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Field Oriented Control of Brushless Direct Current Motor for Electric Vehicle Robot Obstacle Detection and Avoidance

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Abstract **–** This paper presents an approach to implement Field Oriented Control (FOC) brushless direct current motor using PID Controller for electric vehicle obstacle detection and avoidance. A state space model of the BLDC motor with FOC was model and simulated using MATLAB/Simulink to validate the stability of the proposed system. The overall system was validated in real time implementation using micro-controller and Ultrasonic Sensor. The detection and recognition of objects, as well as making an autonomous decision to change its trajectory which is based on predetermined threshold distance of 5cm were analyzed.

Keywords – Field Oriented Control, Brushless DC Motor, PID Controller, Obstacle Detection, Ultrasonic Sensor

I. INTRODUCTION

One of the most important parts of an electric vehicle, which also includes a basic electric drive, an energy storage system, and a transmission body, is the electric propulsion system. A typical drive system for electric propulsion is anticipated to have a high energy density and a quick dynamic response [1]. Designing an electric propulsion system should be compatible with the demands of the vehicle, such as optimal acceleration, high torque, effective speed, and gradeability. In general, factors like machine losses, harmonic distortion, torque pulsations, cogging torque output, etc. affect how well electric propulsion systems convert energy. Additionally, a number of studies have been conducted recently to improve the energy efficiency of electric vehicles. In industrial sectors, improving electric motor energy savings takes into account a few common elements. One of the most important solutions is to use multiple small motors with the closest power rating rather than a single large unit. Another is to build high-efficiency electric motors by improving various design topologies and better classifying the materials used. Then lastly is to maximize efficiency based on some advanced control strategies in electric motor drives [2]. It is commonly known that an electric motor's efficiency varies depending on the working environment in order to accommodate its dynamic properties, or torque-speed nature. Recent developments in permanent magnet technology, such as brushless DC motors (BLDC) and rare earth magnets and samarium cobalt permanent magnet synchronous motors (PMSMs), are being accepted with promise in a variety of commercial and industrial applications [3]. In these high-performance applications, there are a number of benefits that can be taken into account over typical electrical machines, including greater energy density, superior torque to volume ratio, compact and sturdy design, and enhanced efficiency. It can be difficult to implement various control strategies in various industrial drives, such as flux weakening control and vector control [4] [5].

In the navigation system of the robot, obstacle avoidance plays an integral role in movement of the robot in an unknown environment to avoid collision with barriers. Why is it needed? To avoid injury or damage to the robot or obstacle, collision between them. When robots already operate in a well-defined route the need of obstacle avoidance is of great importance as the route is to subject to environmental changes which will cause collision of obstacles in its path. The challenge of efficiently calculating a trajectory is what has necessitated the development of a robot with the ability to detect and circumvent objects in a pre-calculated path, including incoming obstacles that appear unexpectedly. The answer to this trajectory issue is for the robot to use FOC in speed control of BLDC motor and sensors to detect and avoid obstructions, allowing it to become more autonomous by removing the need for external control. The direction and strength of the current flowing to the coils must be continuously altered in order to operate a permanent magnet Brushless DC Motor (BLDC). Permanent magnets with diametrically opposed poles are found inside the rotor. Therefore, the phase currents should move in a way that creates a magnetic field that will either attract or repel the permanent magnet and finally cause the rotor to spin. Every time a permanent magnet pole gets close to a stator coil, the coil has to receive power in a direction that will create an opposite polarity that will pull the magnet pole toward it. On the other hand, if the stator coil and the permanent magnet pole are exactly aligned, a voltage should be applied to the coil to produce a pole that repels the permanent magnet and generates the opposite effect. The motor's rotor will turn in both scenarios. By altering the order in which the voltage is provided to the stator coils, the direction of the rotor's movement can be changed.

The BLDC motor is driven using a technique called field-oriented control, also referred to as vector control. It is an efficient technique to power BLDC motors, although it has some expenses. For instance, vector control requires measuring the motor's phase currents, which increases the cost of a current sensor. The price of the current sensor can be decreased if we are able to substitute a new way for the vector control method that does not require measuring the motor phase currents. Uncontrolled current operation is one possible example of such a technique. This method does not involve current controlling, as the name would imply, and as a result, no current sensor is required. The FOC approach aims to independently control the magnetizing flux and electromagnet torque.

The idea of field-oriented control, often known as vector control, was put forth by F. Blascke in 1971. The d-q reference frame is the basis for the mathematical model of the PMSM [6]. The motor model is instantly changed in these two references frame system, the ABC coordinate system to the DQ coordinate system. In the early 1920s, R. H. Park invented the Park transformation, which is employed in the motor model transformation [7].

The brushless DC motor is known as brushless because it lacks the commutator and brush arrangement, yet it is similar to DC motors with permanent magnets. Due to the electronic commutation of this motor, BLDC motors require no maintenance. The high starting torque and high efficiency of BLDC motors, which ranges from 95 to 98 percent, are traction features. High power density design strategies are appropriate for BLDC motors. Because of their traction qualities, BLDC motors are the most popular motors for use in electric vehicles [8].

The use of electric vehicles was expected to increase in the future because of how well they performed when compared to IC and steam-powered cars. They were also seen as a viable challenger for road transportation. The IC engine vehicles required manual starting, were unreliable, smelled bad, and were not as quick to start as the EVs. However, steam-powered vehicles required lights and had a low thermal efficiency engine. But as time went on, the duration of battery charging became a significant issue with electric vehicles. It takes several hours to recharge a lead acid battery, compared to only taking five minutes to fill a gas tank [9].

II. MATERIALS AND METHOD

The most effective way to regulate a PMBLDC is through Field Oriented regulate (FOC), also known as Vector Control. In order to adjust the size, phase, and frequency of the stator current waveform, the PMBLDC must be powered by an inverter, such as a voltage source inverter. Additionally, in order to execute its theory, field-oriented control needs the BLDC model in a rotating DQ coordinate frame.

In an ABC coordinate frame, the PMBLDC model is derived. The motor model is changed by Park and Clarke transformations to become time independent. The PMBLDC model is still time variable because the Clarke transformation is utilized to transfer from ABC into a stationary DQ coordinate frame. The state space model is made time invariant using rotational park transformation, which changes the model's coordinate frame from to DQ. For regulating AC or DC machinery today, switching power electronics like IGBT are crucial. The desired voltage/current can be provided to control the motor using a current source inverter (CSI) or a voltage source inverter (VSI), which convert DC into AC. As a result, PWM (Pulse Width Modulation) for switching power electronics is crucial for controlling electrical equipment. One PWM technique that produces inverter output with reduced distortion and harmonics is space vector PWM.

The d and q output current components are regulated by proportional-integral controllers (PI) with reference currents in order to manage the speed and torque. FOC techniques require a sophisticated processor, such as a Digital Signal Processor (DSP), that can compute the parameter in real time. The BLDC motor is controlled by Texas Instruments (TI) software, which is used in conjunction with a BLDC motor and HVDC kits that also feature a DSP controller. Figure 1 depicts the FOC block diagram.

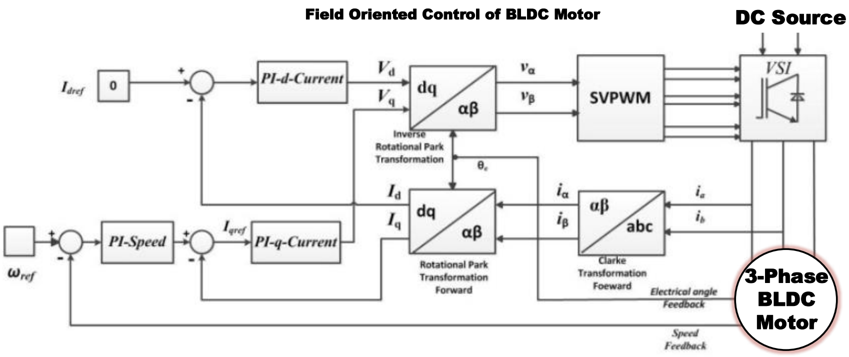

Fig.1 Basic FOC Diagram for BLDC Motor

MATNEMATICAL MODELING OF BRUSHLESS DC MOTOR

Equations (1) and (2) represent the mathematical representation of the armature winding of the BLDC motor.

$$\begin{cases} V_a = Ri_a + \dfrac{d\lambda_a}{dt} + e_a \\ V_b = Ri_b + \dfrac{d\lambda_b}{dt} + e_b \\ V_c = Ri_c + \dfrac{d\lambda_c}{dt} + e_c \end{cases} \quad (1)$$

where

$$\begin{cases} \lambda_a = L_s i_a - M\left(i_b + i_c\right) = L_s i_a + M\left(i_a\right) = \left(L_s + M\right) i_a \\ \lambda_b = L_s i_b - M\left(i_a + i_c\right) = L_s i_b + M\left(i_b\right) = \left(L_s + M\right) i_b \\ \lambda_c = L_s i_c - M\left(i_a + i_b\right) = L_s i_c + M\left(i_c\right) = \left(L_s + M\right) i_c \end{cases} \quad (2)$$

and p is ($\dfrac{d}{dt}$)

Therefore, these equations can be represented by a matrix.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R+\rho\left(L_s+M\right) & 0 & 0 \\ 0 & R+\rho\left(L_s+M\right) & 0 \\ 0 & 0 & R+\rho\left(L_s+M\right) \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (3)$$

where

$$\begin{cases} e_a = E.f_a\left(\theta_r\right) \\ e_b = E.f_b\left(\theta_r\right) \\ e_c = E.f_c\left(\theta_r\right) \end{cases} \quad (4)$$

$$E = k_b\omega_r \quad (5)$$

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega_r} \quad (6)$$

$$T_e = \frac{\left(E.f_a\left(\theta_r\right)\right)i_a + \left(E.f_b\left(\theta_r\right)\right)i_b + \left(E.f_c\left(\theta_r\right)\right)i_c}{\omega_r} \quad (7)$$

$$T_e = k_b\left\{\left(E.f_a\left(\theta_r\right)\right)i_a + \left(E.f_b\left(\theta_r\right)\right)i_b + \left(E.f_c\left(\theta_r\right)\right)i_c\right\} \quad (8)$$

$$J\frac{d\omega_r}{dt} + B.\omega_r = T_e - T_L \quad (9)$$

$$\omega_r = \omega.\frac{p}{2} \quad (10)$$

$$\frac{d\omega_r}{dt} = \frac{p}{2}\left(\frac{T_e - T_L - B.\omega_r}{J}\right) \quad (11)$$

To control the speed and the position, it can be found from equation (12) and (13)

$$G_m(s) = \frac{i_s(s)}{v_s(s)} = \frac{s/L_a}{s^2 + (R_a/L_a)s + \frac{K_t P K_e}{(J L_a)}} \quad (12)$$

$$G_\omega(s) = \frac{\omega_e(s)}{v_s(s)} = \frac{K_e}{s^2 L\frac{J}{P} + R\frac{J}{P}(s) + K_e K_t} \quad (13)$$

EXPERIMENTAL VALIDATION

The prototype was build using a 30A BLDC ESC Electronic Speed Controller as shown in Fig.2. In comparison to other ESCs on the market, this controller is designed exclusively for quadcopters and multi-rotor aircraft. It offers faster and better motor speed control.

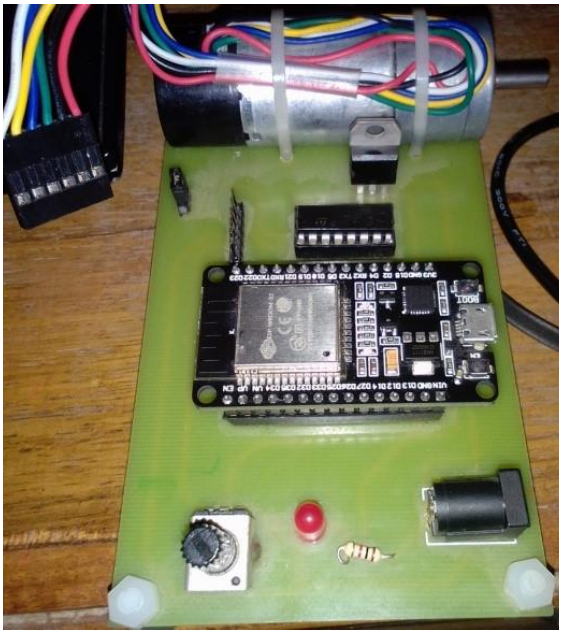

Fig.2: Control circuit with L239D motor driver and speed controller

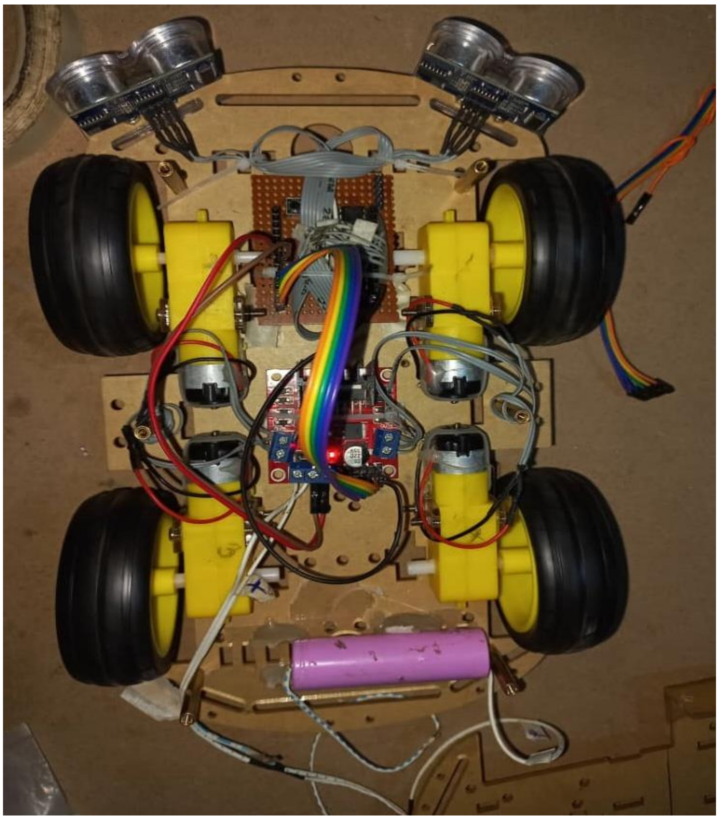

Fig.3: BLDC motor Electric vehicle prototype

III. RESULTS

The simulation and experimental results are presented here.

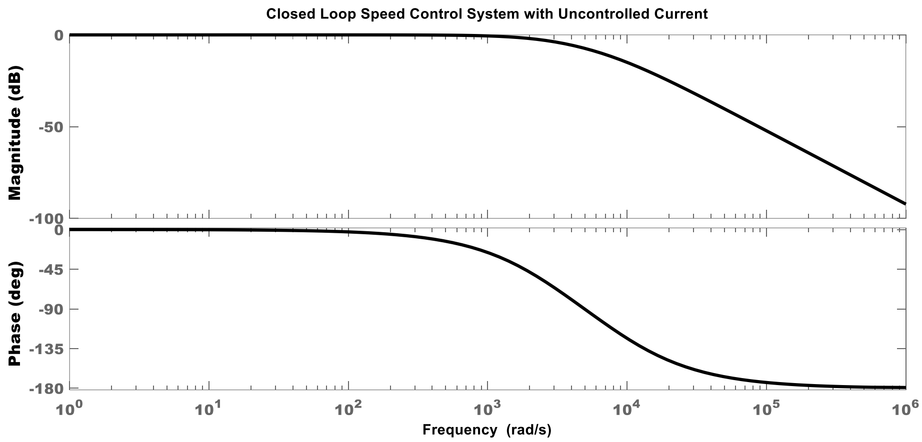

Fig. 4: Bode plot of uncontrol current

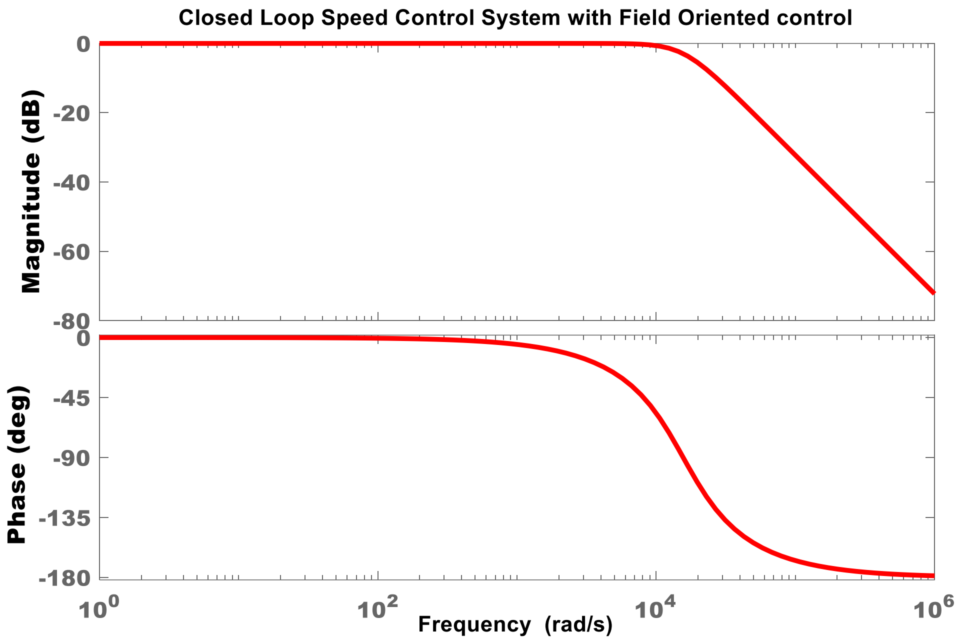

Fig.5: Bode plot of speed control with FOC

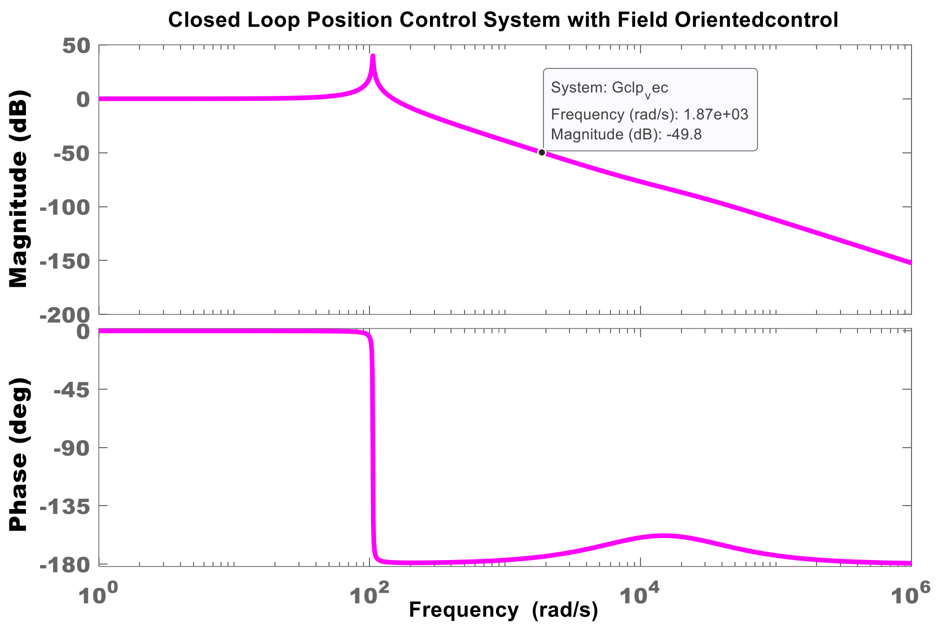

Fig.6: Bode plot of position control with FOC

Fig.7: Electric vehicle moves forward no obstacles detected

Fig.8: Vehicle detects obstacle within 55cm

Fig.9: Vehicle scans and moves left

Fig.10: Detections no obstacle continues and again moves on a forward path

IV. DISCUSSION

The simulation results are shown in Figs. 4, 5, and 6, and they are based on closed-loop transfer functions for speed and position found in (12) and (13) that produce Bode plots. For speed and position control, Figs. 5 and 6 exhibit good stability using FOC.

Prior to hitting an impediment within the detection range (55 cm), as seen in Fig. 7, the vehicle is moving. The car is still moving at this point, with no change in course. Only when an object is spotted within a range of 55 cm is it anticipated to stray from its direction of travel. As demonstrated in Fig. 8, the vehicle recognizes an obstruction at a distance of 55 cm. It is anticipated that at this distance from the target, it will alter its course to avoid colliding with it. This helps shield the object and the car from any harm that might arise from a collision. And Fig. 9 depicts the moment the car starts to veer off course to avoid collision with the object. Finally, as seen in Fig. 10, the vehicle entirely alters its direction of motion. The vehicle has successfully avoided colliding with the object at this moment. After then, it moves along a new path that is free of obstacles once more until it comes across another one that is within its detecting range.

V. CONCLUSION

The study presents the implementation of Field Oriented Control (FOC) using PID Controller for a brushless direct control (BLDC) motor to detect obstacle avoidance electric vehicle. A state space model of the BLDC motor with FOC was model and simulated using MATLAB/Simulink to validate the stability of the proposed system. The overall system was validated in real time implementation using micro-controller and Ultrasonic Sensor. The detection and recognition of objects, as well as making an autonomous decision to change its trajectory which is based on predetermined threshold distance of 5cm were analyzed. And when an obstacle within 55 cm of the robot advances in front of it, ultrasonic waves reflected by the object are sent to micro-controller. The robot halts, then uses the Ultrasonic Sensor to scan to the left and right to determine the current distance. The robot will get ready to make a left turn if the left side is further away than the right side. Each time when obstacle gets into path, the device moves to left direction so that collision is avoided.

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