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Sensorless zero back EMF method for in rotor position control of BLDC motor drive

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Abstract

Electrical Drives is a system comprising various devices which aim at controlling the motion of electrical machines in desired fashion. Using the concept of drive speed of rotation of an electrical machine can be controlled precisely in an optimized manner. A motor drive usually consists of an electric machine along with a power converter with associated controller. The converter manages power flow from source to the motor input terminals. Recently, there has been tremendous advancement in semiconductor technology owing to which very robust, reliable, efficient and compact AC and DC electric motor drives have been designed and developed. The controller handles the command signals and various sensor feedback signals and enables generation of appropriate gate switching signals, according to a control algorithm for the power converter. Also, the algorithm may incorporate fault detection and protection. The signals from the sensor may be machine inverter temperature outputs, rotor position of motor, currents in all phases and inverter bus voltage. Some of the Key features namely, high reliability, straight forward control, and low friction make the brushless direct current (BLDC) motors suitable for the drive applications. A BLDC motor has a better high-speed adjusting performance and power density in comparison to PMSM. According to review of relevant research work the most popular method for determining rotor position of BLDC motor is Hall Sensor method and other methods are also available viz., Variable Reluctance Method, Accelerometer, Zero Back EMF method and six step commutation control method that work well for BLDC motor. The problem of designing drive system is still one of the ubiquitous research problems.

Keywords: BLDC – Brushless D.C. Motor, PMSM- Permanent Magnet synchronous motor, EMF- Electro Magnetic force, ZCD- Zero Cross Detector, BEMF- Back Electro Magnetic force, FWD-freewheeling diode.

Introduction

Design of Motor drives is such that the system works at more efficiency, tolerant to fault, less noisy operation, lighter and can be coordinated according to the requirement. Designing tools and modeling are being developed to assist the machine designing and the efforts in developing the drive. Now a day's research importance is being given on permanent magnet and the reluctance type machines and drives. These motors are well accepted in industrial sectors since their structure are suitable for applications which requires safety. BLDC motor, also termed as PMDC Synchronous motor, is quite popular, owing to their better performance[1,2]. These motors are extensively used in industrial sectors since they have suitable architecture for any safety applications[3,5].

In this paper firstly rotor position estimation is described. In the second section conventional method using sensors is discussed, in further part of the paper some sensorless control methods for BLDC motor have been briefed. In the latter section of the paper modelling of sensorless zero back-EMF technique. Along with simulation results is presented. Last section is the conclusion drawn upon the simulation results. This paper sensorless performance of BLDC motor is analyzed by using zero cross back-EMF method and the simulation is done on MATLAB 7.10.0(R2010a) version. The problem of designing drive system is still one of the ubiquitous research problems.

Rotor Position Evaluation

Evaluating the position of rotor is quite crucial step for controlling BLDC motors. A small error in rotor position evaluation results in poor operation and in some conditions complete failure of motor can happen. Measuring position of rotor is done by either sensor or sensorless approach. In sensored scheme some kind of additional sensors are connected to the stator of the motor, but in sensorless method sensors are absent from stator of the motor[1].

Conventional method of control using sensors

Generally BLDC motors are controlled through electronic commutation. For rotating BLDC motor, the windings in stator are supplied sequentially. Rotor positions itself in order in which winding will be supplied in the following energizing sequence. Conventionally Hall Effect sensors are fixed into the stator winding to sense the position of rotor of BLDC motor[2].

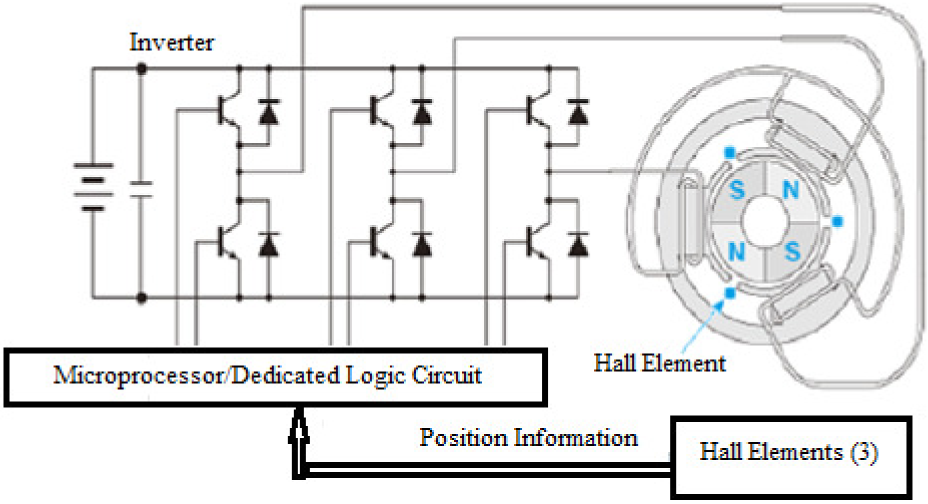

Figure-1: BLDC with sensor control.

The addition of the hall sensors used in stator of BLDC motor will increases the rate and dimension and also an unusual preparation is needed for the sensor. Hence system reliability is reduced as there is increase in number of the components that are used in hardware interfacing. Also, the motor operation at high temperatures, they are temperature sensitive, which could limit[2].

Various sensorless control techniques for BLDC motors

The major techniques used in this topic especially for the trapezoidal back-EMF type of BLDC motors can be categorized as follows:

Back-EMF Sensing Techniques: In zero-crossing approach or the back-EMF sensing technique, detection of the instant at which back-EMF in the unexcited phases crosses the zero is done. Zero crossing initiates the next sequence inverter commutation to occur at the end of at triggered timing interval equal to RC time constant[2]. This is the most economical sensorless control of BLDC motor. This involves detection of back-EMF on unused phase. In these methods an extra error is created due to requirement of virtual neutral point. The estimation of flux needs no neutral voltage, but suffers from disadvantages like complex circuit and long sample time. As a consequence, these techniques used to have medium speed range and poor startup characteristics. These technique based on back-EMF was projected to reduce those limitation.

In PM brushless D.C. machines, the back-EMF is dependent on instantaneous position of the rotor and having a trapezoidal variation with 120º flat duration. It is complicated to evaluate the back-EMF, due to suddenly variations in currents in motor windings and also owing to the voltages induced due to electronic phase switching. Initially magnitude of back-EMF is not adequate enough until rotor reaches at some speed.

“Align and go” is one of the common starting methods, in which by supplying any two stator hence rotor attains a particular position afterwards rotor acceleration is brought upto the required speed as required by commutation sequences. The “align and go” scheme has some disadvantages like demagnetization of permanent magnets due to high starting currents occurs. Zero crossing points are not instants of commutation. The phase shifting of signals should be done by 90° electrical before using it for commutation. To overcome the phase shifting problem following methods are used: i. Detecting of the 3rd harmonic component in back-EMF, ii. Direct current control algorithm, iii. Phase locked loops.

In 3rd-harmonic approach same inductance is assumed in each 3-phase, though this applies for surface-mounted magnet motors only, but in the case of salient rotors, error occurs in estimation of rotor position due to quickly changing currents. Necessity of the machine’s star neutral terminal availability is to evaluate the back-EMF across the terminals of a star-connected machine. The back-EMF technique is mostly applied on low cost applications (fans and pumps)[5].

Back-EMF Integration Technique: This method depends on the integration of back-EMF to extract position information the single phase. Integration starts when back-EMF of the open phases crosses zero. To stop integration threshold are set that has a close similarity to a commutation immediate. At low speeds this method suffers from the problem of error accumulation[3].

Flux Linkage-Based Technique: In this method, calculation of flux linked is done by measuring voltages and currents. The principle on which something based idea is to estimate flux by integrating the machine voltage equation of applied voltage and current. From the starting position, machine specification, and flux linked, position of rotor may be evaluated.

The methods of flux-linkage sensing rely on motor equation of phase voltage. Since the flux linkages make use of the rotor position and current. The phase flux linkage can be evaluated continuously by amalgamate the voltage after deduct the resistive voltage drop from phase voltage of motor.

The open-loop amalgamate is prone to errors due to drift, which can be minimize by pure integrator is exchanged by a low pass filter and another integrator structure. In electrical machines, not practical to compute the phase voltages directly, due to isolation related difficulties, for that reason supplied phase voltage is evaluated from D.C. volts of electronic converters[6].

Freewheeling diode conduction: Freewheeling Diode Conduction method applies current passing through a FWD in single phase. For a few times after reaching zero crossing of the back-EMF in single phase, a very small current is passing through freewheeling diode; during working phase switches are turned off under chopper control. This single phase current flowing in centre of the commutation period. Disadvantage of freewheeling diode conduction method is the accessibility of 6 extra remote power supplies for the comparator circuit to sense current passing through each FWD[3].

Inductance variation sensing: The basic concept in this type is that the variation of inductance is the rate of change of current which is controlled by inductance of motor winding. The variation of inductance is observed after inoculation of current pulse in the motor armature windings. This strategy is more useful near speed zero, when back EMF is not present. This method is satisfactory for the IPM type BLDC motor since it has NdFeB magnet which are having very high performance. In order to get different inductance profiles, a high current pulse is needed. Thus, inductance variation sensing method is not valid for a Sinosoidal PM-type Brushless D.C. motor with magnets made of ferrites.

Modelling of Sensorless Zero BEMF Technique

In sensorless technique, the motor parameter i.e. stator back-EMF is used to identify the instant rotor position. Back-EMF detection technique has been proved as a significant improvement of the conventional sensored methods. BLDC motors exhibit two different types of back-EMF waveforms: i. Trapezoidal , ii. Sinusoidal.

The back-EMF waveform changes its phase every time when the rotor of the motor crosses the stator coil in front of it. The back-EMF waveforms thus produce from the motor stator is made become a zero crossing detector (ZCD). The output of ZCD is a square wave pulses and it is created every time when the back-EMF pulse revise its phase. These square wave pulses hence generated are similar to a hall sensors output and so are used to commute the motor. Square wave pulses from each of the stator windings are fed back to the control logic from motor to achieve commutation[7].

Simulation Results

This circuit uses of Sim Power System library. It is representation of a 3 hp B.L.D.C. motor drive having braking chopper. A 3-phase inverter is used to supply the permanent magnet synchronous motor (with trapezoidal back-EMF), which is made by an Universal Bridge Block.

Figure-2 shows actual model analysis of Brushless D.C. Motor Drive in using MATLAB/Simulink.

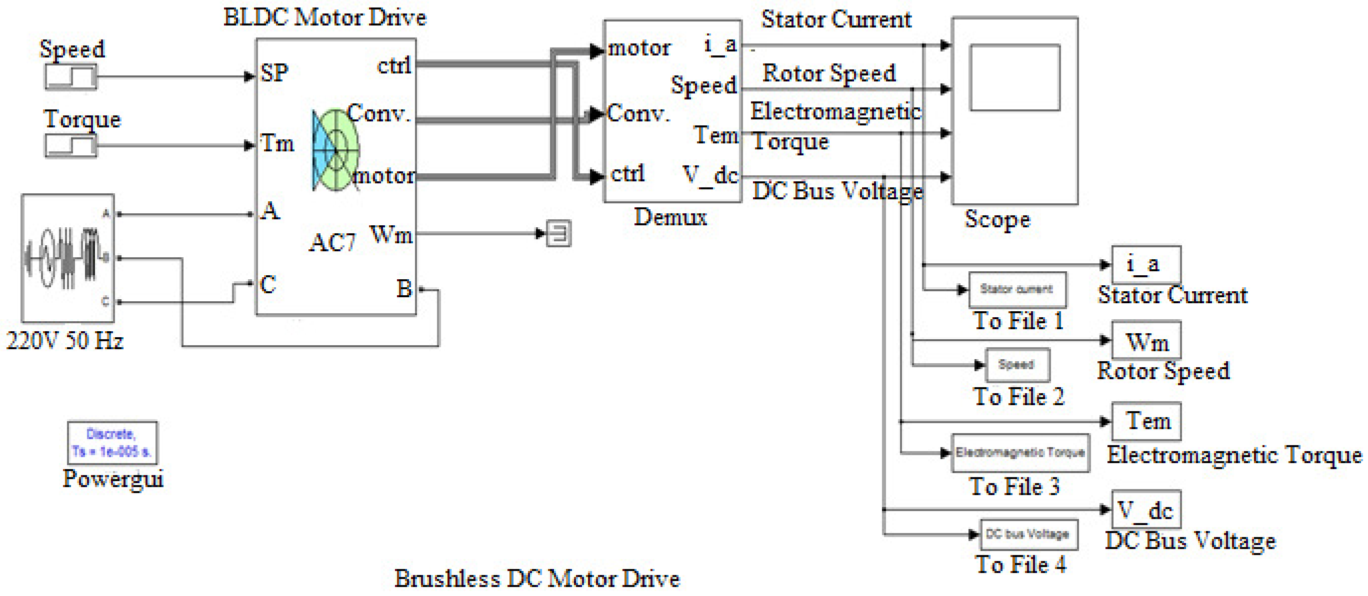

Figure-2: MATLAB/SIMULINK model of Brushless D.C. Motor Drive.

Current Controller

The electronic commutation of the Brushless DC motor is obligatory to detect the phase currents and the current sensing is done by Zero Cross detector method comes under zero BEMF.

The large and small signal speed response is the same whether PWM or Hysteresis current controller are used. The current controller is employed as a conventional Proportional-Integral (PI) controller. Input to the current controller is the output from the speed controller, along with measured DC Bus current. Function of the output of current controller is to control the duty cycle of the PWM pulses.

The sensing sections are divided in two parts: i. Position Sensor System and ii. Current Sensor System. The first section is based on three Zero Cross detector cell placed inside the motor winding, and a magnetic disc in the rotor, with the same number of poles as the motor. The second sensing section is founded on the current sensors. Placing of sensors can be in any of the two from the three phases of the motor.

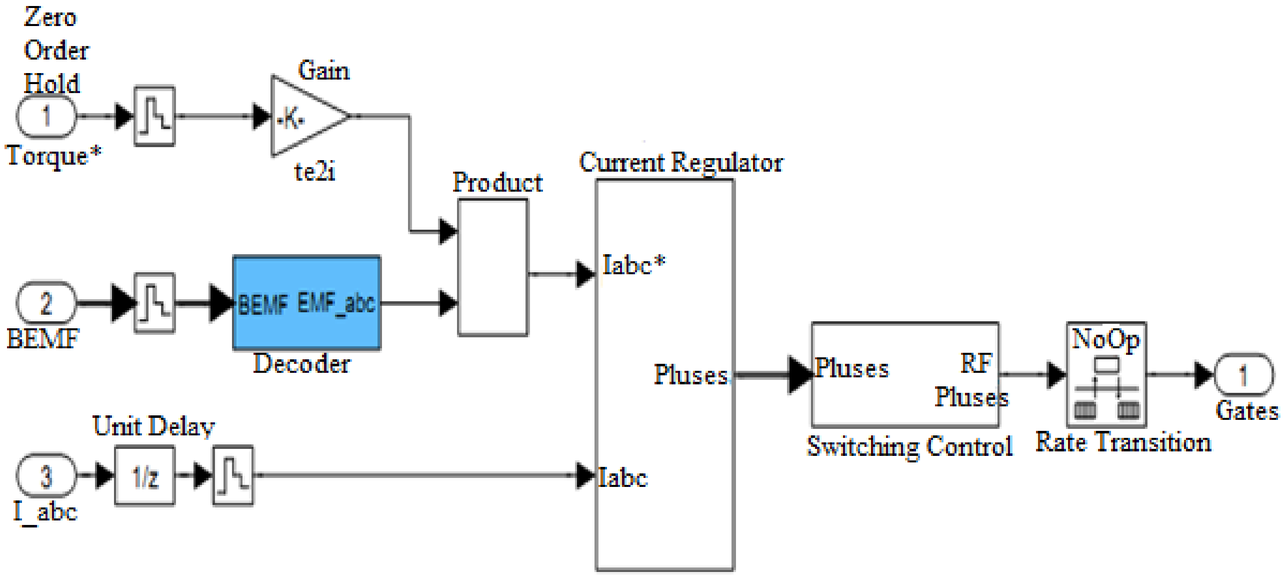

Figure-3: MATLAB/SIMULINK model of Current controller.

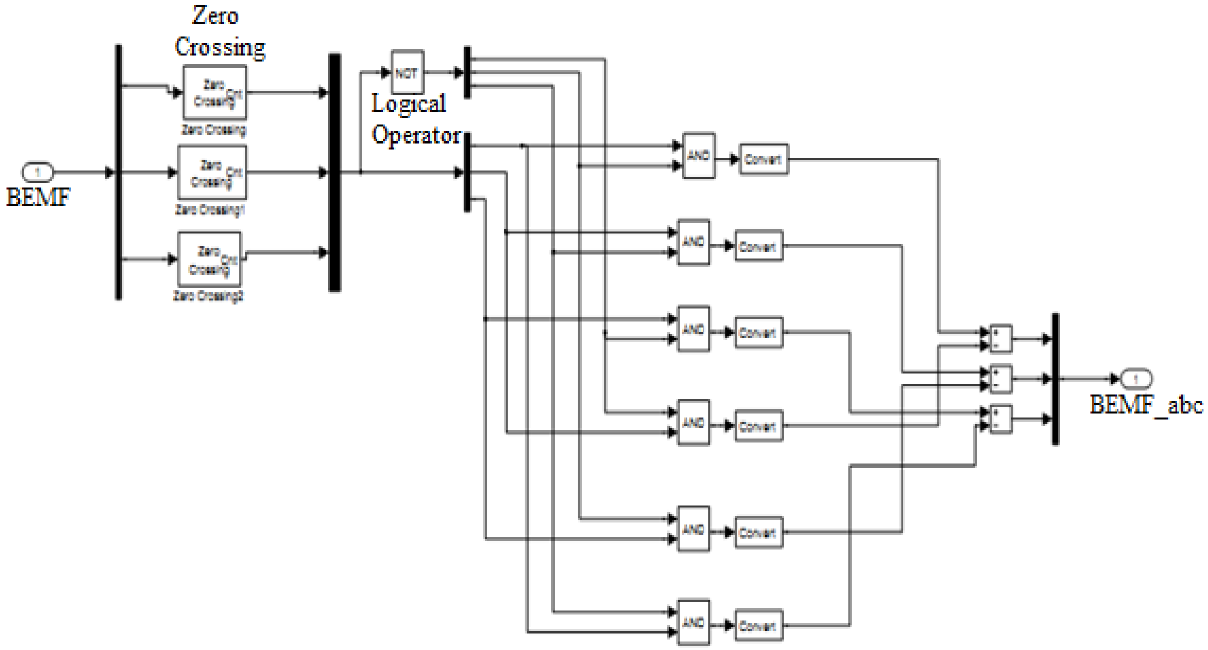

Figure-4: MATLAB/SIMULINK model of Sensorless Rotor position control by zero crossing detectors.

BLDC Motor Drive parameter representations

Table-1 and 2 are drive parameter set of a 3-HP BLDC motor.

Table-1: Three-HP Drive Specifications.

Drive Input Voltage		
	Voltage magnitude	220 V
	Supply Frequency	50 Hz or 60 Hz
Nominal Motor Values		
	Power	3 hp
	Speed	1650 rpm
	Voltage	300 Vdc

Table-2: BLDC Motor Model Parameter.

Parameters of BLDC Motor Drive	Symbols	Value
Stator resistance	r_s	3.7 Ω
Phase inductance of stator	L_s	5.5 mH
Flux linkage		0.175 V.s
Voltage Constant ($V_{\text{peak LL/krpm}}$)		146.6 Volt
Torque Constant (Nm/Apeak)		1.4 Nm
Viscuss friction	B	0.005 N.m.s
Rotor inertia	J	0.087 kg.m^2
Back EMF flat area (degree)		120^0
No. of pole pairs	P	4

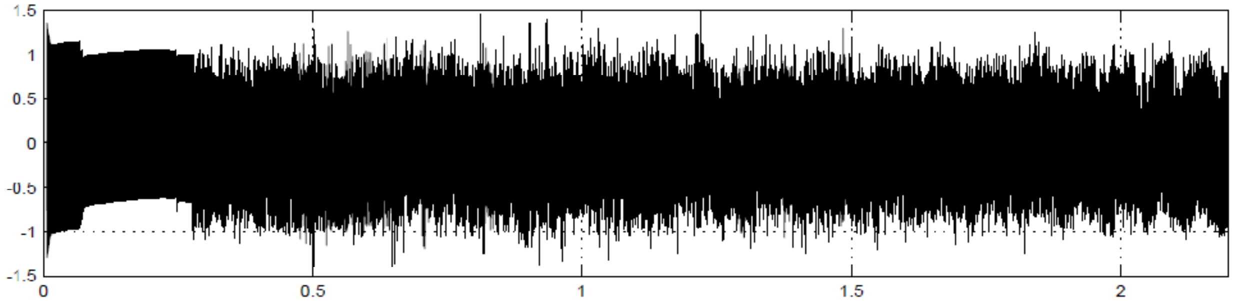

Figure-5a: Stator Current of BLDC Motor.

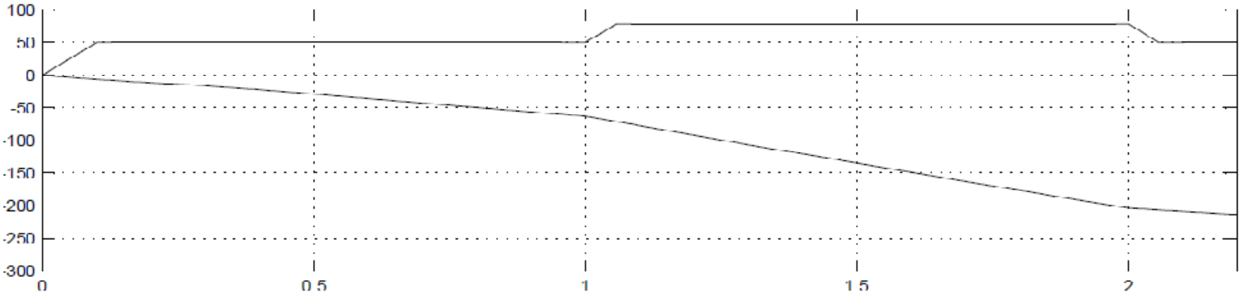

Figure-5b: Rotor Speed of BLDC Motor.

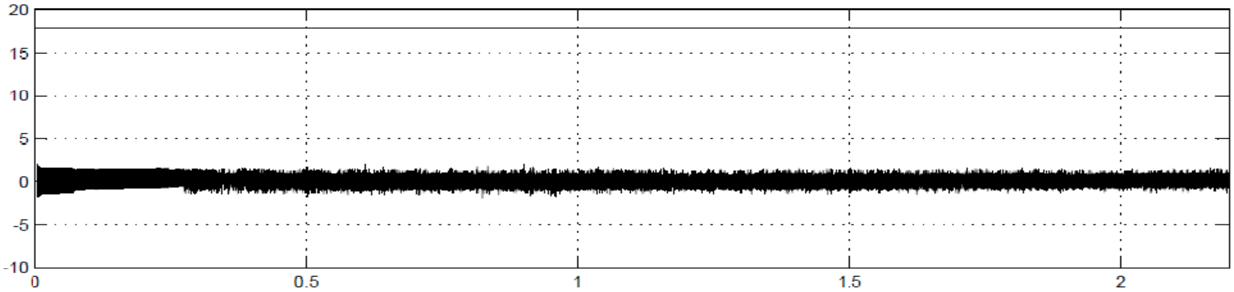

Figure-5c: Electromagnetic Torque of BLDC motor.

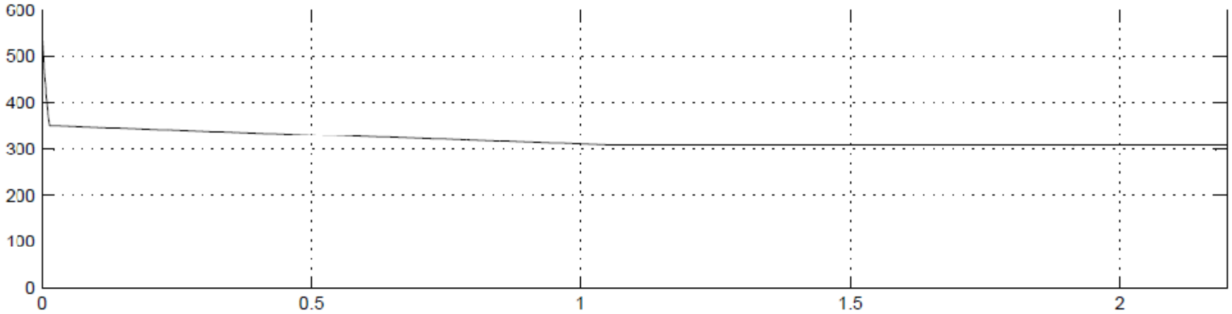

Figure-5d: D C Bus voltage of BLDC Motor.

Figure-5a shows the variation of stator current (ia in Ampere) with time (in seconds) of Brushless Dc Motor. Stator winding current wave shape has distortions due to presence of harmonics in the supply input. Figure-5b graph shows the variation of rotor speed (in rpm) and time (in seconds) of BLDC motor.

Motor speed is varied from Rated Speed 98.5 rad/sec. at 0 second at no load torque., and At t = 0.5 sec.,with minimal load applied on motor. a normal load torque function is reach at rated speed of motor. Here with 8poles, 50 Hz BLDC Motor speed is based on this relation,

$$\text{Speed N} = \frac{120*\text{frequency}}{\text{Number of poles}}$$

$$\omega_m = 2\pi * N$$

Figure-5c shows Electromagnetic Torque (in Nm) of BLDC motor and time (sec). This motor is run no load Electromagnetic torque but it runs rated speed 98.5rad/sec. at 0.5sec torque value is zero, and at starting, nominal torque 5 Nm but that time motor is stop (0 rad/sec). Figure-5d shows the relation between D.C. bus voltages (in volts) time (sec). The 3-phase rectifier circuit provides DC bus voltage. Rectifier circuit though maintains D.C. bus voltage is always constant 300V at 0.2 sec.

Conclusion

According to relevant work it can be concluded that Zero BEMF (ZCD) is able to estimate the rotor position and speed with high precision specially when high speed is considered and the results shows the fast operation, robustness, reliability, smooth operation, noiseless operation and excellent dynamic performance for high speed BLDC motor drive. The controlling of BLDC motors rotor position sensing methods without sensor, such as shaft encoders, resolvers or ZCD, can be improved by eliminating Hall sensors to lessen the economical rate and increase efficiency or consistency.

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