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Design of Controller for Sensorless BLDC Motor using Back-EMF Technique

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Abstract: ***Motor is that the heart of the many industrial automation and motion management applications. Brushless DC (BLDC) motor drives are widely employed in several applications, starting from small to high power applications, thanks to their high potency, low maintenance, need tiny area, salient operation and high torque to power ratio, etc. The rotor position should be non inheritable so as to drive a BLDC motor. The position of the rotor is known by hall sensors and encoders, but when these types of sensors are used to drive BLDC motor, the circuits become very complex and large. Therefore accuracy and performance of BLDC motor drivers should be enhanced through sensorless technology. Many sensorless strategies are existing in literature to sense the rotor position of motor, but this paper explains and proposed zero crossing back-EMF detection method. This paper work on analysis of sensorless techniques to sense the rotor position and PWM based speed control of inverter-fed sensorless BLDC motor. Modeling and simulation of three¬ phase star connected sensorless BLDC motor is done MATLAB environment. An accurate speed estimation has been achieved by using back EMF zero crossing speed estimation method. Fast response with negligible subsiding time has been obtained by this technique of sensorless speed estimation of BLDC motor.***

Keywords: Brushless DC (BLDC) Motor; Electro Motive Force (EMF); Permanent Magnet (PM); Permanent Magnet Synchronous Motors (PMSM); Sensorless Posit ion Control and Zero Crossing Point (ZCP)

1. Introduction

Most of the industries use varied varieties of electrical motors in varied applications; like, elevator, conveyer belt and electrical vehicles etc. Few decades past, conventional DC and AC motors were of common used in all the industries. But these motors don't seem to be effective in era, because of energy crises problems. Nowadays most of the researchers are operating to forestall energy losses in electrical motors and improve overall system potency. Permanent magnetic materials have been evolved since centuries. These materials are extraordinarily spectacular for creating electrical motors, thanks to its high energy density, coercivity and retentivity. Permanent magnetic (PM) material based motors require no secondary supply to create the magnetic coupling domain. Because of these advantages Pm motor are highly efficient and have low inertia, hence high torque to weight ratio. The PM motors are broadly c1assified into groups according to waveforms of back-EMF. One is brushless DC (BLDC) motor and another one is permanent magnet synchronous motor (PMSM). When PM motor connect to power supply and it produce sinusoidal back-EMF that means it is PMSM otherwise produce trapezoidal back¬ EMF that means it is BLDC motor. BLDC and PMSM both motors have need knowledge of rotor position in order to develop a sinusoidal & trapezoidal back-EMF respectively. Nowadays conventional DC motors are replace by BLDC motor, because it has high efficiency, high torque to power ratio, lower maintenance due to brushless architecture and compact size, etc. BLDC motors used in horn appliances and industrial applications like, computer hard drives, CD/DVD player, ceiling fan, transport, heating, ventilations, industrial engineering, motion control systems, position and actuation control system, aero modeling and radio control car, etc. BLDC motor is standard thanks to its easy structural and high potency. But main drawback arises operational of BLDC motor. Because it should need position sensing element to sense the rotor position

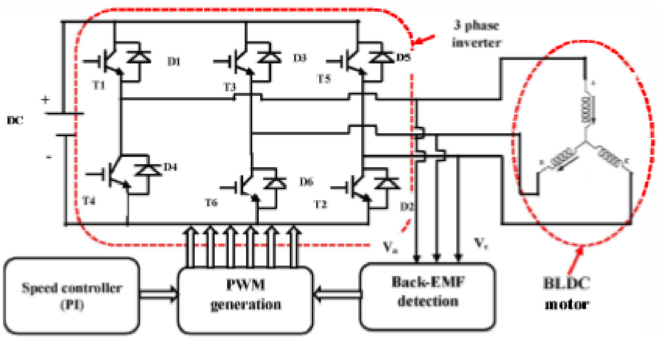

Figure 1: Block Diagram of the Back EMF Based Sensorless Control Technique for BLDC Motor Drive

However BLDC motor have several difficulties once such varieties of position sensors are used. The main difficulty is the hike size of the motor and require special layout for mounting the sensors. Another issue with hall sensors is that their temperature inclined and that they restraint the operation of the motor and at last value of the system increase. Therefore to beat all higher than issues relating to position sensors, researchers are working on sensorless technology for BLDC motor and it is called sensorless BLDC motor. Many sensorless methods are existing in literature to sense the rotor position of BLDC motor; like, zero crossing detection (ZCD) back-EMF, sensing of the conducting state of freewheeling diode in the floating part, terminal current sensing technique and back-EMF integration technique.

2. Principle of speed sensing of BLDC motor

The BLDC motor is a rotating electric machine, it is also known as electronically commutated motors. The BLDC motor is driven by rectangular voltage plus the given rotor position. The rectangular voltage must be properly applied to the three-phase winding system. So that the angle between the stator coil flux and therefore the rotor flux is unbroken on the brink of 90°, to get the maximum generated torque .The common three-phase sensorless controlling technique for BLDC motor is illustrated in fig.1. Inverter block works as an electronics commutator for BLDC motor. It is made by combination of semiconductor switches, like power MOSFETs or IGBTs with anti parallel connected diodes. The PWM generation block generates six-pulse signals in order to filter power electronics switches. Speed control block is used for speed control of the motor. PI controller used for minimize speed error of the motor.

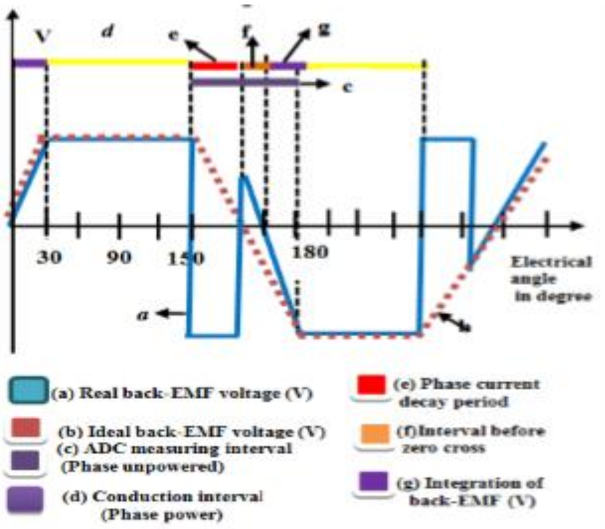

Figure 2: Single Phase Voltage Waveform of BLDC Motor

The Fig. 2 shows single phase voltage waveform of sensorless BLDC motor. The yellow interval (d) suggests that a conductivity interval of a section. During now amount, current flows through the winding and back-EMF voltage is impossible to measure. Cyan lines c) confirm the period of time once the back-EMF voltage may be perceived as section is unpowered. Gray lines (e) show the transient pulse measured on the phase voltages right after the commutation event, which is produced by the current recirculation when the anti parallel diodes are conducting. Green lines (t) determine the time period before the zero cross event, the red line (g) shows the time after zero-cross event, in this period the back-EMF voltage is integrated, and at the end of the red interval, the integrated value of the back-EMF voltage reaches the back-EMF threshold value, and this is the signal to switches to commutate.

3. Techniques to sense the rotor position

A sensorless drive means that doesn't require position sensors in order to drive PM motors .The absolute removal of position sensors, thus reducing the complexity of electrical circuit, its size and cost of motor. In the stimulation of a three-phase BLDC motor, other than the phase-commutation periods, only two out of the three phase windings are conducting at a time and the no conducting phase carries the back-EMF. In this work, various speed sensing methods for BLDC motor are explained, which can be classify in two categories .

1. Direct back-EMF detection.
2. Indirect back-EMF detection.

3.1 Direct Back-EMF detection methods

The back-EMF of unpowered section is perceived and its zero crossing is detected by comparing it with the neutral purpose voltage. The difficulty of this technique is that the speed vary is a smaller and less wide. The methods can be classified as:

1) PWM strategies.
2) Back-EMF zero crossing detection (ZCD) or terminal voltage sensing

3.2 Indirect Back-EMF detection methods

In order to shorten the semiconductor switching noise, the indirect back-EMF detection methods are used. These methods can be classified as:

1) Terminal current sensing or free-wheeling diode conduction.
2) Back-EMF integration.
3) Third harmonics voltage integration.

3.3 Back-EMF zero crossing detection method

The zero-crossing approach is the simple method for back-EMF sensing technique, and is based on catch the quick at which the back-EMF in the floating phase crosses zero. For a normal operation of a BLDC motor, the phase current and back-EMF should be adjust to generate constant torque. In order to produce maximum torque, the inverter should be commutated every 60° by detecting zero crossing of back-EMF on the floating coil of the motor , so that current is in phase with the back EMF.

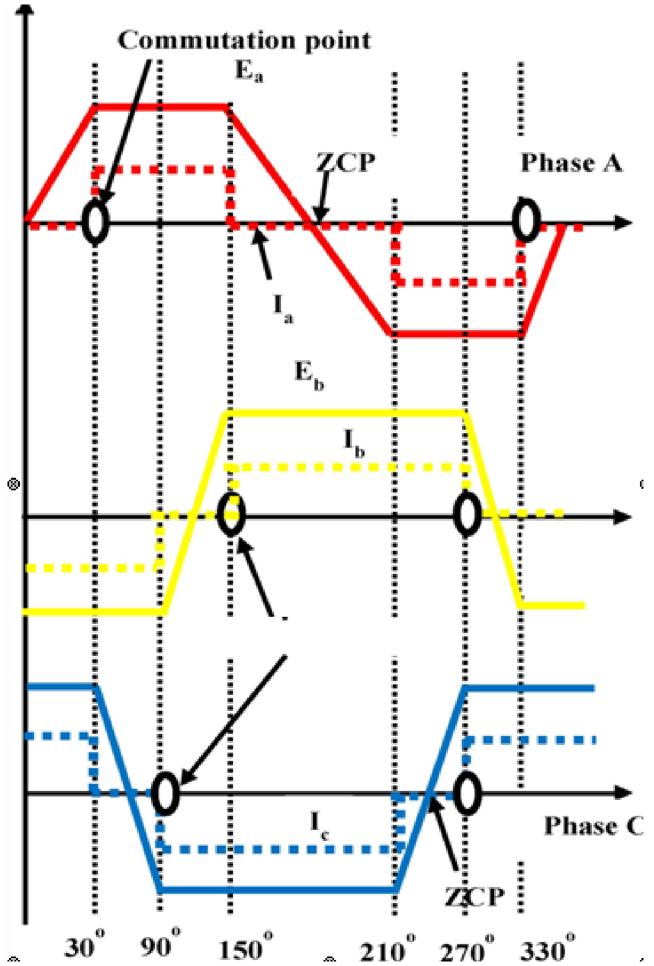

Figure 3: Zero Crossing Points of the Back-EMF and Phase Current Commutation Points

The current commutation purpose shown in fig.3 can be predicted by the ZCP of back-EMFs and a 30° phase shift, using a 6-step commutation arrangement through a 3-phase inverter for propulsive the BLDC motor. Zero crossing back-EMF voltage integration method. Another technique for speed sensing of BLDC motor is back-EMF voltage integration. It is based on simple principle that the integrated value (triangle area) of the non-fed phase's back-EMF voltage after the zero cross is approximately the same at all speeds (S 1 =high speed, S2= medium speed, S3= low speed of the sensorless BLDC motor), as shown in Fig. 4

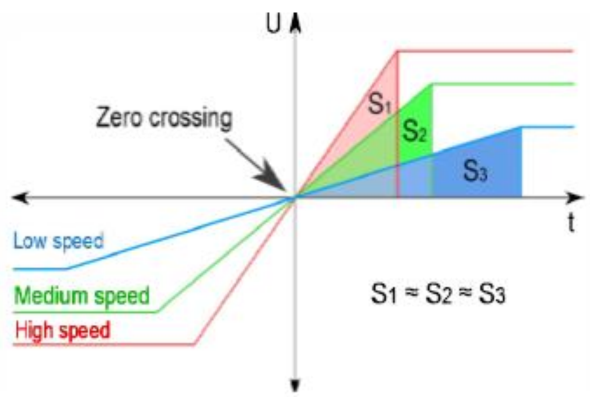

Figure 4: Back-EMF Integration Method

The integration starts when the non-fed phase's back EMF voltage crosses the zero value. Getting the exact time of zero-cross point is not very crucial as the back EMF voltage around the zero cross is relatively low, integration of these low voltage values around the zero cross has tiny result to the ultimate integrated point. Commutation is in behaved when the integrated value reaches a previous threshold value. If a flux weakening operation is required, current advance can be achieved by decreasing the threshold value. In comparison to the quality of sensorless technique supported back-EMF zero cross findings, the integration approach is less sensitive to switching noise and offset voltage problems (resistance precisions, noise, and so on).This brings a lot of precise control in low speeds of motor. On the opposite hand, integration approach is less effective in very high speeds. This work approach sensorless BLDC motor commutation with back-EMF zero crossing method. In order to work the BLDC motor, the control algorithm comprises of following states:

1. Alignment
2. Starting (back-EMF acquisition)
3. Running.

Figure 5 gives the flowchart of the steps involved in the speed sensing of the BLDC motor drive. It consists of alignment, sensorless starting and transition from the starting to the sensorless running. In this work a virtual hall signal is generated supports the detected back electromotive force voltage zero crossing points. At any instant, only one of the phases is open, and this open phase voltage is used to generate the position information of the rotor.

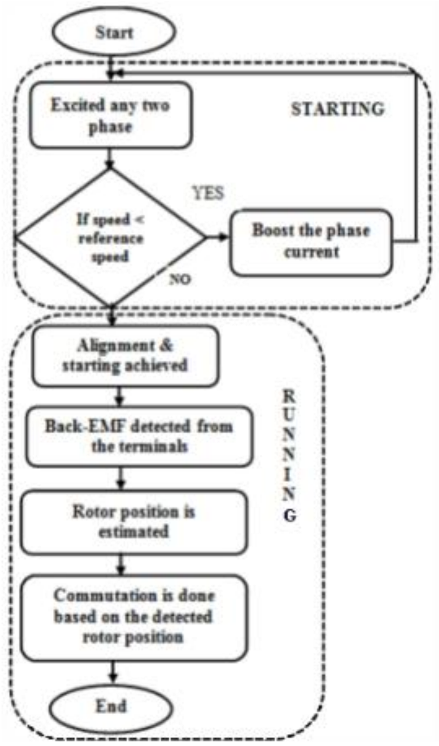

Figure 5: Flowchart of the Back-EMF Zero Crossing Speed Sensing

4. Simulation results and discussion

A 300 Volt, 3 HP, 1650 RPM trapezoidal back EMF based BLDC motor has been simulated in MATLAB/Simulink environment. PWM switch has been used here for the controlling of the electrical inverter output voltage. The zero crossing back EMF detection method, PI control strategy and model of a three-phase sensorless BLDC motor drive with a three-phase inverter bridge has been implemented in the simulation. Table I shows parameters of sensorless BLDC drive used in simulation.

Table 1: Parameters of sensorless BLDC drives

paramters	*unit*	*value*
Input voltage	Volts	220
Supply frequency	Hertz	50
Motor rating	HP	3
Speed	RPM	1650
DC Voltage	Volts	300
Pole pair	Pole	4
Torque	N*m	10
Moment of inertia	kg*m'	0.089
Friction	M*m*Sec	0.005
Resistance	Ohm	0. 2
Inductance	Henry	8.5e·3

The motor speed and rotor position are estimated from terminal voltages using a zero crossing back-EMF detection method. The commutations signals (equivalent to Hall Effect signals) are generated from the rotor position every 60 electrical degrees. The speed control loop uses a PI regulator to provide the force reference for this control block. The waveform of stator current of sensorless BLDC motor is shown in fig.6. Maximum amplitude of stator current of BLDC motor is 13 A for a steady state load torque of 10Nm. Corresponding torque constant has been used in mentioned proportion. The stator current waveform of phase-A to sensorless BLDC motor is shown in fig.6, and phase-B & Phase-C are same as a waveform of phase-A, but 120 electrical degree phase shift to each other. It can be observed from the current waveform that the frequency of the fundamental current is increases in the starting, which directly corresponds to the fact the speed is rising. And that may be verified from the speed response as shown in Fig. 8

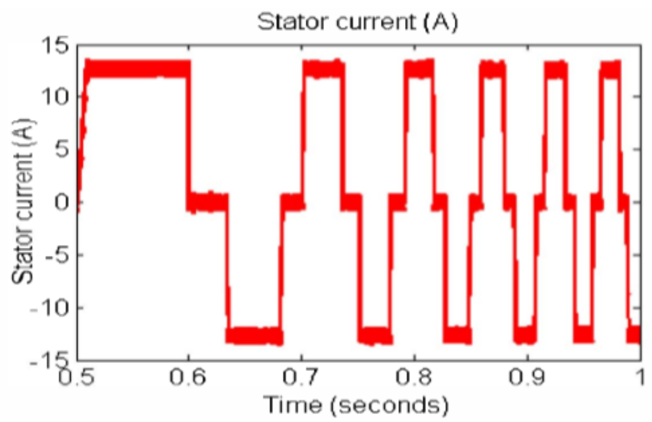

Figure 6: Stator Current of Sensorless BLDC Motor

Figure 7 shows the waveform of three-phase back EMFs (Ea, Eb, Ej) of sensorless BLDC motor, each phase is 120 degree phase shifted with respect to each other. The wave shape of back-EMFs is constant for every sixty degree interval and flat for every one hundred twenty degree. When voltage of any two phases is constant means these are connected to positive and negative DC link voltage respectively at that time interval the voltage transition take place in the floating phase. That floating terminal's voltage is the back EMF of that un-connected phase as there is no current in that phase. Floating terminal's voltage is being integrated over time when net integration becomes some threshold value the next phase is to be energized.

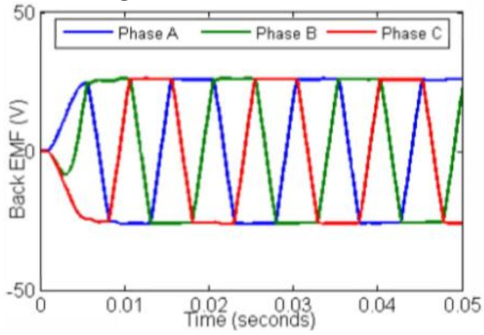

Figure 7: Back-EMFs of Sensorless BLDC Motor

Fig. 8 & 9 shows the rotor speed of sensorless BLDC motor at a rated torque and gain value of Kp = 1.223 & Ki = 42.354, and the speed reference is 100 and 1000 rpm respectively. By properly taking gain value of Kp & Ki, the speed response of BLDC motor is obtained. The gain value of Kp & Ki has been calculated by approximation of the transfer function of the system.

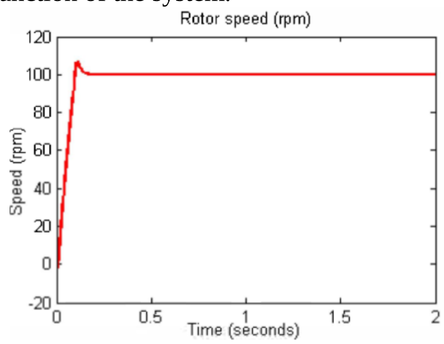

Figure 8: Reference Rotor Speed is 100 rpm of BLDC

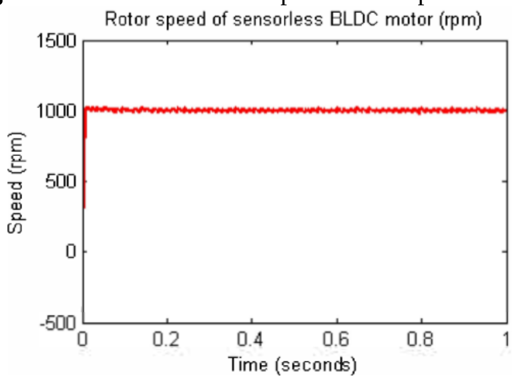

Figure 9: Reference Rotor Speed is 1000 rpm ofBLDC Motor

Figure 8 shows that there's no overshoot and undershoot within the speed response of the BLDC motor. Figure 10 shows torque vs. speed curve for sensorless BLDC motor. These curves necessary for choose associate degree in operation purpose for system. There are two operating regions:

1) The speed is in steady state (grey region).

2) The motor accelerates (yellow region) the coordinate axis represents the load force applied to the BLDC motor and also the coordinate axis represents the speed of the motor.

The limits of the operating region represent the maximum load torque that the drive can support to maintain the desired speed. So the grey region indicates the load torque for a constant speed and the yellow region indicates the load torque in acceleration.

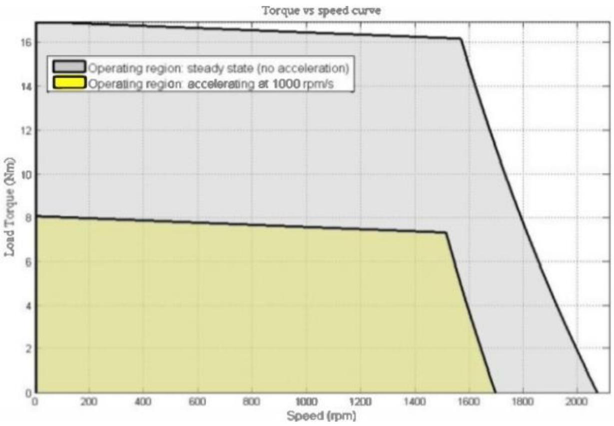

Figure 10: Torque vs Speed Curve of Sensorless BLDC Motor

One of the best advantage of the proposed method is method is that without being the information of the neutral point voltage it can provide the exact speed estimate. Another performance of this method is that it is not sensitive to switching noise, no filtering is required hence good motor performance at low and medium speed ranges. The subsiding time of back voltage zero crossing sensorless speed management technique may be as low as up to 0.05 sec. as shown in fig. 8. So in terms of the response proposed method is extremely fast.The maximum overshoot higher than the reference speed is nearly zero at a reference of one thousand revolutions per minute. And it's significantly low at reference speed of a hundred revolutions per minute as shown in fig. 7 and 8. The terminal voltage sensing methodology has been extensively used for low cost industrial applications such as fans, pumps and compressor drives where periodic speed variation is not required. For an example, for commercial vehicles application, a motor pump unit, is developed which employs back-EMF zero-crossing technique for control.

5. Conclusion

In this paper the working of sensorless BLDC motor explained. The zero crossing back-EMF detection method has been applied to sense the rotor position of sensorless BLDC motor has been presented. Position sensors may be completely taken away, thus reducing further cost and size of motor accumulation. The control system for three-phase star connected PWM inverter-fed sensorless BLDC motor is designed and simulated using MATLAB/ Simulink platform. Authors have used mechanical parameters of sensorless BLDC motor to calculate gain worth of PI controller. The zero crossing back-EMF with PWM closed loop control has been used to obtain fast operations and good transient and steady state speed response of sensorless BLDC motor. Achieved speed response of sensorless BLDC motor discovered to be in no time. Even the accuracy of the tactic is incredibly sensible as shown within the responses that no overshoot or underneath shoot is found within the speed response that is an indices for accuracy during transient. The limitation of zero crossing back EMF method is that it can only be used in medium to high speed applications of BLDC motor. At low speeds the transient accuracy of this technique isn't sensible.

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