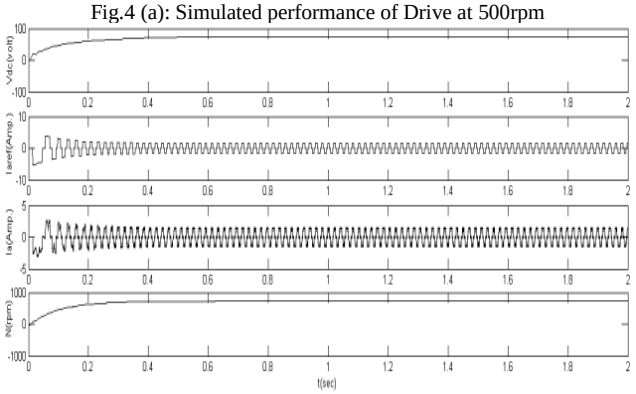

Fig.4 (b): Simulated performance of Drive at 750rpm

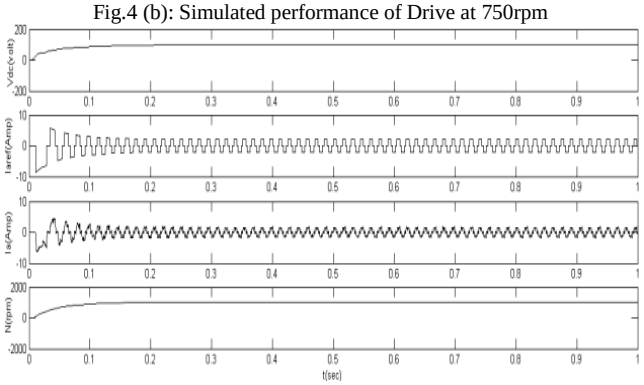

Fig.4 (c): Simulated performance of Drive at 1000rpm

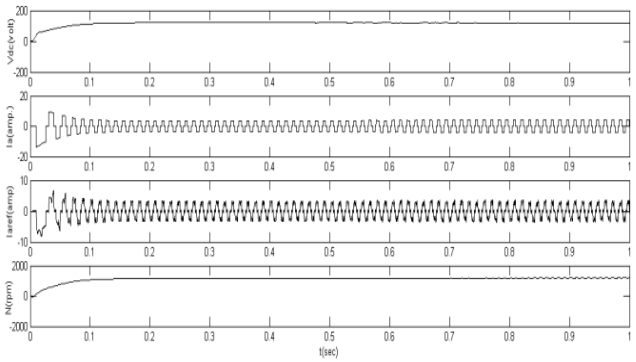

Fig.4 (d): Simulated performance of Drive at 1200rpm

B. Hardware implementation of PMBLDCM drive

The prototype of PMBLDC motor is operated under similar conditions for validation of simulated results i.e. constant torque and variable speed. Complete control scheme is implemented in dSPACE software and the results obtained are presented in Fig.5 (a-d) for validation of proposed concepts.

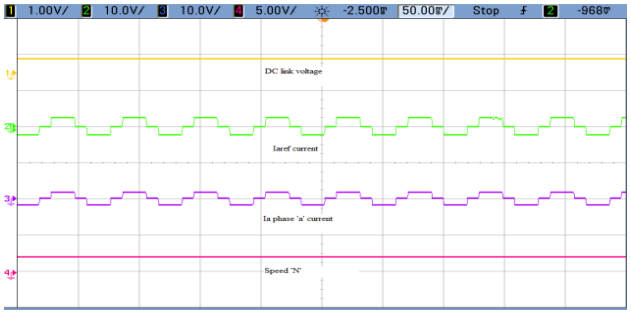

Fig.5 (a): Hardware results of Drive at 500rpm

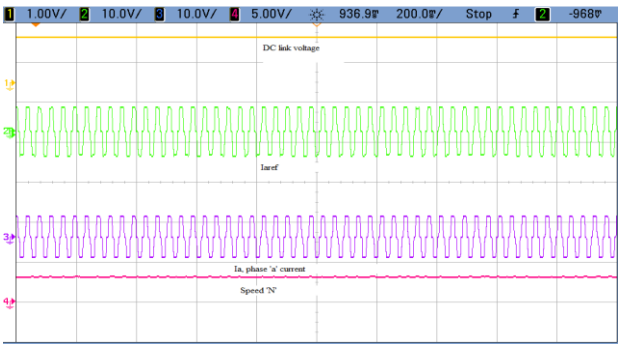

Fig.5 (b): Hardware results of Drive at 750rpm

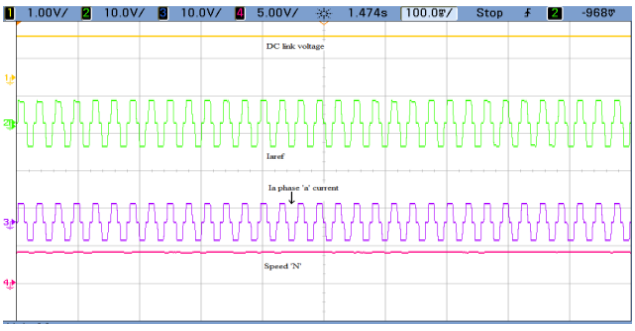

Fig.5 (c): Hardware results of Drive at 1000rpm

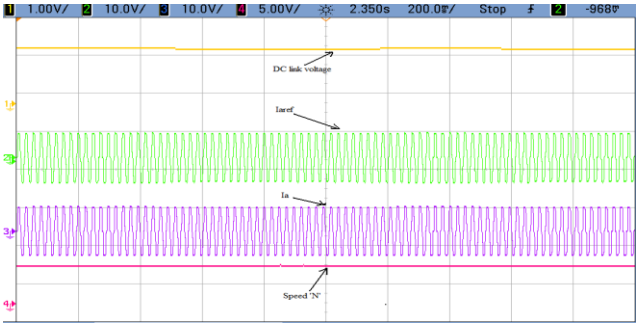

Fig.5 (d): Hardware results of Drive at 1200rpm

C. Power quality improvement of PMBLDCM Drive

Figure 6 shows the resultant waveform of AC mains current and its harmonic spectra with proposed Cuk PFC converter for PMBLDCM drive. The result clearly shows the reduction of THD near 5% with sinusoidal input current waveform.

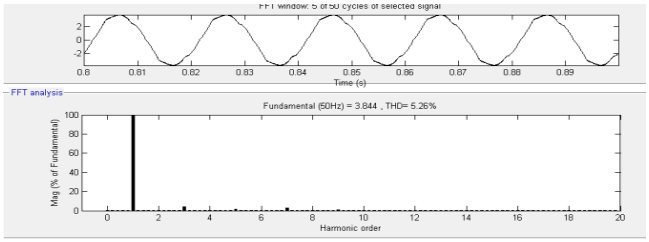

Fig.6: Harmonic Spectra of Current at AC mains with PFC drive at 1200rpm Speed

VI. CONCLUSION

A single current sensor based speed controller has been proposed in conjunction with a Cuk converter based PFC topology for a PMBLDCM drive targeted to pumping application. The PFC converter has ensured desired power quality at input AC mains with desired speed control of the target application. The drive has demonstrated very good performance in wide range of speed with constant current and torque. Therefore, the cuk converter based PMBLDCM drive having single current sensor has been found suitable for the application involving speed control for constant torque applications.

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