BLDC MOTOR CONTROL BY PID CONTROLLER IN MATLAB FOR ELECTRICAL VEHICAL APPLICATION

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Abstract - Recent advancements in magnetic materials and power electronics, coupled with the availability of inexpensive, powerful processors, have led to a significant increase in the use of brushless direct current (BLDC) motors across various applications. These applications range from household appliances to the automotive, aerospace, and medical industries. The widespread adoption of BLDC motors is attributed to their numerous advantages over other motor types, including high efficiency, rapid dynamic response, extended operational lifespan, relatively quiet operation, and broader speed ranges. Due to the increasing deployment of BLDC motors in many real-world applications in place of traditional motors, it is essential to explore and specify their control methods in detail. This paper examines several speed and current control techniques for BLDC motors. These methods include hysteresis band control, variable DC-link voltage, and pulse width modulation (PWM) control strategies. Each of these control strategies involves proportional-integral-derivative (PID) gains, which are optimized using the particle swarm optimization (PSO) algorithm. By employing fast Fourier transform (FFT) analysis, the regulator behavior is studied through frequency analysis of the output signals, and total harmonic distortion (THD) is calculated. This analysis helps in identifying the most effective control strategy for BLDC motors.

Key Words: Speed Control, BLDC Motor, Closed Loop, Review.

1. INTRODUCTION

DC motors operate on direct current, derived either from a DC power source or a battery, which supplies electricity at a constant voltage. When a DC motor's leads are connected to a battery or DC source, the motor converts electrical energy into mechanical energy. The operation of a DC motor relies on the principle that like magnetic poles repel each other, while unlike poles attract each other By controlling the current flowing through the coil, the electromagnetic field can be turned on or off, or its direction can be reversed by switching the current's direction by 180 degrees. The wire ends terminate on a commutator. The armature also includes bearings that support it within the motor, the motor's drive shaft, and the commutator connections. The windings in the armature continuously loop around it and use either single or parallel conductors, potentially circling several times around the stack teeth. The strength of the generated electromagnetic field is determined by the amount of current sent to the coil, the coil's size, and the core around which it is wrapped.

The direction of the electromagnetic fields is controlled by turning specific coils on or off in sequence, creating a rotating magnetic field. These rotating fields interact with the magnetic fields of the stator's magnets (which can be either permanent magnets or electromagnets) to generate a force on the armature, causing it to rotate. Some DC motors use electromagnets in the stator to create their magnetic fields, allowing for greater control over the motor. At high power levels, DC motors are often cooled using forced air. The commutator plays a crucial role by enabling each armature coil to be activated in sequence. Brushes typically provide the current to the coil by maintaining moving contact with the commutator. In contrast, some modern brushless DC motors use electronics to switch the current to each coil, eliminating the need for brushes and thus avoiding wear and sparking issues.

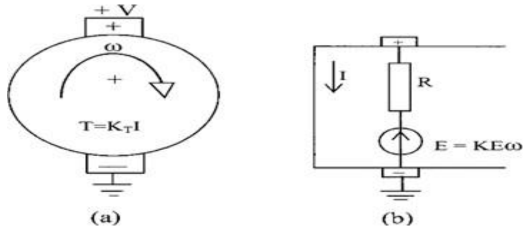

Figure 1: Schematic representation of DC motor

2. METHODOLOGY

The design of modern brushless motors is akin to that of AC motors, specifically the permanent magnet synchronous motor (PMSM). As depicted in Figure 2, a typical brushless DC motor features stator windings similar to those found in a polyphase AC motor, with the rotor comprising one or more permanent magnets. Unlike AC synchronous motors, BLDC motors incorporate a mechanism to detect the rotor's position (or magnetic poles) and use this data to generate signals that control electronic switches. The Hall effect sensor is the most commonly used position/pole sensor, though some motors employ optical sensors.

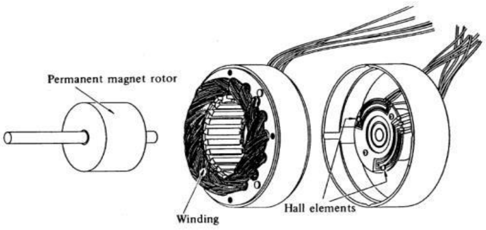

Figure 2: Constructional view of a BLDC Motor

Mathematical model of BLDC motor:
In a similar approach, BLDC motor modeling can be represented as a synchronous machine with three-phase windings. A BLDC motor, a type of multi-phase motor, is powered by a three-phase voltage source, as shown in Figure 3. The peak voltage should remain within a specific range, neither falling below the back-EMF induced voltage nor exceeding the motor's maximum voltage limit.

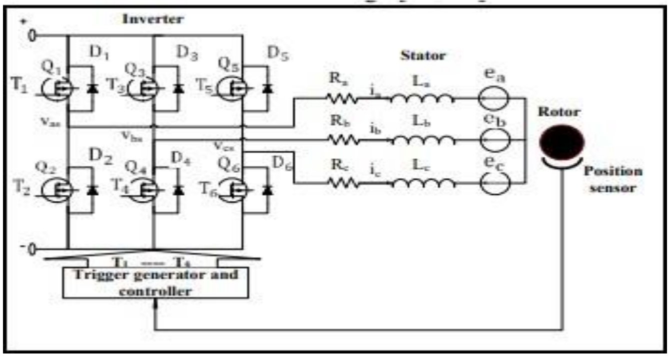

Figure 3: Three-phase BLDC motor equivalent circuit

The matrix representation of the phase voltage equations for the BLDC motor can be derived using Kirchhoff's voltage law as follows:

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} 0 & L-M & 0 \\ 0 & 0 & L-M \\ L-M & 0 & 0 \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

Where,
Vas, Vbs and Vcs represent the stator voltages.
R denotes the phase stator resistance, which remains constant across all windings.
ia, ib and ic are the stator phase currents.
ea, eb and ec represent the back-EMF phase voltages.

Through subtraction calculations of the phase voltage equations, the line voltage equation can be derived as:

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R & -R & 0 \\ L-M & M-L & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} 0 & R & -R \\ 0 & L-M & M-L \\ -R & 0 & R \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a - e_b \\ e_b - e_c \\ e_c - e_a \end{bmatrix}$$

This equation represents a linear combination of the other two voltage equations. To simplify the subsequent system model construction, only two equations are required. By utilizing the following balancing relationship, one equation can be discarded, and one variable can be omitted.

$$ia + ib + ic = 0$$

The equations can be modified using the previously mentioned equations as follows:

$$\frac{d}{dt}(i_a) = -\frac{R \cdot i_a}{(L-M)} + \frac{2(V_{ab} - e_{ab})}{3(L-M)} + \frac{(V_{bc} - e_{bc})}{3(L-M)}$$

$$\frac{d}{dt}(i_b) = -\frac{R \cdot i_b}{(L-M)} + \frac{2(V_{ab} - e_{ab})}{3(L-M)} + \frac{(V_{bc} - e_{bc})}{3(L-M)}$$

The rotor location is associated with the trapezoidal back-EMFs. Each phase has a 120° phase shift, thus the equation for each phase can be expressed as:

$$e_a = \frac{(k_e \cdot \omega_m \cdot F(\theta_e))}{2}$$

$$e_b = \frac{(k_e \cdot \omega_m \cdot F(\theta_e - \frac{2\pi}{3}))}{2}$$

$$e_c = \frac{(k_e \cdot \omega_m \cdot F(\theta_e + \frac{2\pi}{3}))}{2}$$

Where

ke is the back-emf constant
wm is the rotor speed and
ɵe is electrical rotor angle which is equal to

$$ɵe = (p * ɵm) / 2$$

Where,

p is the number of poles and

ɵm is the mechanical rotor angle

$$θm = ∫ wm t dt$$

Derived from Newton's second law and similar to the DC motor, the analysis of BLDC motor power and torque can be approached from an energy transfer perspective. The transmission of power to the rotor through the air-gap, where torque is exerted, is commonly referred to as electromagnetic power.

$$pe = ea * ia + eb * ib + ec * ic$$

The entirety of the electromagnetic power is converted into kinetic energy after accounting for stray and mechanical losses, thus

$$pe = Te * wm$$

Where Te is the electromagnetic torque, so that from equations the electromagnetic torque can be extracted as

$$Te = kt/2\ [F(\theta e)ia + F(\theta e - 2\pi/3)ib + F(\theta e + 2\pi/3)ic]$$

The motion equation account as

$$Te - TL = J * dwm/dt + kf * wm$$

Where

TL is the load torque,
kt is the torque constant,
kf is the viscous friction constant and,
J is the rotor moment of inertia

Closed Loop Control Closed Loop control of BLDC motor: One of the conventional methods for closed-loop control of BLDCs involves utilizing either current and speed feedback, solely speed feedback, or no feedback for both current and speed.

Speed feedback

Speed feedback is obtained by measuring the voltage and current (VI) at the BLDC motor's terminals in the provided model. This estimated speed is then fed back negatively to assess any deviation from the desired speed. The hall sensor output is utilized for synchronization and pulse width modulation (PWM) control. A proportional-integral (PI) controller processes the error signal and utilizes it to generate PWM signals. This control approach is advantageous due to the simplicity of VI measurement at the motor's output terminals.

1. **No speed/ current feedback:**

In the block diagram presented, the alternative control strategy operates without speed or current feedback. Here, the focus is on establishing a closed loop for current control. In this setup, a PID controller receives only a reference current as input. VI measurement is conducted once more at the BLDC motor's terminals. The measured current is then compared with the desired reference, and based on this comparison, gate pulses for the inverter are generated to regulate the current flow.

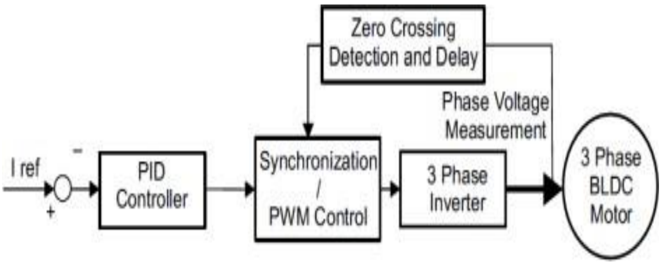

Figure 3: No speed / current feedback control strategy

2. **Speed and current feedback:**

This approach to closed-loop speed control for BLDC motors incorporates similar feedback mechanisms as the previous technique. However, feedback is integrated into various components along the control path. Initially, the actual speed is compared with the desired reference speed. Subsequently, a PI controller processes the resulting error, leading to the computation of a reference current. This current is then compared with the current measured at the output terminal before being further adjusted by passing it through a PID controller. This method necessitates two stages of tuning and additional circuitry, making it the most intricate technique. Following this, the PWM control unit, responsible for generating logic pulses for PWM control, receives the output of the PID controller.

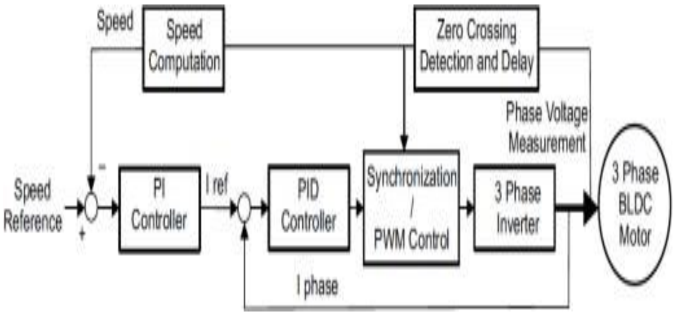

Figure 4: Speed and current feedback control strategy

3. MATLAB/SIMULINK

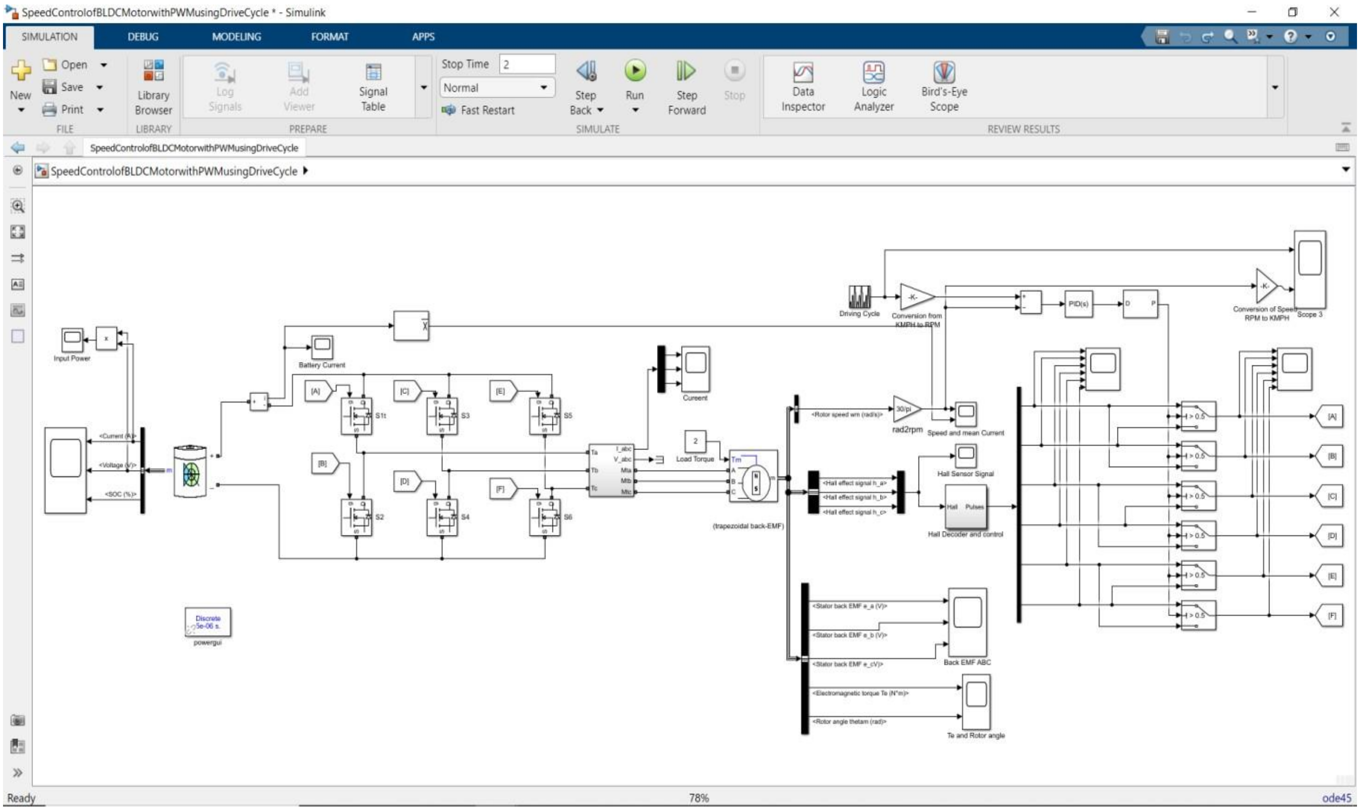

Figure 5: MATLAB/SIMULINK Circuit Diagram

4. RESULTS

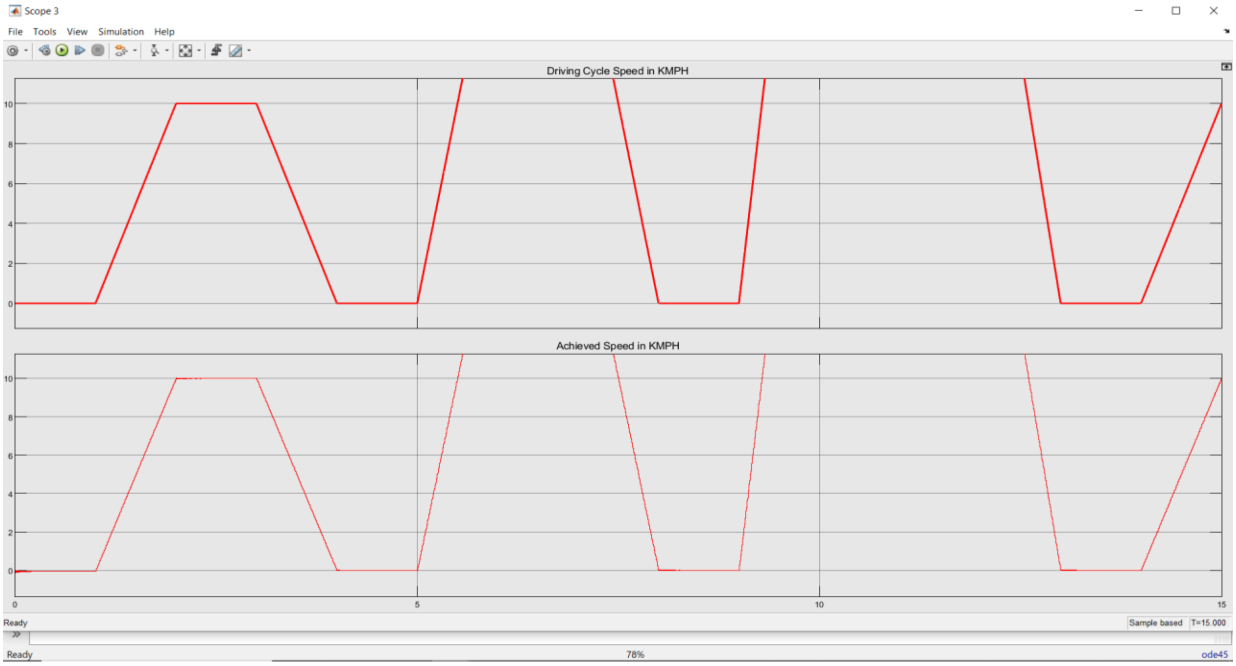

Figure 6: Waveform of driving cycle and achieved speed

5.CONCLUSION

BLDC motors offer numerous advantages compared to brushed DC and induction motors, making them highly desirable across various applications. One key advantage is their superior speed versus torque characteristics, enabling precise control over motor operation. This feature is particularly valuable in applications requiring rapid dynamic responsiveness, where BLDC motors excel. Additionally, BLDC motors boast greater efficiency and dependability, resulting in reduced energy consumption and enhanced reliability. These factors contribute to longer operational lifespans, making BLDC motors a cost-effective choice over their counterparts. Moreover, BLDC motors operate more quietly than traditional motors, reducing noise pollution in various settings. They also offer broader speed ranges, allowing for versatile performance across different operational requirements. Another significant benefit is the reduction in arcing, which enhances safety and prolongs the motor's lifespan. Additionally, BLDC motors exhibit a higher delivered torque-to-size ratio, maximizing output in constrained spaces.

These advantages render BLDC motors particularly beneficial in applications where space and time constraints are prevalent. In aerospace applications, where weight is a critical consideration, BLDC motors offer a compelling solution due to their lightweight construction and efficient operation. Their ability to deliver high torque in compact sizes makes them ideal for powering various aerospace systems, ranging from actuators to propulsion systems. Various studies have examined and evaluated the performance of BLDC motors under different conditions. These outcomes have been meticulously documented and analyzed within the context of BLDC motor applications. Through rigorous testing and experimentation, researchers have gained insights into optimizing BLDC motor performance, addressing specific challenges, and expanding their range of applications.

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