Sensorless Speed Control of Brushless DC Motor by MATLAB

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Abstract - *Sensorless BLDC motors are widely used in household appliances, vehicles, aircraft, consumer electronics, medical devices, automated industrial equipment, and instrumentation. Because of their design, these motors are employed in a variety of industrial areas. Sensorless BLDC motors are popular due to their increased efficiency, reliability, power, acoustic noise, smaller size, lighter weight, greater dynamic response, enhanced speed vs load torque, wider speed range, and extended life. It offers a number of advantages, including the elimination of the motor's neutral voltage, a predetermined phase shift network, a low starting speed, and a low cost. This study use MATLAB SIMULINK to give a straightforward and dependable method for detecting reverse emf zero-crossings for sensorless operation. An abstract summarizes, in one paragraph (usually), the major aspects of the entire paper in the following prescribed sequence. The zero crossings of the reverse emf are projected obliquely from the terminal voltages that are monitored in relation to the dc negative pole, and thus approach never involves any integration. Furthermore, when using line voltages, neutral potential and common mode noise are no longer needed. Through simulation, the efficiency of the control strategy based on zero-crossing detection from terminal voltage differences was studied.*

Key Words: **Sensorless operation, Zero Crossing Detector, Reverse EMF, Speed control method**, **Brushless DC Motor**

1. INTRODUCTION

It has several advantages, including the elimination of motor neutral voltage, a set phase shift circuit, a low beginning speed, and inexpensive cost. Instead of brushes, this BLDC motor is commutated electronically using power switches. The voltage surges are caused by the remaining current that is restricted when power switches produce armature current. In the condition of sensorless BLDC motor driving, commutation torque ripple has already been reduced. Analysis, design, and implementation of a high-performance sensorless method for BLDC motors are completed. BLDC motors also referred to as Permanent Magnet Direct Current Synchronous motors are still one of the motor types that have grown in popularity in recent years, owing to their superior features and performance. The BLDC motor, which lacks position and speed sensors, has received a lot of interest. Square wave control and sinusoidal current control are the two most common BLDC motor control techniques.

To calculate the zero-crossing time of the reverse emf, multiply the terminal voltage of the floating winding by the motor's neutral point. Integration begins when the reverse emf crosses zero and ends when the given threshold value is reached, resulting in immediate commutation. Frequency-independent phase shifter for sensorless BLDC motor control, capable of shifting the zero-crossing point of the input signal with a defined phase delay. Jung and Ha have developed an extended Kalman filter estimator for a brushless dc motor to estimate speed and rotor position. The rotor position is obtained indirectly by sensing the reverse emf from one among the three motor terminal voltages of a three-phase motor. The necessity to establish the right values for the covariance matrix parameters, which represent the errors in modeling and measurements, is a barrier to using the extended Kalman filter technique for rotor position estimation. Sensorless control techniques based on the reverse emf's Zero Cross Point (ZCP) have been widely employed in low-cost applications. The zero-crossing detector (ZCD) detects the ZCP of the reverse emf, and the pulse is created by moving 30° from the ZCP. When the BLDC motor is at rest or at zero speed, the reverse emf cannot be calculated using the ZCP technique.

As a result, a unique control is required for the smooth and dependable sensorless control operation of BLDC motors. Furthermore, the intricacies of sensorless motor starting were not discussed. However, the direct commutation instant detection approach suggested lacks the flexibility to advance the commutation instant, which may be implemented utilizing reverse emf zero-crossing detection techniques. By measuring the motor terminal voltages, we devised and constructed an integrated circuit enabling the sensorless operation of a BLDC motor. Frequency independent phase shifter for sensorless BLDC motor control, capable of shifting the zero-crossing point of the input signal with a defined phase delay. For speed and rotor position estimation, an extended Kalman filter estimator for a brushless dc motor has been created. commutation instant boosts torque generation, especially in high-speed BLDC motor operating. The technique of zero-crossing detection was utilized to start the BLDC machine successfully in sensorless mode. The concept is developed in this paper to present a simple running mode algorithm. In this paper, we present a simple and reliable approach for detecting reverse emf zero-crossings in sensorless operation using MATLAB/SIMULINK, as well as hardware implementation using DSP. DSP is required in hardware circuits to generate

the right moment for pulse production. The zero crossings of the reverse emf are approximated indirectly from the terminal voltages measured concerning the dc negative terminal, and no integration is required. Moreover, when line voltages are employed, neutral potential and common mode noise are no longer required. Along with this BLDC motor model, the dynamic behavior of the motor, including no-load, load, and load transients, has been investigated. The efficiency of the sensorless control detection and localization of zero-crossing via terminal voltage differences has been studied using simulation.

1.1 Period of Normal Conduction

The terminal voltage waveform is substantially identical to the reverse-EMF waveform. The terminal voltages, rather than the reverse-EMFs, can be employed to detect the commutation points of the BLDC motor in the proposed sensorless control. As the rotor speed increases, so does the phase lag's percentage contribution to the entire period. The latency will disrupt the current alignment with the reverse-EMF, causing major issues with high-speed computation. The phase lag in commutation can induce substantial pulsing torques in such drives, which can cause rotor speed oscillations and excessive copper losses. The cut-off frequency of the LPF is established at 2.5 kHz in this research by taking into account both the phase lag and the harmonic dispersion of the reverse-EMF. The hysteresis comparator is used to correct for the phase lag of the reverse-EMFs caused by the LPF to establish the optimal inverter commutation sequence based on rotor position. Furthermore, high-frequency ripples in the terminal voltages can avoid numerous output transitions.

1.2 Period of commutation

The traditional start-up procedure shows certain unforeseen limitations that may affect the BLDC motor's performance. To circumvent these constraints, a simple start-up approach is given that not only achieves the highest starting motor torque but also controls the stator current. Unlike the usual technique, which only excites two stator windings, the suggested start-up scheme excites all trio stator windings by employing a specified starting voltage vector. The voltage vector V3 is orthogonal to Vi and is positioned between voltage vectors V1 and V2. It is selected as the next applied voltage vector to maximize starting motor torque during startup. It should be noticed that by varying the pulse width of the switching devices, the amplitude of the stator current for alignment of the rotor position may be simply modified. Shows the three-phase current responses of the BLDC motor when the switch is turned on and the pulse widths of the two switches B- and C- are modulated at the same time. PWM signal duty cycles when the switching period Ts is 100 μ seconds. The size of the stator current can be readily controlled by modifying the duty cycle, which can be determined by taking the initial torque required at

alignment into account. According to the rotor position before alignment, the motor may revolve in reverse during alignment. However, because the maximum reverse rotation angle is just 90 mechanical degrees, it does not affect fuel pump operation. After the rotor position has been aligned, the start-up method is considered for accelerating the BLDC motor from a standstill to a certain speed, 3000rpm, which is a minimum speed for the automobile fuel pump application. Because the sensorless scheme does not start on its own, the motor must be started and brought to a particular speed where the zero-crossing position of the reverse-EMF may be detected.

2. Objective

The paper is to develop a sensorless brushless DC (BLDC) motor control system. Sensorless techniques based on a hysteresis comparison and a possible start-up method with a high beginning torque are proposed. The hysteresis comparator compensates for the phase delay of the reverse EMFs caused by a low-pass filter (LPF) while also preventing numerous output transitions caused by noise or fluctuation in the terminal voltages. The rotor position is maintained at rest for the greatest starting torque without the need for an extra sensor or any motor parameter information.

3. Proposed System

The proposed system consists of the voltage source inverter receiving the direct current voltage. The voltage source inverter is a three-phase voltage source inverter with a 120 degree mode of operation. It comprises three legs, each of which contains two MOSFETs. In all, six MOSFETs are employed in the voltage source inverter. MOSFETs are Metal Oxide Semiconductor Field Effect Transistors. It is the voltage control device's switching device. If we adjust the Vgs (Gate Source Voltage), we get a sinusoidal pulse with modulation signals. We can regulate the Vds (Drain Source Voltage), which is the output voltage. Induced via changing modulation. It is defined as the ratio of the reference signal voltage to the carried signal voltage. In my application, the reference signal is a three-phase sinusoidal signal with a displacement of 120 degree and the carrier signal is a triangular signal. The inverter will supply power to the BLDC motor by adjusting the modulation.
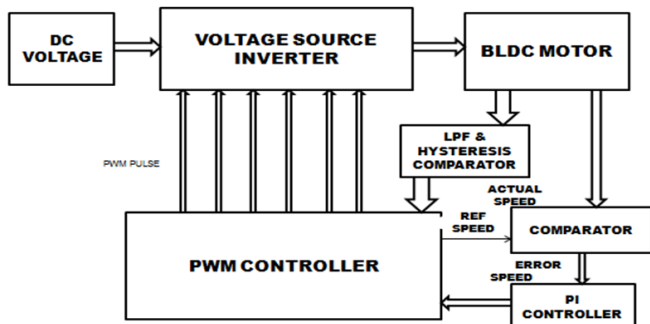
Fig -1: Block diagram of the sensorless brushless dc motor

As a result of Faraday's law, reverse emf will be induced in the stator winding. As a result, this return emf will be in the opposite direction as the source voltage. So, if we can detect this reverse emf, we can feed it into the hysteresis comparator. However, the reverse emf form is trapezoidal because of the motor's salient pole rotor. We can't readily distinguish "0" and "1" in this trapezoidal reverse emf. As a result, the reverse emf provided to the LPF will be converted from trapezoidal to sinusoidal. This is passed on to the hysteresis comparator. The hysteresis comparator is the difference between the upper and lower values. It is an alternating current motor with a stator similar to a three-phase induction motor. The rotor is comprised of a permanent magnet with four poles (projected Pole) It lacks rotor winding, mechanical commutator, and brushes, yet its speed-torque constant is similar to that of a DC shunt motor. This is referred to as a BLDC motor. To provide power to the motor stator winding, an electronic commutator (voltage source) inverter is employed.

4. SENSORLESS BLDC MOTOR SIMULATION

The voltage source inverter receives the input DC voltage and converts it to AC voltage. To generate the reverse emf, a sinusoidal V/F control PWM approach is applied to the BLDC motor, causing the motor to start as an induction motor. This emf is detected using a voltage sensor, and the voltage is passed to the hysteresis comparator. The hysteresis comparator determines which winding should be energized first; this comparator compares the EMFs of two phases and generates PWM pulses; these pulses are fed to the inverter, and the inverter supplies voltage to the motor; however, the voltage sensor produces trapezoidal reverse emf, and when this trapezoidal reverse emf is fed to the low pass filter, it produces sinusoidal reverse emf. The hysteresis current controller compares the actual motor current and references current waveforms; the difference is output as PWM pulses by the current controller. The voltage source inverter receives this pulse.
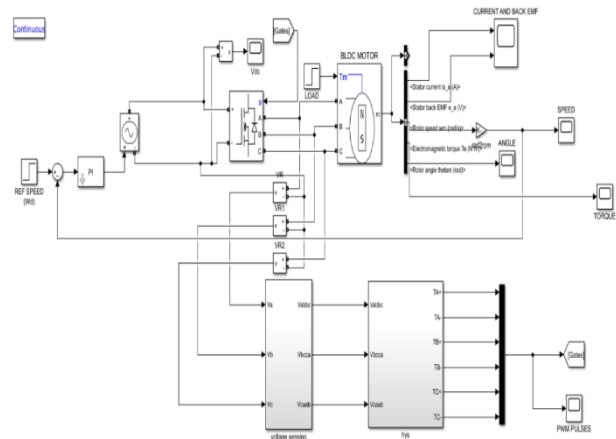

Fig -2: Simulation of Sensorless BLDC Motor

Table -1: Sample Table format

Parameters	
Motor rating	1.5Hp
Rated torque	2.5N-m
Type of motor	BLDC Motor
Supply voltage	420V
Rated speed	4630rpm
Rated current	5A

The inverter will supply voltage to the motor, reducing stator current. Sensorless control is achieved by the use of a hysteresis comparator approach, which includes LPFs for suppressing high switching frequency ripples, hysteresis comparators for creating three-phase commutation signals, and a gating signals generator for generating six Pulses. When detecting the three-phase terminal voltages, each one is fed into an LPF to reduce the high switching frequency fluctuation or noise. Because the BLDC motor only has two phases activated at any given moment, the back-EMF may be determined from its terminal voltage in the duration of an open phase (60°). The only variation between the reverse-EMF and its terminal voltage throughout the two-phase conduction period (120°) is a stator impedance voltage drop, which may be negligible when compared to the DC voltage source. The sensorless method inverter will supply voltage to the motor, reducing stator current. Sensorless control is achieved by the use of a hysteresis comparator approach, which includes LPFs for suppressing high switching frequency ripples, hysteresis comparators for creating three-phase commutation signals, and a gating signals generator for generating six Pulses. When detecting the three-phase terminal voltages, each one is fed into an LPF to reduce the high switching frequency fluctuation or noise. Because the BLDC motor only has two phases activated at any given moment, the back-EMF may be determined from its terminal

voltage in the duration of an open phase (60°). The only variation between the reverse-EMF and its terminal voltage throughout the two-phase conduction period (120°) is a stator impedance voltage drop, which may be negligible when compared to the DC voltage source. The sensorless method is simulated in MATLAB/SIMULINK in fig. 2.

5. Results and Discussion

In the proposed system, the simulated graph of BLDC current and Back Emf shows that initially the motor start from negative value of -2A and after steadily attains its peak current of 2.5A for the time of 0.005s. The total amplitude of the current is 5A and its time period for 1 cycle is 0.02 seconds. In the BLDC Back EMF, amplitude of the Back EMF is 100v for the time period of 0.005s and 0.02s for full cycle has shown in the fig.3.
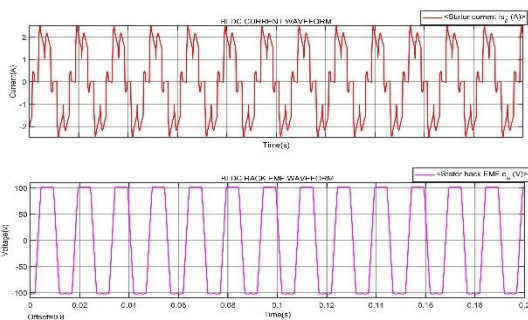
Fig -3: BLDC Current and reverse EMF

In the motor speed waveform, the initial speed of BLDC motor is 500 rpm at time t = 0 and the final speed is rated to 2000 rpm at time t=4.25s has shown in fig.4.
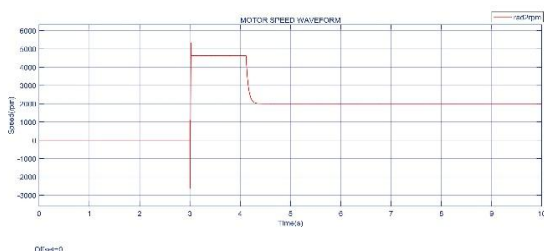
Fig -4: Motor Speed

In the torque waveform, the initial minimum value is -38.7205 N-m and the maximum value is 40.27 N-m. The constant peak value of torque is 2.5 N-m and minimum constant value is 1.32 N-m has shown in fig. 5.
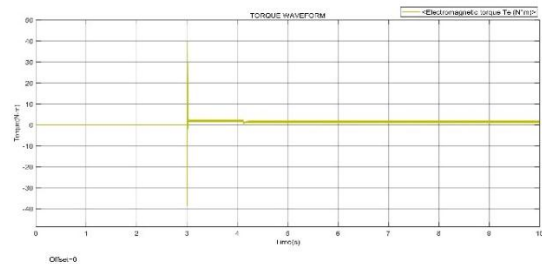
Fig -2 Torque Waveform

From the rotor angle waveform, the rotor angle starts rising from the time of 3s and it gets reached upto 1777.75 at the time of 10s has shown in fig.8.
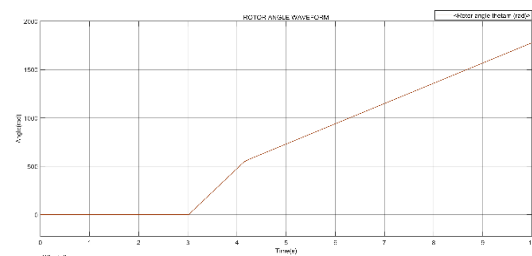
Fig -5: Rotor Angle Waveform

From the PWM pulse generator, the gate pulse if value 1 starts generated after the time period of 3s in fig.6.
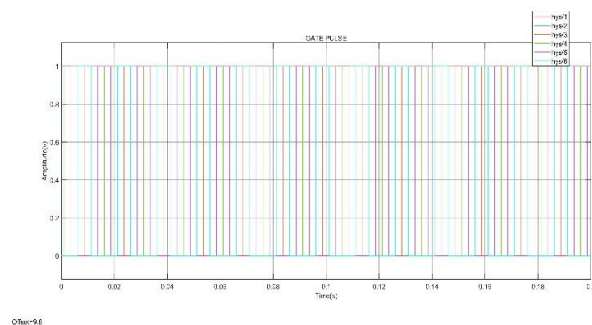
Fig -6: Gate Pulse Waveform

The dc voltage is 283.329v at initially and it gets peak value of 500v. A constant voltage is 214.5 after the time period of 4..3s has shown in fig.7.
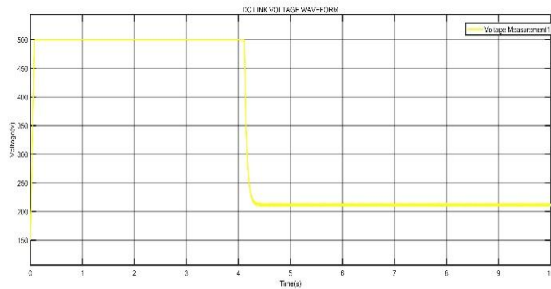
Fig -7: DC Link Voltage

The voltage is compared by hysteresis comparator block and their waveforms are shown in fig. 8 and 9.
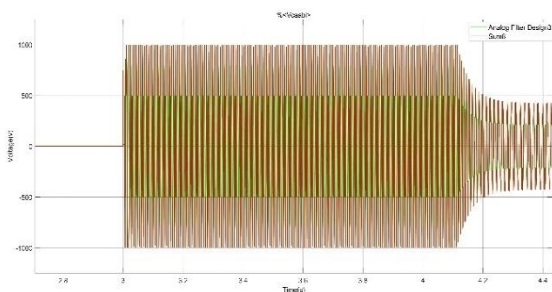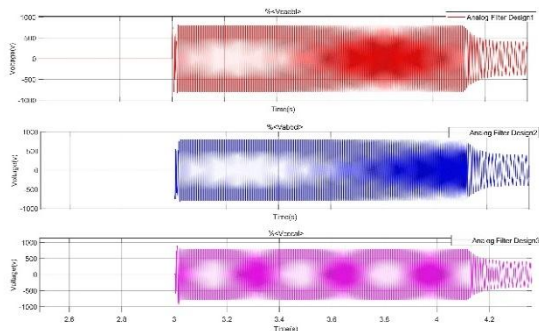

Fig -8: Hysteresis Comparator 1

Fig -9: Hysteresis Comparator 2

5. Conclusion

This paper proposes a sensorless control based on a terminal voltage hysteresis comparator and a potential start-up approach with a high starting torque. By changing both the resistance ratio and the output voltage level of the hysteresis comparator, the maximum commutation phase lag is lowered from -13° to 3°. The commutation signal is almost parallel to the back-EMF. High-frequency fluctuations in the terminal voltage can prevent numerous output transitions at a hysteresis comparator. The stator current ripples were decreased by using the hysteresis current controller. The PI controller is used to accomplish closed-loop speed control.

REFERENCES

[1] Bharathi Sankar A and Dr.Seyezhai R (2014), "Sensorless Control of BLDC Motor using Back EMF-based Detection Method"., IJEE, Vol.-No.6, Issue No.02.

[2] Carlson R and Milchel L. M (1992), "Analysis of torque ripple due to phase commutation in brushless dc machines", IEEE Trans. Ind. Appl., Vol. 28, No. 3, pp. 632–638

[3] Kim D.K and Lee K.W (2006), "Commutation torque ripple reduction in a position sensorless brushless dc motor drive", IEEE Trans. Power Electron., Vol. 21, No. 6, pp. 1762–1768.

[4] Liu Y and Howe D (2007), "Commutation torque ripple minimization in direct-torque-controlled PM brushless dc drives", IEEE Trans. Ind. Electron., Vol. 43, No. 4, pp. 1012–1021.

[5] Merin John and Vinu Thomas (2014), "Position Sensorless Control of BLDC motor based on Back EMF difference estimation method", IEEE.

[6] Saranya R, Saravan Kumar S. and Baskaran. R (2014), "Sensorless Operation Brushless DC Motor Drive using Back EMF Technique", Vol -No-3, Issue No -4 PP; 255-257., IJER.

[7] Son Y.C, Jang K.Y. and Suh B.S (2008), "Integrated MOSFET inverter module of low-power drive system", IEEE Trans. Ind. Appl., Vol. 44, No. 3, pp. 878–886

[8] Tae-Won Chun, Quang-Vinth and Hong-Hee Lee (2014), "Sensorless Control of BLDC Motor Drive for an Automotive Fuel Pump Using a Hysteresis Comparator", IEEE, Vol-29, No.3.

[9] Xia C and Li L (2009), "A control strategy for four-switch three-phase brushless dc motor using single current sensor", IEEE Trans. Ind. Electron., Vol. 56, No. 6, pp. 2058–2066.

[10] Zhang L and Qu W.L (2008), "A new torque control method for torque ripple minimization of BLDC motor with un-ideal back EMF", IEEE Trans. Power Electron., Vol. 23, No. 2, pp. 950–958.