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Review on Control Techniques for BLDC Motor

Anu Priya A[1] | Dr. S. Senthil Kumar[2]

[1]PG Scholar, Department of Electrical Engineering, Government College of Engineering, Salem, Tamil Nadu, India.
[2]Professor, Department of Electrical Engineering, Government College of Engineering, Salem, Tamil Nadu, India

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ABSTRACT

This paper possess review on control technique employed to drive BLDC motor used in Electric vehicles. Due to their compact size, low maintenance, and high efficiency, BLDC motors are extensively used in EVs. However, controlling the motor speed and torque is crucial for achieving optimal performance and efficiency. Various control techniques have been developed for BLDC motors, ranging from simple scalar techniques to more complex vector control methods. This paper provides a comprehensive review on these control techniques, including their advantages, limitations, and applications. In particular, the paper discusses the importance of sensor-based control methods for EV applications, which rely on motor sensors to provide feedback for precise control of motor speed and torque. The paper also highlights recent advancements in control techniques for BLDC motors, such as model-based predictive control and machine learning-based control methods. Finally, the paper concludes with a discussion of different BLDC motor control employed in EV applications, which emphasizing the need for further research to optimize performance, efficiency, and reliability of sensor-based and sensor-less control techniques in EVs.

KEYWORDS:BLDC motors, Electric vehicles (EVs), Control techniques, Sensor-based control, Closed-loop control, Scalar control, Vector control.

1. INTRODUCTION

In recent years, the popularity of brushless DC (BLDC) motors has risen significantly, mainly due to their high efficiency, compact size, and low maintenance requirements. They are widely used in various applications, including electric vehicles (EVs). An EV relies on an electric motor to drive the wheels, and the choice of motor is crucial for achieving optimal performance, range, and efficiency. Because of its high torque density, exceptional efficiency, and minimal noise, a BLDC motor is an excellent option for electric vehicles. In contrast to traditional DC motors, BLDC motors use electronic commutation to control the armature winding.

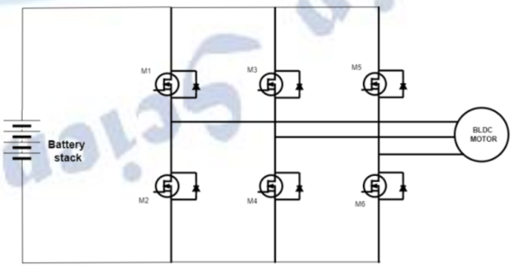

Figure 1 BLDC motor structure

This means that the commutation process is performed by the motor controller, rather than by physical brushes. This eliminates the need for brush maintenance and reduces the risk of sparking and arcing, resulting in longer motor life and improved reliability. In an EV, the motor must be controlled precisely to achieve optimal performance and efficiency.

The motor controller must be able to regulate the motor speed and torque according to the driving conditions, such as vehicle speed, load, and terrain. Various control techniques have been developed for BLDC motors, ranging from simple scalar techniques to more complex vector control methods. The selection of a control method is reliant on the specific application demands and the level of precision required for control.

2. OVERVIEW ON CONSTRUCTION OF BLDC MOTOR

A.CONSTRUCTION

Brushless DC (BLDC) motors are electric motors that use a permanent magnet rotor and a stator with windings to generate a rotating magnetic field. The basic structure of a BLDC motor includes a rotor with permanent magnets, a stator with windings, and a controller to control the current in the stator windings.

The stator windings are typically arranged in a three-phase configuration, although single-phase and two-phase configurations are also used in some applications. The windings are placed in slots on the stator core, which is made of laminated steel to reduce eddy current losses. The stator windings are energized in a specific sequence to create a rotating magnetic field that interacts with the permanent magnets on the rotor.

The rotor of a BLDC motor can have two types of construction: surface-mounted magnets (SMM) or interior-mounted magnets (IMM). In SMM motors, the permanent magnets are mounted on the surface of the rotor, while in IMM motors, the magnets are embedded inside the rotor core.Commutation is the process of switching the current in the stator windings to maintain the correct direction and magnitude of the magnetic field. In BLDC motors, commutation is achieved using electronic switches, such as MOSFETs or IGBTs, controlled by a microcontroller or other electronic circuitry. The commutation sequence is determined based on the position of the rotor and the desired direction of rotation.

As the rotor rotates, it generates a back electromotive force (EMF) in the stator windings, which is proportional to the speed of the rotor. This back EMF can be used to estimate the speed and position of the rotor, allowing for precise control of the motor(Mohanraj et al., 2022).

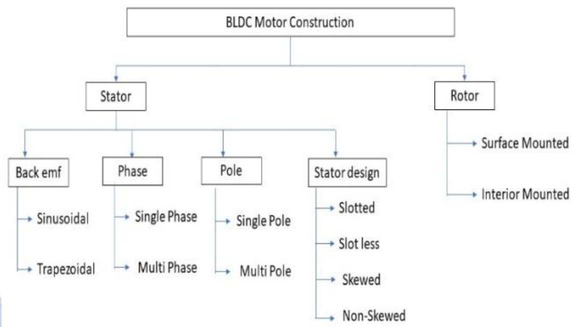

Figure 2 Classification of BLDC motor construction

B. PRINCIPAL

BLDC (brushless DC) motor operates based on the interaction between the magnetic field created by the stator windings and the magnetic field generated by the permanent magnets on the rotor.

When an electric current is passed through the stator windings, it generates a magnetic field that rotates around the stator. The permanent magnets on the rotor, which are arranged in a specific pattern, produce a magnetic field that interacts with the stator magnetic field. As the magnetic fields interact, they produce a torque that causes the rotor to rotate. The direction of the torque depends on the polarity of the stator and rotor magnetic fields. The speed of the motor can be controlled by changing the frequency and amplitude of the electric current supplied to the stator windings.

To achieve continuous rotation, the polarity of the stator windings must be switched at the appropriate time to maintain the interaction between the stator and rotor magnetic fields. This process is called commutation and can be accomplished through various techniques, including sensor-based and sensor less control methods.

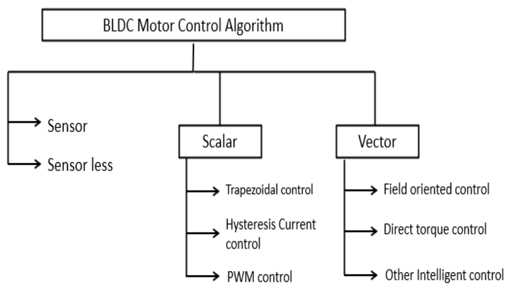

Figure 3 Control strategies of BLDC motor

3. SENSOR AND SENSOR LESS CONTROL OF BLDC MOTOR

BLDC (Brushless DC) motors are electric motors that are commonly used in various industrial and consumer applications, such as electric vehicles, HVAC systems, robotics, and power tools. BLDC motors can be controlled using either sensor-based or sensor less methods.

Sensor-based BLDC motors use position sensors, to detect the rotor position and commutate the motor windings. The position sensors provide feedback to the motor controller about the exact position of the rotor, which allows the motor to operate smoothly and efficiently. The motor controller uses this information to determine which winding to energize next and at what time, based on the position of the rotor. Sensor-based BLDC motors offer higher accuracy and reliability compared to sensor less BLDC motors since they provide direct feedback to the motor controller about the rotor position. However, they are more expensive and complex since they require additional sensors.

There are different types of position sensors that can be used to control BLDC motors. The most common types of position sensors used in BLDC motors are Hall-effect sensors, resolver sensors, and encoder sensors.

Hall-effect sensors

Hall-effect sensors are the most common type of position sensor used in BLDC motors. They are small, inexpensive, and reliable sensors that can detect the presence and polarity of a magnetic field. Hall-effect sensors can be placed on the stator of the motor and detect the magnetic field of the rotor. They are usually placed in a 120-degree configuration around the stator to detect the position of the rotor with respect to the stator.

Resolver sensors

Resolver sensors are another type of position sensor that can be used in BLDC motors. They are typically more expensive than Hall-effect sensors, but they offer higher accuracy and reliability. Resolver sensors use a rotor and a stator with wire windings to detect the position of the rotor. The resolver sensor provides analog signals that are proportional to the angle of the rotor. Resolver sensors are often used in applications where high precision is required, such as aerospace and defense.

Encoder sensors

Encoder sensors are the most precise type of position sensor used in BLDC motors. They can provide high-resolution position information and are typically used in applications where high accuracy is critical, such as robotics and medical equipment. Encoder sensors use a rotating disk with slots or markings that are detected by a sensor to determine the position of the rotor. The encoder sensor provides digital signals that are processed by the motor controller to determine the position of the rotor.

Sensorless BLDC motors, on the other hand, do not require position sensors to operate. Instead, they rely on the back-emf (electromotive force) generated by the motor windings to determine the position of the rotor. The motor controller uses the back-emf signal to estimate the position of the rotor and commutate the motor windings accordingly. Sensor less BLDC motors are less expensive and simpler compared to sensor-based BLDC motors since they do not require additional sensors. However, they are less accurate and reliable since the back-emf signal can be affected by external factors such as temperature, load, and noise.

The choice between sensor-based and sensor less BLDC motors depends on the specific application requirements and cost considerations. Sensor-based BLDC motors are commonly used in high-performance applications where accuracy and reliability are critical, such as electric vehicles, robotics, and industrial machinery. Sensor less BLDC motors are commonly used in low- to medium-performance applications where cost and simplicity are more important, such as household appliances and toys.

4. Control Strategies of BLDC Motor

One of the key components of an EV is the brushless DC (BLDC) motor, which is responsible for converting electrical energy into mechanical energy to drive the wheels of the vehicle. To achieve optimal performance and efficiency, various control strategies can be employed for the BLDC motor. These strategies include sensor control, sensor less control, field-oriented control (FOC), direct torque control (DTC), and predictive control. has its benefits and drawbacks, and the selection of the technique is dependent on the specific requirements and application. Effective control of BLDC motor is essential for achieving maximum efficiency, extending battery life, and improving overall performance of the EV.

This paper, explore some of the common control strategies used for BLDC motors in EVs and their advantages and disadvantages.

C. SCALAR CONTROL OF BLDC MOTOR

The scalar control of BLDC motor employs trapezoidal control, hysteresis control, current control, PWM control and so on these control use sensors for control input to effectively drive the motor. The scalar control can also be employed without using sensor by intelligent control techniques.

(Purna et al., 2007) This paper discusses the implementation of a hysteresis current controller with a speed feedback loop to reduce torque ripples in Brushless DC motors (BLDCM). The controller maintains a constant current in the motor by generating reference currents from the reference torque, which is limited using the speed error signal. The closed-loop control system achieves closed-loop speed control by using a PI controller and adding a hysteresis current controller loop with speed error feedback.

In hysteresis current control technique, the current control can be done effectively than conventional current control (Noor Azam et al., 2013) This paper proposes a current blocking strategy for BLDC motor drives in electric vehicles to prolong battery life. The strategy turns off all transistor switches in the inverter when the actual motor torque is reduced to zero, which is established using a hysteresis comparator. The current control method implemented in THC motor drive provides current limitation and protection by restricting the current error within a pre-defined band gap. The proposed current blocking strategy prevents the current drained from the batteries when the torque demand is released to set to 0 Nm.

(Faiz et al., 2012) in this paper closed-loop control for a BLDC motor utilizing a torque hysteresis controller (THC) is proposed. The THC method is employed to regulate the phase current and torque of the BLDC machine, ensuring current protection and keeping the current and torque values within certain limits around the reference value. To govern torque, the Hysteresis controller must regulate the three-phase current, and the motor currents must be maintained at their references, which are generated based on torque demand and decoded signals received from Hall Effect sensors. Related concept is used in this paper (KumarP et al., 2015) the torque hysteresis control technique is used to control the BLDC motor and closed loop feedback is done using PI controller.

(Kevat et al., 2018) This paper focuses on the closed-loop speed response of a three-phase brushless DC motor. Hall Effect sensors are used to sense the rotor position, and a commutation block for inverter is used to feed gate pulses to turn on the motor.

The closed loop control of BLDC motor provide PWM generation using commutation controller block other than hysteresis current controller PWM generation. The speed signal for control operation in BLDC motor closed loop control can be obtained using conventional controller P,PI, PID, FUZZY logic and also intelligent controllers are employed.(Singh & Garg, 2012) This paper compares conventional PI controller and fuzzy logic-based speed controllers for a BLDC motor The study proposes a fuzzy logic speed controller to address issues with the conventional PI speed controller, such as starting current, overshoot in torque, and slow speed response. PWM signals for the inverter are generated using a hysteresis current controller. (Mahmud et al., 2020) this paper provides BLDC motor closed loop control PID controller scheme. The PWM signal are obtained by inverter commutation block. This paper provides the comparison of speed feedback employing PID is compared to the performance with PI and Fuzzy logic controllers. (Arulmozhiyal & Kandiban, 2012) in this paper a, combination of two controller is used PID and fuzzy logic converter for closed loop feedback generation. In the paper, the Fuzzy PID controller is designed with a two-input FLC structure featuring interrelated rules, and has error, error change, and control signal inputs and outputs classified as linguistic variables. (Kiruthika et al., 2013) This paper presents another closed loop structure using fuzzy PID together. The proposed Fuzzy PID controller for a BLDC motor, will dynamically updates the PID controller's parameters.

There is also other intelligent controller available for control of BLDC where PWM signal are generated using digital control. In this paper (Sankar & Seyezhai, 2014) the development of commutation logic using FPGA. The FPGA is responsible for receiving hall sensor data from the motor and generating gate pulses to operate the transistor switches of the three-phase inverter.

D. VECTOR CONTROL

In vector control operation the control signals are obtained either using senor or other equivalent methods to perform sensor less control is review. Field-Oriented Control (FOC) is a widely used technique in Brushless DC (BLDC) motors that provides precise and efficient control of torque and speed. FOC involves transforming stator currents and voltages from the stationary reference frame to the rotor reference frame, allowing for independent control of torque and flux.(John et al., 2011) in the paper the FOC control is used for BLDC motor drive, the FOC system employs a pair of P-I controllers that work in tandem by driving the direct current component to zero and keeping track of the requested torque through the quadrature current. The six power switching devices are regulated by space vector modulation (SVM), which is more efficient in utilizing bus voltage compared to sinusoidal pulse width modulation (SPWM).(Gujjar & Kumar, 2017) this paper discusses the utilization of a sensor less approach for rotor position sensing in FOC control. This technique helps reduce costs and simplifies implementation by using digital signal controllers (DSCs) and microprocessors. Additionally, the paper examines and compares the performance of two control techniques, namely sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM) for PWM generation.

In Direct Torque Control (DTC) controller directly regulates the torque and flux of the motor, without the need for current control loops. DTC utilizes a hysteresis-based controller that compares the measured stator voltage and current with their reference values. The controller then selects the optimal switching state of the inverter based on the hysteresis bands of the torque and flux. This approach provides a simple and efficient way of controlling the motor, as the switching states of the inverter are directly based on the error between the actual and reference values of torque and flux.

However, DTC also has some limitations, such as increased torque ripple and higher switching frequency compared to other control techniques. These limitations can be mitigated using advanced control algorithms and modulation techniques,

(Li et al., 2011) though direct torque control (DTC) approach shows potential in reducing torque fluctuations by directly managing the electromagnetic torque, which is less susceptible to unpredictable factors. In this paper, a new method is presented to decrease torque ripple by selecting the zerovoltage vector and approximating the electromagnetic torque using the line back-EMF constant.

E. SENSORLESS CONTROL

The sensor less control of BLDC motor is also reviewed in this paper.(Patil et al., 2020) This paper discusses the limitations of conventional direct torque control (DTC) in brushless DC (BLDC) motors, which can result in high torque ripples. The paper presents a modified adaptive DTC with a PID controller, which is compared to an artificial neural network (ANN) based DTC method. The ANN-based DTC method employs an optimized switching table to reduce torque ripple. The paper also discusses sensor-less BLDC motor control using the back EMF method. (Nair et al., 2017) in this paper, a Direct Torque Control (DTC) strategy for Brushless DC (BLDC) motors that operates without sensors, relying instead on the Kalman Filter algorithm to estimate torque is used. To achieve faster torque response than conventional six-step Pulse Width Modulation (PWM) techniques, the method employs a predefined voltage vector obtained from an optimal switching table. The DTC control algorithm generates a quasi-square wave current, while the Kalman Filter algorithm estimates the electromagnetic torque without requiring feedback sensors. The Kalman Filter algorithm is intelligent enough to track the actual torque waveform, resulting in a more precise torque estimation.(Arab Markadeh et al., 2008) In this paper, a method is suggested to attain direct torque control without the use of sensors in a brushless DC motor. By using the rotor flux vector position, rotor angle modifier, and torque error, the technique selects the suitable switching pattern from a look-up table to limit the produced torque error within a predetermined hysteresis band. Additionally, a rotor flux observer is utilized to estimate the rotor flux vector angle, while a simple and robust sliding mode observer is employed to compute the back-EMF.

F. FGPA DIGITAL CONTROL

(Sathyan et al., 2009) the paper proposes a novel digital pulse width modulation (PWM) control scheme for brushless DC (BLDC) motor drives using field programmable gate arrays (FPGAs). The proposed method uses digital signal processing techniques to generate PWM signals for controlling the motor and provides flexible control of various motor parameters.

The system architecture consists of a Hall-effect sensor interface, FPGA-based digital controller, and power inverter. The Hall-effect sensors are utilized to detect the rotor position of the motor, and based on their input, the digital controller produces the necessary PWM signals. The proposed method is shown to provide improved motor control compared to traditional analog control methods.

G.NON-LINEAR CONTROL

(Ubare et al., 2019) In this paper, a nonlinear model predictive control (NMPC) scheme is proposed to achieve energy-efficient control of a brushless direct current (BLDC) motor in electric vehicles (EV). The control structure includes a PI controller and NMPC with nonlinear constraints on currents and speed. The proposed strategy is designed to regulate the desired torque and speed of the motor, while minimizing energy consumption. The main contribution of the paper is to provide a solution for the EV speed controller by employing an NMPC strategy that incorporates energy-efficiency considerations.

The below table summarize the above review in a simplified manner.

Control algorithm	Control Technique	Sensor/Sensor less operation	PWM generation	Reference
Scalar	Hysteresis current control	Hall sensor Speed senor	Hysteresis controller	[2]
		Hall sensor Current block strategy	Hysteresis controller	[3]
	Torque Hysteresis Control	Hall sensor Speed senor	Hysteresis controller	[4]
	Speed Control	Hall Sensor Speed sensor	PID controller, Inverter Controller	[8]
	Digital control	Hall sensor	FGPA	[10]
Vector	Field oriented control	Encoder Speed sensor Current sensor	Space vector	[12]
		Sensor less Uses digital signal controller	SPWM and SVPWM	[13]
	Direct torque control	Hysteresis band controller	Space vector	[14]
		Sensor less	Kalman filter algorithm	[15]
	FGPA control	Hall sensor	FGPA based digital controller	[17]
	Model Predictive control	speed, position, current sensor	Torque hysteresis	[19]

Thus, above review provides a complete insight into the different current scheme employed in BLDC motor control.

5. CONCLUSION

In conclusion, brushless DC (BLDC) motors have gained popularity in various industrial and consumer applications owing to their superior efficiency, reliability, and low maintenance requirements. However, controlling the speed and torque of BLDC motors can be challenging from the above reviewed in recent years papers, a wide range of control techniques for BLDC motors, including traditional techniques like six-step commutation and advanced techniques like field-oriented control, direct torque control, and intelligent controls are stated. These control techniques have been implemented using different hardware platforms, including microcontrollers, digital signal processors, and field programmable gate arrays, to achieve high performance, efficiency, and flexibility. The sensor-based control uses conventional controller as well as combination of two controllers to obtain optimum control input for the controller and sensor less control techniques using observer-based algorithms and back-EMF estimation methods have also been developed to eliminate the need for external sensors. Overall, the continued development of control techniques for BLDC motors has enabled their widespread adoption in many industries, and further advances in this field are expected to continue to drive innovation and progress.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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