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Rotor Position Sensorless Control of BLDC Motor based on Back Emf Detection Method

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Abstract

In this paper an improved back emf detection method is proposed. The motor neutral voltage is elemenated and the phase back emf zero crossing point can be directly extracted by detecting voltage difference between the phase terminal and the midpoint of the dc link. Here filtering circuit is not needed and the BLDC motor is provided with PWM control of 100% duty ratio which is presented in this paper. To perform the inverter commutation, there is a need of six commutation signals which is obtained by sensing only one of the three phase terminals that reduces the cost of the sensing circuit. The reduction of the imbalance in the six commutation signals which are caused by the asymmetrical behavior of the three phase windings in BLDC motor had been reduced in a varied speed range. It simplifies the starting procedure and achieves the motor performance over a wide speed range. This proposed method is analyzed through the simulation results using MATLAB Simulink.

Keywords*: BLDC motor, zero cross detector, sensorless, torque ripple.*

1. Introduction

Brushed DC motors depend on a mechanical system to transfer current, while AC and brushless DC motors use an electronic mechanism to control current. The brushed motors have a wound armature attached to the center with a permanent magnet bonded to a steel ring surrounding the rotor. As the brushes come into contact with the commutator the current passes through to the armature coils. Brushed motors are not only larger than their brushless counter parts; they also have a shorter service life. The brushes in the brushed motor are usually made of carbon or graphite compounds which wear during use [1-4]. These brushes will require maintenance and replacement over time, so the motor will need to be accessible to ensure continued service. As the brushes wear the not create dust but noise caused by the rubbing against the commutators [5-7].

AC induction motors and BLDC motors do not depend upon the mechanical system (brushes) to control current. The AC and BLDC motors pass current through the stator (electromagnet) which is connected to AC power directly or via a solid-state circuit. In AC induction motors the rotor turns in response to the "induction" of a rotating magnetic field within the stator, as the current passes[8],[9]. Rather than inducing the rotor in a brushless DC motor, permanent magnets are bonded directly to the rotor, as the current passes through the stator, the poles on the rotor rotate in relation to the electromagnetic poles created within the stator, creating motion. A BLDC motor is highly reliable since it does not have any brushes to wear out and replace.

Advances in the semiconductor and magnetic material industries made it possible to mass-produce low cost BLDC machines in large quantities. Ideally, these motors can be deployed in any of the areas where more traditional (brushed dc, synchronous, and induction) motors have been used. The BLDC motors are particularly gaining market share in robotics, consumer appliances, power tools, and manufacturing automation. A typical BLDC motor consists of a Permanent Magnet Synchronous machine (PMSM) fed with a Voltage Source Inverter (VSI). As the rotor magnets typically have high electrical resistance, the rotor losses are small contributing the higher efficiency. The motor case can be entirely enclosed and protected from dirt or other foreign matter. A BLDC motor, for the same mechanical work output, will usually be smaller than a brushed DC motor, and always smaller than an AC induction motor. The BLDC motor is smaller because its body has less heat to dissipate. From that

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standpoint, BLDC motors use fewer raw materials to build, and are better for the environment. Brushless motors have longer service lives and are cleaner and quieter because they do not have parts the rub or wear during use [10-11].

2. Sensorless Method With Back EMF Difference Estimation

The proposed scheme utilizes the Back EMF difference between two phases for BLDC sensorless drive instead of using the phase Back EMF. Figure 1 shows the equivalent circuit of an Y connection BLDC motor and the inverter topology.

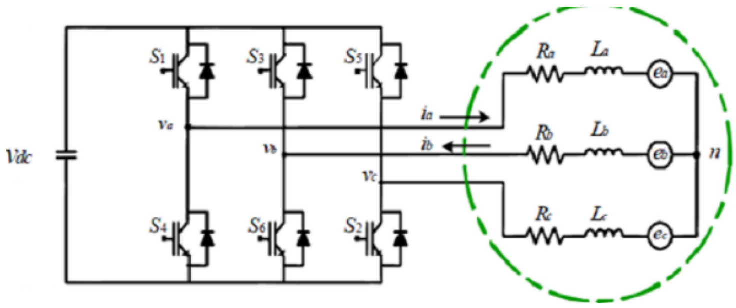

Figure 1. Circuit Diagram of BLDC Motor and Inverter

The zero-crossing points of the back EMF in each phase may be an attractive feature to use for sensing, because these points are independent of speed and occur at rotor positions where the phase winding is not excited. However, these points do not correspond to the commutation instants. Therefore, the signals must be phase shifted by 90° electrical before they can be used for commutation. The detection of the third harmonic component in back EMF, direct current control algorithm and phase locked loops have been proposed to overcome the phase-shifting problem.

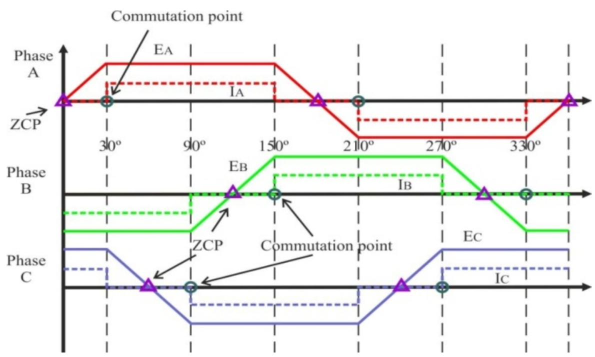

Figure 2. Phase Back Emf of BLDC Motor

The Figure 2 shows the Phase Back EMF of BLDC Motor. Table 1 displays the commutation sequence with back EMF difference estimation method which implies that positive sign indicates the current entering in to the stator winding and the negative sign indicates the current leaving from the stator winding. At any instant two stator windings are energized and one winding is floating. Equation (1), (2) & (3) implies the voltage equation of the stator windings.

$$V_{an} = R_a i_a + L_a \frac{di_a}{dt} + e_{an} \quad (1)$$

$$V_{bn} = R_b i_b + L_b \frac{di_b}{dt} + e_{bn} \quad (2)$$

$$V_{cn} = R_c i_c + L_c \frac{di_c}{dt} + e_{cn} \quad (3)$$

Table 1. Commutation Sequence with Back Emf Difference Estimation Method

e_{ac}	e_{ba}	e_{cb}	S_1	S_2	S_3	S_4	S_5	S_6
0	0	0	0	0	0	0	0	0
1	-1	1	1	0	0	0	0	1
1	-1	-1	1	1	0	0	0	0
1	1	-1	0	1	1	0	0	0
-1	1	-1	0	0	1	1	0	0
-1	1	1	0	0	0	1	1	0
-1	-1	1	0	0	0	0	1	1
0	0	0	0	0	0	0	0	0

To simplify the explanation of how to operate a three phase BLDC motor, a typical BLDC motor with only three coils is considered. When motor coils are correctly supplied, a magnetic field is created and the rotor moves. The most elementary commutation driving method used for BLDC motors is an on-off scheme: a coil is either conducting or not conducting. Only two windings are supplied at the same time and the third winding is floating. Connecting the coils to the power and neutral bus induces the current flow. This is referred to as trapezoidal commutation or block commutation. The strength of the magnetic field determines the force and speed of the motor. By varying the current flow through the coils, the speed and torque of the motor can be adjusted. The most common way to control the current flow is to control the average current flow through the coils. PWM (Pulse Width Modulation) is used to adjust the average voltage and thereby the average current, inducing the speed.

3. Align and Go Technique Used in BLDC Motor

In PM brushless DC machines, the magnitude of the back EMF is a function of the instantaneous rotor position and has trapezoidal variation with 120º flat span. However, in practice, it is difficult to measure the back EMF, because of the rapidly changing currents in machine windings and induced voltages due to phase switching. Figure 3 shows the switching states of inverter and initial rotor position of BLDC Motor. The back EMF is not sufficient enough at starting until the rotor attains some speed. Therefore, it is a usual practice to make the initial acceleration under open-loop control using a ramped frequency signal so that the back-EMF is measurable for the controller to lock in. One of the popular starting methods is “align and go”, in which the rotor is aligned to the specified position by energizing any two phases of the stator and then the rotor is accelerated to the desired speed according to the given commutation sequences. The “align and go” method suffers demagnetization of permanent magnets due to large instantaneous peak currents at starting.

3.1. Allingment of Rotor Position

In the BLDC motor, only two phases of the three-phase stator windings are excited at any time by utilizing alternative six excited voltage vectors $V_1 \sim V_6$, which are sketched in Fig. 3(b). That is why the current can flow into only two of the three windings and commutated every 60° of electrical angle. At standstill, the initial rotor position is aligned in to one of six positions that are determined by the six excited voltage vectors to energize two phases of the BLDC motor.

After aligning the rotor position, the start-up procedure is considered for accelerating the BLDC motor from standstill up to a specific speed, as the sensorless scheme is not self-starting, the motor should be started and can be brought to a certain speed at which the zero-crossing point of the back-EMF can be detected. As the frequency is gradually increased, the rotor speed also increases. The magnitude of a reference voltage is adjusted as proportional to the rotor speed. A phase angle can be obtained from integrating the rotor speed and the pulse width of the gating signals is modulated with the reference voltage magnitude. The six PWM signals with 60° phase displacement are generated corresponding to the phase angle without any rotor position information. When the rotor speed reaches at 2500rpm, the back-EMF can be sensed to provide the rotor position information and the system is switched to the sensorless control.

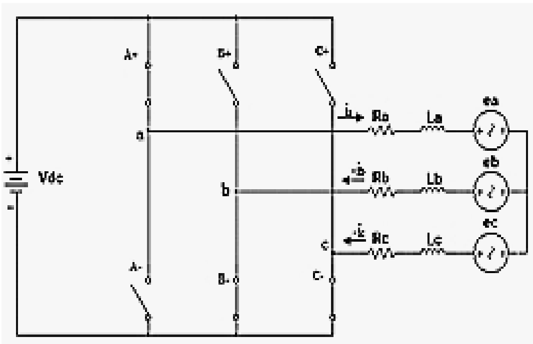

Figure 3(a). Switching State of The Inverter

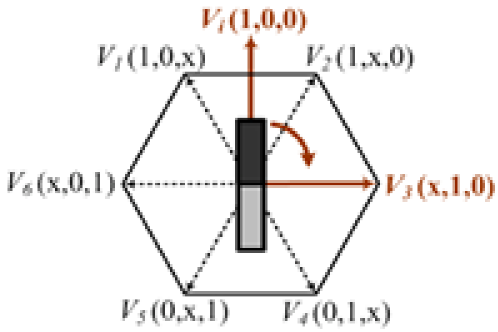

Figure 3(b). Initial Rotor Position

As it is well known, the deviation of these voltage vectors is every 60° of electrical angle. The stator flux is not orthogonal to the rotor flux generated by the permanent-magnet at the beginning of the start-up point if the conventional alignment method is used. Thus, the initial motor torque can't obtain the maximum value at this time. Also, the stator winding incurs a high uncontrollable current by means of the fixed dc power supply and motor parameters. This might damage the stator winding of the motor if the active time for aligning a rotor position is too long. The conventional start-up method reveals some unexpected drawbacks that might degrade the performance of the BLDC motor. To overcome these restrictions, a simple start-up method not only to achieve the maximum starting motor torque but also to control the stator current is proposed. The principle of this technique can be remarkable as explained in Figure 3. The current path and position of the initial voltage vector V_i are shown in Figure 3 respectively. In Figure 4 flow chart for proposed start-up method sensorless operation have been explained.

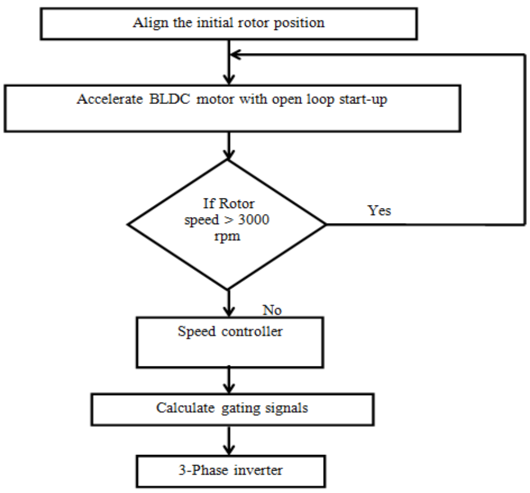

Figure 4. Flow Chart for Proposed Start-Up Method

Unlike the case in the conventional method where only two stator windings are excited, all three stator windings are energized in the case of the proposed start-up scheme by using a specific initial voltage vector V_i (1,0,0). As the rotor is located between Voltage vector $V_1$and V_2, the voltage vector $V_3$is orthogonal to V_i. It is chosen as the next applied voltage vector in order to achieve maximum starting motor torque at start-up. This method can prevent a surge of current that may damage the motor as in the case of utilizing the conventional method, and also it is robust with motor parameter changes. The motor may rotate reversely during alignment according to the rotor position before alignment.

4. Simulation Results

The closed loop controller for a three phase brushless DC motor is modeled using MATLAB/Simulink is shown in Figure 5. Permanent Magnet Synchronous motor with trapezoidal back EMF is modeled as a Brushless DC Motor. The controller receives the actual speed signals as its input, converts it in to appropriate voltage signals. The gate signals are generated by comparing the actual speed with the reference speed. Thus a closed loop speed control is achieved with the help of PI control, present in the controller block. The three phase stator back EMF signals are input of the Zero Crossing Detector. The output of the Zero Crossing Detector is given to the PI controller, which have the inputs from the Zero Crossing Detector and actual speed of the BLDC motor. The MATLAB simulation diagram of overall are obtained for proposed concepts.

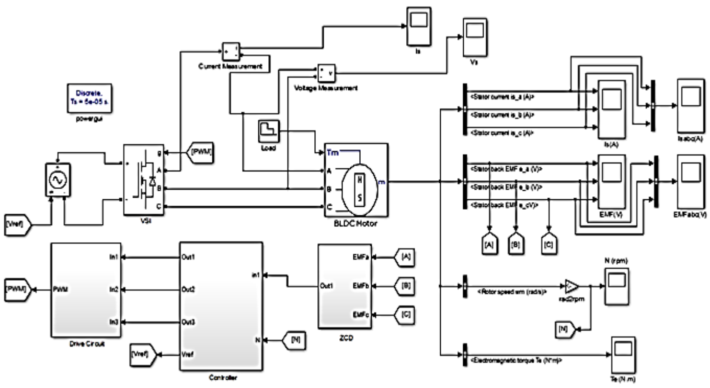

Figure 5. Simulink Model of proposed Sensorless BLDC Drive

After aligning the rotor position to a known initial condition, the open loop start- up method is implemented to run the motor to the rated speed. By attaining the specific rated speed the BLDC motor switches to the Sensorless control where the back emf is detected. Figure 6 shows the Speed Response Curve of the BLDC Motor.

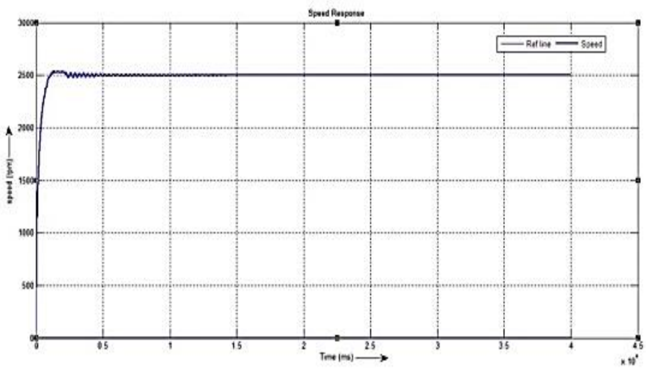

Figure 6. speed response curve

5. Conclusion

In this paper, the back emf zero crossing point can be directly extracted by sensing the difference between them with proper PWM strategy. To obtain the six commutation signals, there is no need of motor neutral voltage and no filtering circuit. Pwm duty ratio can reach maximum as 100% with no extra power supplies for sensing circuit. Based on the proposed method there is possible to implement in industrial application with low cost.Only three motor terminal voltages want to be measured thus eradicating the need for motor neutral voltage. Running the machine in sensorless mode is then projected, in this paper, making use of the innovative zero-crossing detection algorithm. The applications of brushless DC (BLDC) motors and drives have grown significantly in recent years in the appliance industry and the automotive industry. Sensorless BLDC drive is very preferable for compact, low cost, low maintenance, and high reliability system. The conventional sensorless method based on neutral motor point has limited its application since it has relative speed range, suffering from high common Mode voltage noise and high frequency switching noise.

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