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A Review Paper on Sensor-less BLDC Motor Control

[1] Shilpa S, [2] Venkatesh S
[1]Student, [2]Associate Professor
[1]Department of Electronics and Instrumentation,
[1]RV College of Engineering, Bengaluru, India

Abstract: Sensorless control has emerged as a promising technique for Brushless DC (BLDC) motors, enabling the elimination of position sensors. This paper highlights the significance of sensorless control by leveraging advanced algorithms for precise rotor position estimation through analysis of back EMF signals. This enables accurate rotor commutation and efficient BLDCM control. Zero-crossing detection is a vital component in BLDC motor control, ensuring precise commutation timing for efficient and optimal motor performance, enhancing overall motor operation and functionality. Sensorless control algorithms, combined with advanced motor control techniques, enable accurate and swift responses to control commands, resulting in precise and effective BLDC motor control.

IndexTerms **- Brushless DC Motor, Back EMF, Zero Crossing Detection.**

INTRODUCTION

Driving a brushless motor requires control electronics for precise commutation. However, this is possible only if the control electronics "know" the exact position of the rotor at all times. Traditionally, this information is provided by sensors, e.g. Hall sensors, installed inside the motor. But it can be done differently. Sensorless control methods use current and voltage information from the motor to determine the rotor position. The motor speed can then be derived from changes in the rotor position, and this information can be used for speed control. More advanced sensorless control methods can even control the current (torque) and the rotor position. Implementation of sensor-less BLDCM control has a range of benefits, such as lower cost and space savings, because cables, connectors, and sensitive electronic circuits become unnecessary.

Sensorless BLDC control offers both economic and technical benefits.

- Cost Reduction: Sensorless BLDC control eliminates the need for external position sensors, such as Hall effect sensors, which helps reduce the overall system cost. By removing the cost of sensors and associated wiring, manufacturing and maintenance expenses can be significantly reduced.
- Increased Reliability: With sensorless control, there are no physical sensors that can wear out or malfunction over time. This enhances the overall reliability of the motor system, reducing the need for sensor replacements or repairs.
- Simplified Design: Sensorless control simplifies the motor system design by eliminating the need for sensor placement, wiring, and signal conditioning circuitry. This results in a more streamlined and compact system design, making it easier to integrate into various applications.
- Improved Efficiency: Sensorless control algorithms can optimize motor performance and efficiency by precisely estimating the rotor position. This allows for better control of the motor's speed, torque, and direction, leading to improved energy efficiency and reduced power consumption.
- Enhanced Durability: Sensorless control eliminates the wear and tear associated with physical sensors, making the motor system more durable and robust. The absence of sensors also reduces the risk of sensor failures due to environmental factors like dust, moisture, vibrations and magnetic field.
- Greater Flexibility: Sensorless control enables the motor to operate in a wider range of conditions and environments. The estimation algorithms can adapt to varying motor parameters and load conditions, providing flexibility in different applications and operating scenarios.
- Higher Performance: Sensorless control algorithms, coupled with advanced motor control techniques, can achieve precise and rapid responses to control commands. This allows for improved motor performance, including faster acceleration, smoother operation, and better dynamic response.

BACKGROUND

Motors can be classified based on their power type (AC or DC) and the mechanism they employ to generate rotation. Brushless DC motors in Figure 3.1, as their name suggests, operate without the use of brushes. Unlike brushed motors, where current is delivered to the rotor coils through brushes and a commutator, brushless motors have a different configuration.

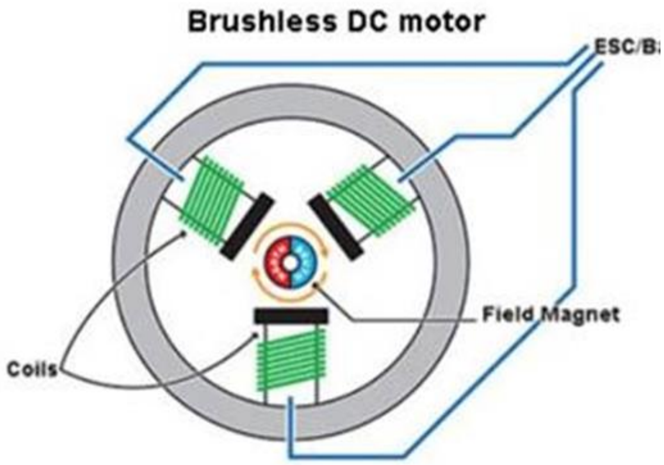

Figure 0.1 BLDC Motor
(Source: Google Images)

In brushless motors, the rotor consists of permanent magnets, while the coils are fixed in place on the stator. This means that the coils remain stationary, eliminating the need for brushes and a commutator since there is no requirement to transfer current to rotating. coils.

1. Two types of BLDC motor control:

i. Sensored BLDC motor control: Sensored brushless motors are a type of brushless motors that incorporate positional sensors within them. These sensors provide feedback on the rotor's position to the controller, enabling precise synchronization of the drive pattern with the rotor position. Various Sensored motors may utilize different sensor configurations, typically positioned at 60-degree or 120-degree intervals. It is essential to consider these sensor arrangements when setting up a controller. The primary advantage of Sensored motors is their ability to create a closed-loop system, allowing the controller to accurately determine the rotor position and synchronize the drive pattern accordingly. However, one limitation of these motors is their dependence on the sensors for proper functionality. In environments with high levels of dust, vibration, or moisture, the performance of the sensors may be compromised, potentially leading to motor failure, depending on the motor's build quality. In summary, Sensored brushless motors offer the advantage of precise rotor position detection and synchronization. Nevertheless, they are susceptible to sensor-related issues in challenging operating conditions, emphasizing the importance of considering environmental factors and the motor's robustness.

ii. Sensorless BLDC control refers to a method of controlling a BLDC motor without the use of external position sensors such as Hall effect sensors or encoders. Traditional BLDC motor control typically relies on position sensors to provide feedback about the rotor position, which is essential for accurate and efficient motor control. However, sensorless control techniques eliminate the need for these sensors, reducing system complexity, cost, and potential points of failure. In sensorless BLDC control, the motor's rotor position is estimated using various techniques and algorithms based on the back electromotive force and the motor's electrical characteristics. These algorithms typically use the measurements of motor phase currents and voltages to estimate the rotor position and speed.

Back EMF

The structure of a BLDC motor involves a rotor comprising permanent magnets, while the stator consists of steel laminations with windings placed in axial slots. These windings are arranged in a trapezoidal configuration, generating a corresponding trapezoidal back EMF as indicated in the fig. 4.1.

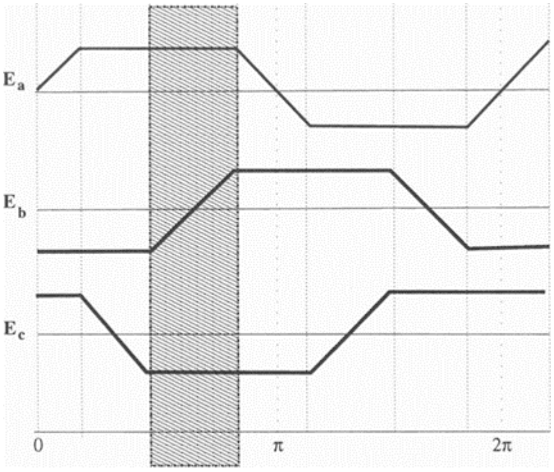

Figure 0.2 Trapezoidal waveform of Back EMF
(Source: Google Images)

Trapezoidal commutation, also known as six-step commutation, is widely employed in high-speed applications and scenarios where higher starting torque is desired. It is a cost-effective choice compared to other commutation methods due to its simplicity in terms of control algorithms. Trapezoidal commutation can also be performed based on the motor's back EMF, which allows the elimination of Hall sensors. In a typical three-phase BLDC motor with trapezoidal current, one winding is positive, one winding is negative, and one is open. The open winding can be used to detect the zero-crossing point of the back EMF, which corresponds to what would be a signal change in a Hall sensor. However, the back EMF is proportional to motor speed. This means that at very slow speeds especially at start up, the back EMF will be very low, so the motor must be started in open-loop mode until sufficient speed and back EMF are generated. At that point, the controller can be switched to back EMF sensing for commutation.

Zero Crossing Detection

Zero-crossing detection is a fundamental technique utilized in BLDC motor control to precisely determine the timing of commutation events. It involves identifying the points at which the back EMF waveform intersects the zero-voltage level. This information is critical for accurately transitioning between motor phases and ensuring smooth and efficient motor operation. Zero-crossing detection can be achieved through both hardware and software implementations. In hardware, a comparator circuit is employed to compare the incoming signal with zero, generating a square wave as a response. This hardware-based approach provides real-time zero-crossing information. In software implementation, the input signal is acquired and sampled appropriately. Through signal processing and logic operations, the software algorithm identifies the zero-crossing points, generating a square wave output as shown in fig. 4.2. This software-based approach relies on accurate signal acquisition and appropriate sampling techniques to extract the zero-crossing information.

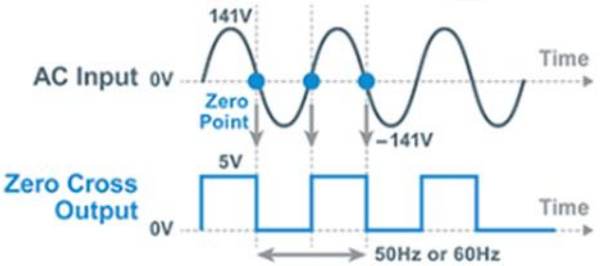

Figure 0.3 Zero Crossing Detection Waveform
(Source: Google *Images)*

Both hardware and software-based zero-crossing detection techniques have their advantages and considerations. Hardware implementation provides real-time response and can be simpler to integrate into motor control systems. Software implementation, on the other hand, offers flexibility and adaptability, allowing for advanced signal processing and algorithmic enhancements.

Overall, zero-crossing detection is a vital component in BLDC motor control, enabling precise commutation timing and ensuring the efficient performance of the motor. The choice between hardware and software implementation depends on the specific application requirements, system constraints, and desired functionality.

DESIGN METHODOLOGIES

A study made on sensorless BLDC [2] presented the limitation of the commonly used back-emf sensorless detection technique for controlling the speed of BLDC motors in electric vehicles. The existing technique faces challenges in controlling the motor at low speeds due to noise signals near pulse width modulated (PWM) back-emf zero-crossing points. As a result, the duty cycle of the direct sensorless back-emf technique is limited to less than 100% to ensure a minimum turn-off time for accurate back-emf sampling and control action. To overcome these limitations, the paper proposes an enhanced PWM back-emf zero-crossing detection method implemented using a microcontroller. This method aims to enable speed control of the BLDC motor over a wide speed range. By enhancing the det ection mechanism, the proposed approach improves the accuracy and reliability of back-emf zero-crossing detection, allowing for more precise speed control even at low speeds.

In 2023 a group of people published a study [3] Considering the complexities and costs associated with a motor control system, proposed a sensorless control technique for a BLDC motor utilizing zero crossing detection of the Back-EMF. To support the proposal, the paper presents a mathematical model and implements a MATLAB Simulink Model based on the Back-EMF zero crossing detection method. The model's different blocks and their functions are discussed in detail, providing a comprehensive understanding of the system's operation. By employing the zero-crossing detection approach, the proposed sensorless control method offers a cost-effective and simplified solution for BLDC motor control, eliminating the need for additional sensors. The mathematical model and Simulink implementation serve as practical demonstrations of the proposed technique, showcasing its feasibility and effectiveness.

[4] explains the accuracy of identifying the commutation point is crucial for sensorless control of BLDC motors, as it directly impacts performance and load capacity. Their study focuses on analysing the relationship between the terminal voltage waveform and the deviation of the commutation point, particularly in cases of advanced or lagging commutation. Additionally, the analysis considers the detection error caused by voltage spikes and zero-crossing inaccuracies.

K. Kolano [5] proposed a new control method for systems with BLDC motors, aiming to replace the traditional sensor-based control approach. Instead, the system utilizes a switching estimation algorithm to determine the inverter's switching points. These points are calculated by a microcontroller based on the switching signals from Hall sensors, but they can also be adjusted using an external optimization algorithm. The introduced control method offers several advantages, particularly in improving the commutation of BLDC drives with unbalanced Hall sensors. The author developed both the computation of sensor misalignment and the proposed correction method to enhance the functionality of closed-loop speed control systems using BLDC motors. The technique demonstrates favourable results in both static and dynamic states, showcasing its effectiveness.

A journal article published in the year 2006 [6] introduced a novel method for detecting the rotor position of a BLDC motor used in hard disk drives (HDDs) during standstill and start-up phases. The goal is to accelerate the rotor to a specific speed where conventional sensorless control methods based on back EMF become effective. The proposed method addresses issues such as temporary reverse rotation or starting failures commonly encountered in HDDs. The estimation of the initial rotor position is based on the variation of current response resulting from the magnetic saturation of the stator core of the BLDC motor when current flows along the magnetic axis. A key advantage of this method is that it can be implemented using only one current sensor at the DC link of the inverter, which is a prerequisite for HDD drives. Moreover, the method does not rely on the motor model and exhibits robustness to motor parameter variations. Experimental results demonstrate the effectiveness of the proposed method in achieving stable motor start up even in the presence of significant mechanical disturbances. By utilizing this approach, the paper addresses the challenges associated with rotor position detection and ensures a reliable and smooth start up process for HDDs.

[7] focuses on a low inductance BLDC motor with a nonstandard trapezoidal waveform and asymmetric three-phase back-EMF. Firstly, it analyses the impact of nonideal back-EMF on the detected commutation point when a sensorless method is employed. The article then compares the fluctuations in electromagnetic torque driven by square wave current using different commutation points, and proposes an optimal commutation control method. Additionally, considering the low inductance motor with nonideal back-EMF and a buck front-end drive circuit structure, an integrated nonlinear model is established that incorporates precise back-EMF parameters for both the motor and the buck drive circuit. The feasibility of model linearization is examined based on this nonlinear model. The article proposes a linearization method using input-output feedback and designs a steady-state controller based on the linearized model.

CONCLUSION

This review on sensorless control for BLDC motor design provides valuable insights into the diverse range of methods available for implementing sensorless control. A well-designed sensorless control system can offer numerous benefits, such as cost savings, reduced complexity, and enhanced reliability. By eliminating the need for additional position or speed sensors, sensorless control of BLDC motor reduces the overall system cost and complexity. Despite its advantages, sensor-less motor controllers have limitations, including difficulty in achieving precise control at different load conditions, susceptibility to noise, and challenges in rotor position estimation at lower speeds. Hence, the design methodologies of sensorless BLDC motor control discussed can be effectively employed to improve the implementation of sensorless controls for BLDC motors.

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