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A LOW COST SIMPLIFIED CONTROL STRATEGY FOR PMBLDC MOTOR DRIVE FOR PERFORMANCE IMPROVEMENT

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ABSTRACT

Three current sensors are required to measure motor phase currents in closed loop speed control of PMBLDC Motor drive. Usually, current sensors are expensive, and torque fluctuations may occur due to differences in current sensor sensitivities. These drawbacks can be eliminated by placing a single current sensor in a DC link of the converter. In this paper, a simplified control strategy has been proposed. The proposed control technique has only one current sensor and two input DC sources. This proposed method is a simple, low cost and enhances performance of the PMBLDC Motor drive i.e., reduced torque ripple, less voltage stress and fast dynamic performance.

KEYWORDS: Closed Loop, PMBLDC Motor, Torque Ripple

INTRODUCTION

Due to absence of brushes and commutator make Brushless DC Motor (BLDCM), good choice for high performance applications [1]. Cost minimizing of the electrical machine drives is more attractive for low cost applications [2]. The low cost BLDC motor drive is achieved by the reduction of switching devices, cost down of control, and saving of hall and current sensors. Many studies have been focused on how to reduce the cost of the BLDC motor and its control system without performance degradation [3]–[5]. So, some research carried out on sensor less Brushless DC Motor, there are some control strategies to eliminate position sensors [6]. Sensor less technique presented in [7] uses a voltage integrator and a PLL to process the third harmonic EMF. In [8] only two Hall-ICs are used for the permanent magnet rotor position and for the speed feedback signals.

In [9], virtual Hall sensor signals are made by detecting the zero crossing points of the stator terminal voltages, and there is no need to build a 30◦ phase shift, which is prevalent in most of the sensor less algorithms.

For closed-loop current control of brushless DC motors, instantaneous phase currents are measured using appropriate current sensors. But the current sensors and the associated accessories increase the complexity of the system, cost and size of the motor drives and decrease the reliability of the system. Also the use of different current sensors can cause undesirable imbalance in phase currents as well as torque ripples due to differences in current sensor sensitivities. To overcome these problems, a new single current strategy for high performance BLDC motor drives is proposed [10]. It is based on estimation and regulation of phase currents, using two single sensors for dc-link voltage and current. In this method, the phase currents are reconstructed in a two-stage process including estimation and regulation. Estimation is based on dynamic motor model, while regulation relies on the inverter switches states and the measured dc-link current. In

[10], a simple position sensorless control strategy for four-switch three-phase BLDC motor drives using single current sensor is proposed. The proposed position sensorless scheme is based on the detection of zero crossing points (ZCPs) of three voltage function that are derived from the difference of line voltages measured at the terminals of the motor but in this control scheme single input dc source is used, failure of single dc source causes reliability problems, to overcome this problem, in this paper, closed speed control of a PMBLDC Motor Drive using single current sensor controlled technique with two input DC sources has been investigated. The PMBLDC Motor Drive with proposed control strategy gives less torque ripple, smooth speed control and less voltage stress. Another advantage of this method is that due to two sources, reliability of the system increases. The proposed control technique of the PMBLDC Motor Drive is low cost because it requires only one current sensor.

DESCRIPTION AND IMPLEMENTATION OF PROPOSED SIMPLIFIED CONTROL STRATEGY OF PMBLDC MOTOR DRIVE

The proposed simplified control strategy with single current sensor is compared with three current sensors method. Figure 1 shows conventional closed loop speed control of PMBLDCM drive of three current sensors method. This method has the drawbacks of: expensive current sensors and torque ripples due to differences in current sensor sensitivities. These drawbacks can be avoided by placing a single current sensor in a DC link.

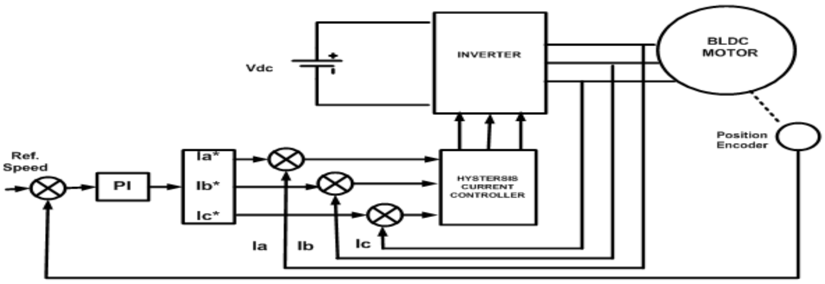

Figure 1: Conventional Closed Loop Speed Control of PMBLDCM Drive Using Three Current Sensors Method

Figure 2 shows proposed model of closed loop speed control of PMBLDCM drive with two input DC source with single current sensor. Actual speed of the motor is compared with the reference speed of the motor which gives speed error and it is fed to the PI controller, which gives the reference torque signal, this reference torque signal is compared with the actual motor torque, which gives the reference DC link current signal which is compared with the actual DC link current, this error signal is fed to hysteresis controller to produce gate pulses to the MOSFET to control the input DC voltage. The strategy becomes simple, because the control only needs one dc current sensor instead of three stator current sensors.

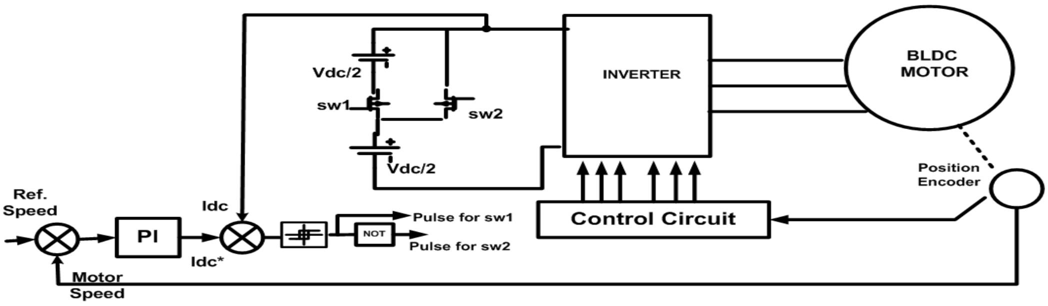

Figure 2: Schematic of Proposed Closed Loop Speed Control of PMBLDCM Drive with Two Input DC Source Using Single Current Sensors Method

The advantage of this method is that performance of the drive is improved i.e., reduced torque ripple, less voltage stress and fast dynamic performance of PMBLDCM drive. The speed of PMBLDCM has been found to be proportional to the dc link voltage; thereby, controlling the dc link voltage, a smooth speed control is observed.

The main components of the proposed control strategy of the PMBLDC Motor drive are: BLDC Machine, speed regulator and current controllers. Description and implementation of each component is given as follows:

Speed Controller

The modelling of a speed controller is quite important as the performance of the system depends on this controller. At *kth* instant of time, $\omega_r^*(k)$ is reference speed, $\omega r(k)$ is rotor speed then the speed error $\omega e(k)$ can be calculated as,

$$\omega_e(k) = \omega_r^*(k) - \omega_r(k) \tag{1}$$

This speed error is processed through a speed controller to get desired control signal. The PI controller is the simplest and most commonly used speed controller. The output of the PI controller is the Torque at *kth* instant, then it is given as,

$$T\ (k) = T\ (k\text{-}1) + Kps[\omega e(k) - \omega e(k\text{-}1)] + Kis.\ e(k) \tag{2}$$

Where Kps and Kis are the proportional and integral gains of the speed controller.

Current control

For current control the actual DC current is compared with reference DC current and the error is given to hysteresis

Current controller to produce the switching signals for the switches. Controlling the input DC voltage controls the speed of the drive. These error signals are amplified by gain c1 and then compare with carrier waveform f (t). The logic for generating switching sequence is as

$$\text{If } c1\ \Delta Idc > f(t) \text{ then } Sdc = 1 \tag{3}$$

$$\text{If } c1\ \Delta Idc \le f(t) \text{ then } S_{dc} = 0 \tag{4}$$

This current control generates the desire firing signals to power electronics switches at DC supply side. Here VDC1 is fixed and switching logic is applied to VDC2 and desired voltage control we get it.

$$V_{DC}=V_{DC1}+V_{DC2}*S_{dc} \tag{5}$$

VSI Inverter

Below table gives the logic to develop firing pulse for voltage source inverter. During duration 0^0 to 60^0, phase A upper switch is ON, phase B lower switch is ON and Phase C switch are OFF. In three phase BLDC drive only two phases are excited. Similarly for other duration logic is followed as given in below table.

$$V_{ab} = E_a - E_b + L\frac{dIa}{dt} - L\frac{dIb}{dt} \tag{6}$$

Duration	Phase A	Phase B	Phase C
0^0 to 60^0	+	-	OFF
60^0 to 120^0	+	OFF	-
120^0 to 180^0	OFF	+	-
180^0 to 240^0	-	+	OFF
240^0 to 300^0	-	OFF	+
300^0 to 360^0	OFF	-	+

PMBLDC Machine

Modeling of a BLDC motor can be developed in the similar manner as a three phase synchronous machine. Since its rotor is mounted with a permanent magnet, some dynamic characteristics are different. Flux linkage from the rotor is dependent upon the magnet. Therefore, saturation of magnetic flux linkage is typical for this kind of motors. Following assumptions are made in modeling of PMBLDC Machine.

- Magnetic Saturation of the machine is neglected
- There is no change in the rotor reluctances with angle
- Three phases are balanced.

$$v_a = Ri_a + L\frac{di_a}{dt} + e_a \quad (7)$$

$$v_b = Ri_b + L\frac{di_b}{dt} + e_b \quad (8)$$

$$v_c = Ri_c + L\frac{di_c}{dt} + e_c \quad (9)$$

The above equations in the matrix form is

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R+pL & 0 & 0 \\ 0 & R+pL & 0 \\ 0 & 0 & R+pL \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (10)$$

Where $L_a = L_b = L_c = L = L_s - M$ [H]

L_s is the armature self inductance

M is the mutual inductance

$R_a = R_b = R_c = R$ Armature resistance in ohm

v_a, v_b, v_c Are the terminal phase voltages in volts

i_a, i_b, i_c Motor input current in amperes

e_a, e_b, e_c Are the motor back emf in volts

p in the matrix represents $\frac{d}{dt}$

Due to the permanent magnet mounted on the rotor, its back emf is trapezoidal. The back emf can be expressed as

$$e_a(t) = K_E * \emptyset(\theta) * \omega(t) \quad (11)$$

$$e_b(t) = K_E * \emptyset\left(\theta - \frac{2\pi}{3}\right) * \omega(t) \tag{12}$$

$$e_c(t) = K_E * \emptyset\left(\theta + \frac{2\pi}{3}\right) * \omega(t) \tag{13}$$

Where KE is the back emf constant and ω is the mechanical speed of the rotor.

The permanent magnet also influences produced torques due to the trapezoidal flux linkage. Given that K_T is the torque constant. The produced torques

$$T_E = (e_a i_a + e_b i_b + e_c i_c)/\omega \tag{14}$$

The resultant torque, T_E, can be obtained by the following expressions.

$$T_a(t) = K_T * \emptyset(\theta) * i_a(t) \tag{15}$$

$$T_b(t) = K_T * \emptyset\left(\theta - \frac{2\pi}{3}\right) * i_b(t) \tag{16}$$

$$T_c(t) = K_T * \emptyset\left(\theta + \frac{2\pi}{3}\right) * i_c(t) \tag{17}$$

$$T_E(t) = T_a(t) + T_b(t) + T_c(t) \tag{18}$$

But torque can also be expressed as.

$$T_E(t) - T_L(t) = J\frac{d\omega(t)}{dt} + B * \omega(t) \tag{19}$$

Where T_L load torque in N-m

J rotor inertia in [kgm^2]

B damping constant

RESULTS AND DISCUSSIONS

To evaluate the performance of the proposed PMBLDCM drive system, simulation work is carried out on MATLAB/ SIMULINK environment. The performance of the PMBLDCM drive system is analyzed inters of the motor speed, stator current and electromagnetic torque, DC link voltage etc. The performance of the drive is tested for constant rated torque (2 Nm) at rated speed. The parameters of the BLDC motor are, Rs = 0.75Ω, Ls =200e-6mH, P = 4, J = 0.4e-3Kg-m^2.

PMBLDC MOTOR DRIVE WITH SINGLE CURRENT SENSORS AND SINGLE DC SOURCE

Performance of PMBLDCM Drive during Starting

The performance of the PMBLDCM drive using single current sensors method is evaluated when the motor is feed from 400V DC supply at rated torque of 2 Nm with a reference speed of 1000 rpm. Figure 3 shows MATLAB/SIMULINK model of closed loop speed control of PMBLDCM drive using single current sensors method.

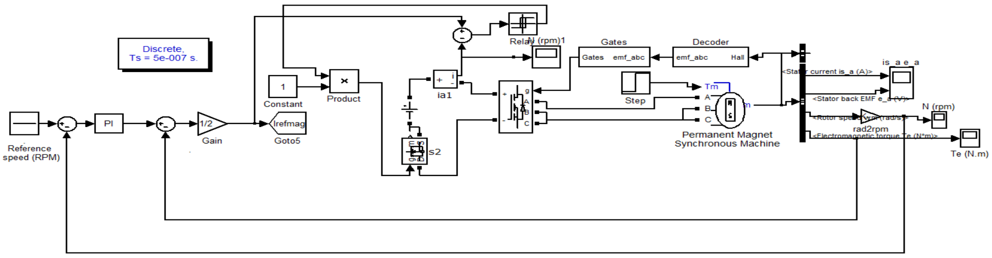

Figure 3: MATLAB/SIMULINK Model of Closed Loop Speed Control of PMBLDCM Drive Using Single Current Sensors Method

Figure 4 shows the performance of the single current sensors single DC fed PMBLDCM drive during stating period. Figure 4(a) shows the speed response of the drive, the drive reaches to steady speed of 1000 rpm at t=0.016 sec. Figure 4(b) shows the stator current response, at the time of starting it takes a current of 4.8amps, after t=0.02 sec it takes a steady current of 2 amps. Figure 4(c) shows the torque response at the time of starting at t=0.02sec a load is applied and motor develops a torque of 2Nm, at no load during starting motor is developing a torque of 6Nm. Figure 4(d) shows the stator voltage response, this voltage varies between 0 to 400v. Figure 4(e) shows the response of DC link voltage, in this DC link voltage varies from 0 to 400v.

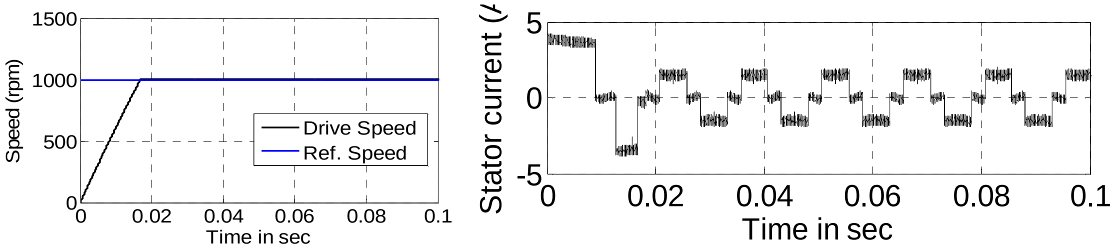

Figure 4 (a): Speed Response Figure 4 (b): Stator Current

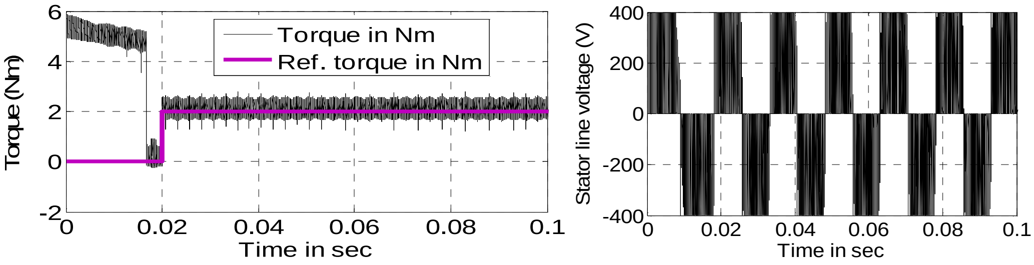

Figure 4 (c): Torque Response Figure 4 (d): Stator Voltage

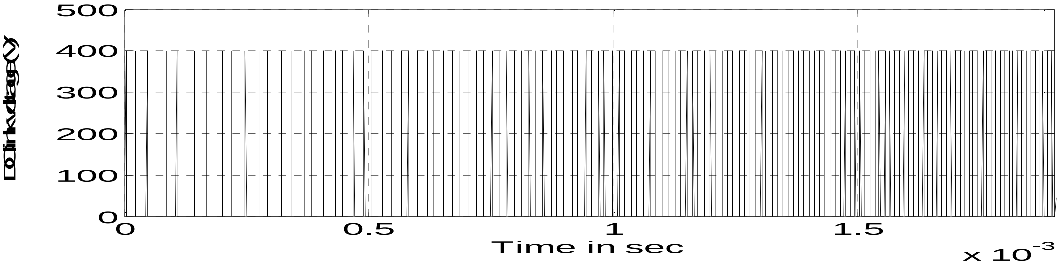

Figure 4 (e): DC Link Voltage

Figure 4: Performance of the Single Current Sensors Single DC Fed PMBLDCM Drive during Stating (a) Speed Response (b) Stator Current (c) Torque Response (d) Stator Voltage (e) DC Link Voltage

Performance of PMBLDCM drive during Increase in Speed

Figure 5 shows the performance of the single current sensors and single DC fed PMBLDCM drive for variable speed i.e. when speed increases from 1000 rpm to 1400 rpm at a constant load torque of 2Nm.

Figure 5(a) shows the speed response of the drive, the drive reaches to steady state speed of 1400 rpm from 1000 rpm in 0.03 sec. Figure 5(b) shows the stator current response, motor takes a current of 4.8 A, during this speed transaction, when motor reaches a steady speed of 1400 rpm motor takes a steady current of 2A. Figure 5(c) shows the torque response, at t=.2 sec speed increases from 1000 rpm to 1400 rpm during this period drive develop a torque of 5Nm for a period of 0.01 sec after this motor develop a constant torque of 2Nm.

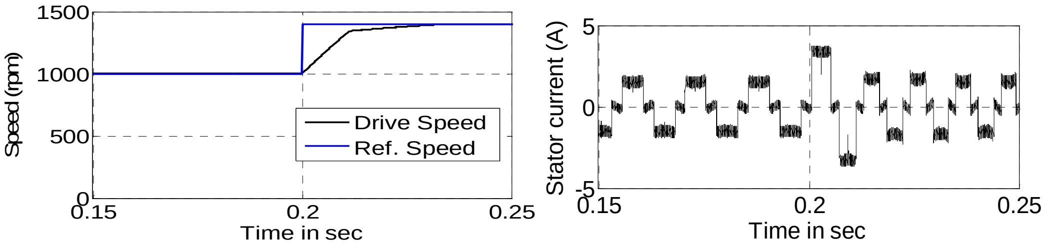

Figure 5 (a): Speed Response

Figure 5 (b): Stator Current

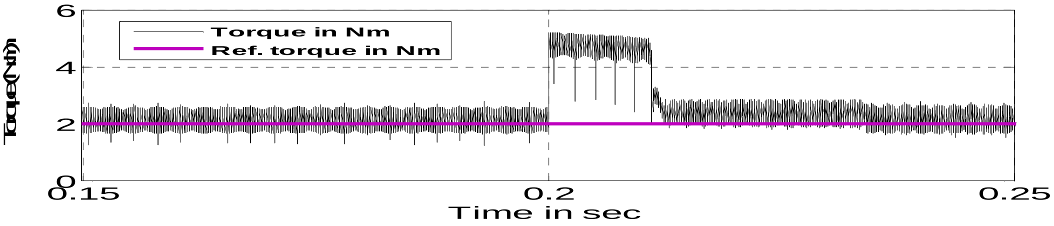

Figure 5(c): Torque Response

Figure 5: Performance of the Single Current Sensors Single DC fed PMBLDCM drive when Speed Increases from 1000rpm to 1400 rpm (a) Speed Response (b) Stator Current (c) Torque Response

Performance of PMBLDCM Drive during Decrease in Speed

Figure 6 shows the performance of the single current sensors single DC fed PMBLDCM drive for variable speed i.e. when speed decreases from 1400 rpm to 1200 rpm at a constant load torque of 2Nm.

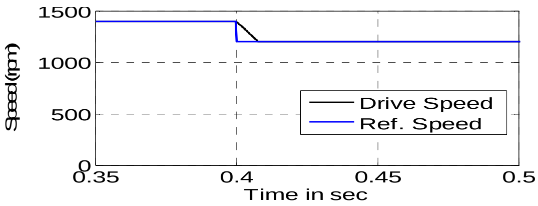

Figure 6 (a): Speed Response

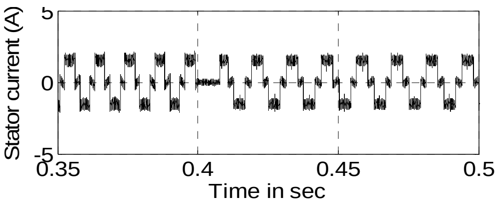

Figure 6 (b): Stator Current

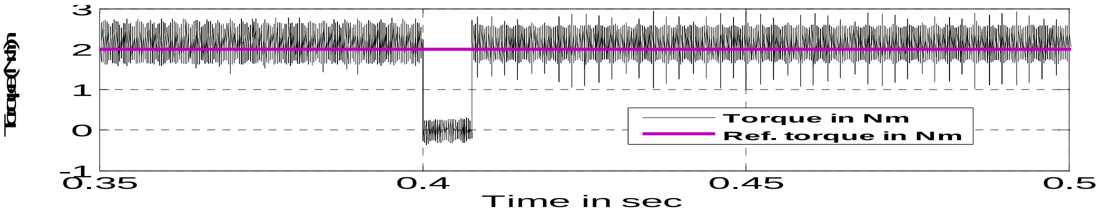

Figure 6 (c): Torque Response

Figure 6 Performance of the Single Current Sensors Single DC Fed PMBLDCM Drive when Speed Decreases from 1400rpm to 1200 rpm (a) Speed Response (b) Stator Current (c) Torque Response

Figure 6(a) shows the speed response of the drive, the drive reaches to steady state speed of 1200 rpm from 1400 rpm in 0.005 sec. Figure 6(b) shows the stator current response, motor takes a very small current, during this speed transaction, when motor reaches a steady speed of 1200 rpm motor takes a steady current of 2A. Figure 6(c) shows the torque response, at t=0.4 sec motor speed decreases from 1400 rpm to 1200 rpm during this period drive develop a torque of 0.01Nm for a period of 0.005 sec after t=0.405 sec motor develop a constant torque of 2Nm.

PMBLDC MOTOR DRIVE WITH SINGLE CURRENT SENSOR AND WITH TWO DC SUPPLIES

Figure 7 shows proposed MATLAB/SIMULINK model of closed loop speed control of PMBLDCM drive with two input DC source using single current sensors method.

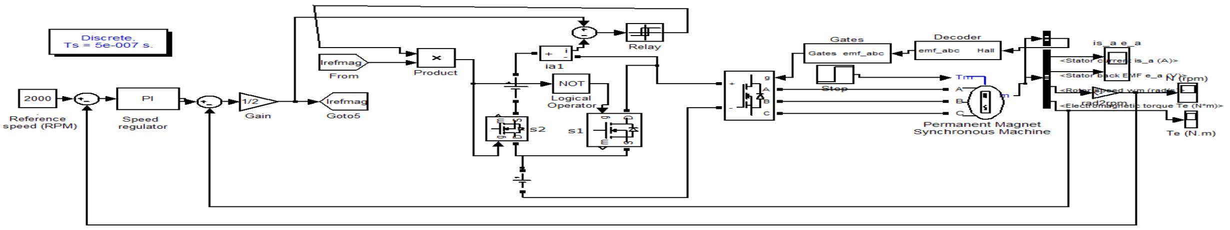

Figure 7: Proposed MATLAB/SIMULINK Model of Closed Loop Speed Control of PMBLDCM Drive with Two Input DC Source Using Single Current Sensors Method

Performance of PMBLDCM drive during Starting

The performance of the PMBLDCM drive using single current sensors with two input DC source is evaluated, while the motor is feed from two separate DC source of 150v each at rated torque of 2 Nm with a reference speed of 1000 rpm. Figure 8 shows the performance of the single current sensors two DC fed PMBLDCM drive during stating period. Figure 8(a) shows the speed response of the drive, the drive reaches to steady speed of 1000 rpm at t=0.002 sec. Figure 8(b) shows the stator current response, at the time of starting it takes a current of 15 amps upto t=0.002 sec, after t=0.02 sec it takes a steady current of 2 amps. Figure 8(c) shows the torque response at the time of starting at t=0.02sec a load is applied and motor develops a torque of 2Nm. Figure 8(d) shows the stator voltage response, this voltage varies between 0,150V and 300V. Figure 8(e) shows the response of DC link voltage, in this DC link voltage varies between 150 to 300V.

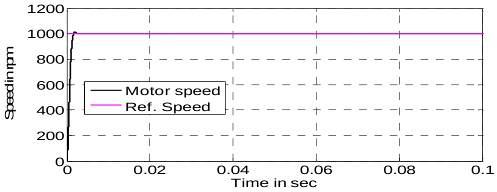

Figure 8 (a): Speed Response

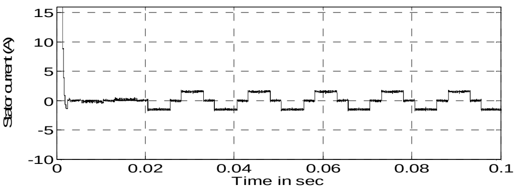

Figure 8 (b): Stator Current

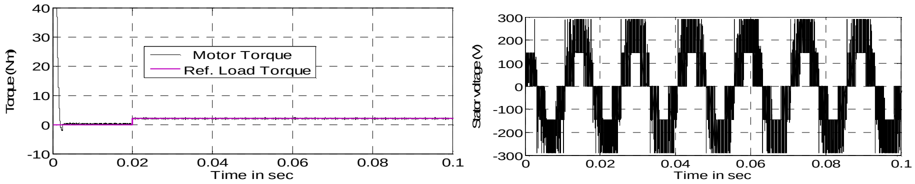

Figure 8 (c): Torque Response **Figure 8 (d): Stator Voltage**

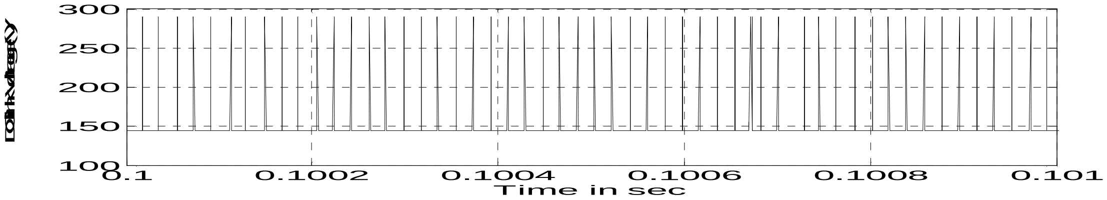

Figure 8 (e): DC Link Voltage

Figure 8: Performance of the Single Current Sensors Two DC Supply Fed PMBLDCM Drive during Stating (a) Speed Response (b) Stator Current (c) Torque Response (d) Stator Voltage (e) DC Link Voltage

Performance of PMBLDCM drive During Increase in Speed

Figure 9 shows the performance of the single current sensors single DC fed PMBLDCM drive for variable speed i.e. when speed increases from 1000 rpm to 1400 rpm at a constant load torque of 2Nm. Figure 9(a) shows the speed response of the drive, the drive reaches to steady state speed of 1400 rpm from 1000 rpm in 0.038 sec. Figure 9(b) shows the stator current response, motor takes a current of 4.8 A, during this speed transaction, when motor reaches a steady speed of 1400 rpm motor takes a steady current of 2A. Figure 9(c) shows the torque response, at t=0.2 sec speed increases from 1000 rpm to 1400 rpm during this period drive develop a torque of 3Nm for a period of 0.0375 sec after this motor develop a constant torque of 2Nm.

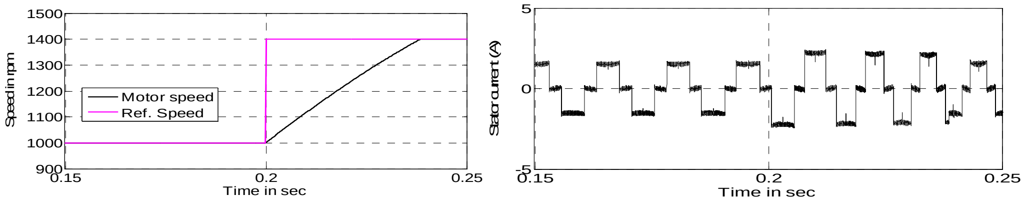

Figure 9 (a): Speed Response **Figure 9 (b): Stator Current**

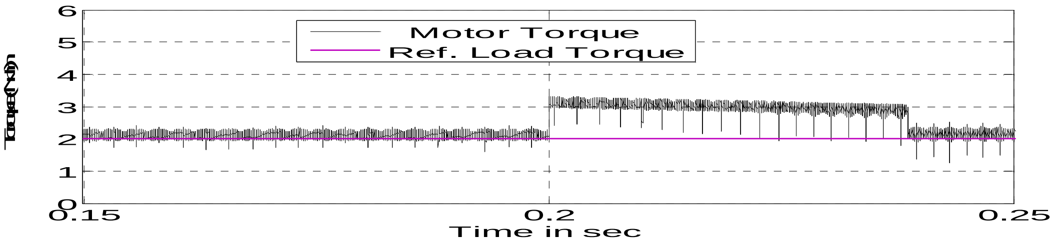

Figure 9 (c): Torque Response

Figure 9: Performance of the Single Current Sensors Single DC fed PMBLDCM Drive when Speed Increases From 1000rpm to 1400 rpm (a) Speed Response (b) Stator Current (c) Torque Response

Performance of PMBLDCM drive during decrease in speed

Figure 10 shows the performance of the single current sensors single DC fed PMBLDCM drive for variable speed i.e. When speed decreases from 1400 rpm to 1200 rpm at a constant load torque of 2Nm.

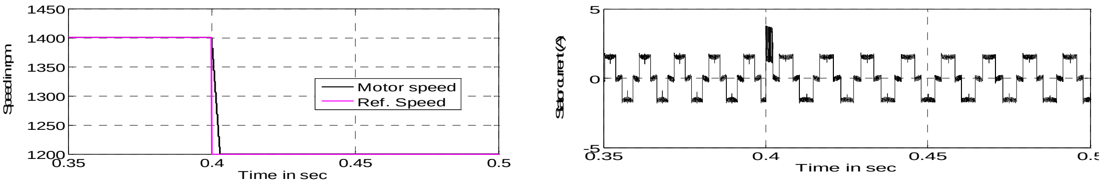

Figure 10 (a): Speed Response **Figure 10 (b): Stator Current**

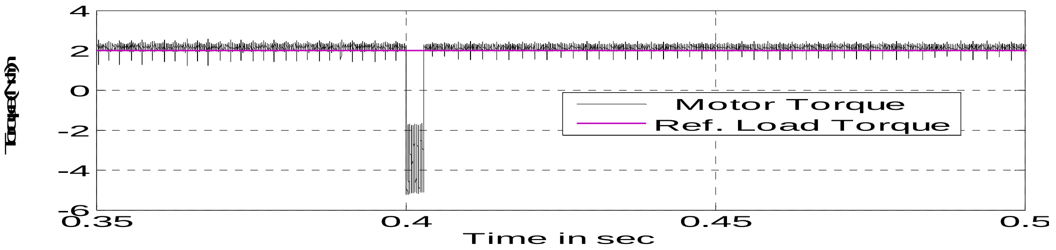

Figure 10 (c): Torque Response

Figure 10: Performance of the Single Current Sensors Two DC Supply Fed PMBLDCM Drive when Speed Decreases from 1400rpm to 1200 rpm (a) Speed Response (b) Stator Current (c) Torque Response

Figure 10(a) shows the speed response of the drive, the drive reaches to steady state speed of 1200 rpm from 1400 rpm in 0.005 sec. Figure 10(b) shows the stator current response, during this speed transaction and when motor reaches a steady speed of 1200 rpm motor takes a steady current of 2A. Figure 10(c) shows the torque response, at t=0.4 sec motor speed decreases from 1400 rpm to 1200 rpm during this period drive develop a negative torque for a period of 0.005 sec after t=0.405 sec motor develop a constant torque of 2Nm.

Table 1, shows the comparison of PMBLDCM drive using single current sensor single dc supply method and proposed method. Single current sensor controlled technique with two input DC source fed brushless dc motors is a simple, low cost technique with enhanced performance of dive is obtained i.e., reduced torque ripple, less voltage stress and fast dynamic performance of PMBLDCM drive. In case failure of one dc source, the drive will operate, and stoppage of work can be avoided in industrial applications.

Table 1: Comparison between Single Current Sensors & Single Dc Supply and Single Current Sensor & Two Input Dc Supply

Speed in Rpm	Single Current Sensors and Single Dc Supply	Single Current Sensors and Two Dc Supplies
Current Sensors	01	01
Dc Supply	01	02
Reliability	Less	More
Torque ripples	±0.7	±0.5
Voltage stress	Vdc	Vdc/2

CONCLUSIONS

In this paper, a simplified control strategy for closed loop control of PMBLDC Motor drive has been developed. The proposed control technique requires only one current sensor instead of three current sensors. So, the biggest advantage of the proposed control method is low cost. In this paper, two input DC sources are considered along with single current sensor. In case failure of one dc source, the drive will operate, and stoppage of work can be avoided in industrial applications. The speed of PMBLDC Motor drive has been found to be proportional to the dc link voltage, thereby, controlling the dc link voltage, a smooth speed control is observed.

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