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Design of BLDC Motor Controller

S. Suraj[1], P Gokul Raja[2], D.J. Arun[3], Aravindan P[4]

[12]U.G Student, Dept. of Robotics and Automation, P.S.G College of Technology, Coimbatore – 641004
[34]Project Associate, Dept. of Electrical and Electronics Engineering, P.S.G College of Technology, Coimbatore – 641004

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Abstract - *This research paper demonstrates the successful implementation of Brushless DC (BLDC) motor control without the need for external position or speed sensors. The sensorless method offers a cost-effective solution with diverse applications. By varying the duty cycle of Pulse-Width Modulation (PWM) signals sent to the motor driver, remote speed adjustments are achieved via a user-friendly IoT application. The integration involves an Arduino Uno and an ESP8266 ESP-01 Wi-Fi module to enable remote control. Users interact with the Blynk IoT application, which features a slider for speed adjustment. The Arduino translates the slider's position into specific PWM duty cycle values, which, in turn, determine the motor's speed. This opens up new possibilities for automation, particularly within computer-integrated manufacturing where it enables material-based speed adjustments.*

Key Words: electrical machines, brushless DC motors, PWM, Wi-Fi Module, Control algorithm

1. INTRODUCTION

The widespread presence of DC motors in numerous applications highlights their crucial role in our everyday lives. Among these, the Brushless DC (BLDC) motor has gained significant attention due to its inherent advantages, which include noise reduction and improved efficiency. BLDC motors are nowadays becoming more and more popular in various applications due to their superior controllability and performance such as high efficiency due to reduced losses, compactness, long operating life, high dynamic response, noiseless operation, low maintenance, lower switching loss, low rotor inertia and better speed versus torque characteristics [7],[8]. In addition, the ratio of delivered torque to the size of the motor is higher, making it useful in applications where space and weight are critical factors, especially in aerospace applications [1]. Moreover, in certain hazardous locations, the application of DC brushed motors is limited because of the arcing [6]. However, achieving precise control of BLDC motors requires careful consideration of the motor's specifications when choosing a suitable driver and controller. Their efficient performance, along with sensorless and sensor-based control methods, makes them adaptable for various applications. To fully harness the capabilities of a BLDC motor, it is essential to select the driver and controller judiciously, taking into account factors such as power requirements, voltage compatibility, and control method. Furthermore, this project investigates the incorporation of IoT technology for remote control, enhancing the motor's usability and accessibility. By examining the intricacies of BLDC motor control and its alignment with the motor's specifications, this project contributes to the expanding field of motor control and automation.

2. CONTROL METHODS

First, the sensored control methods are discussed. One of the control methods used for controlling BLDC motors is the six-step commutation.

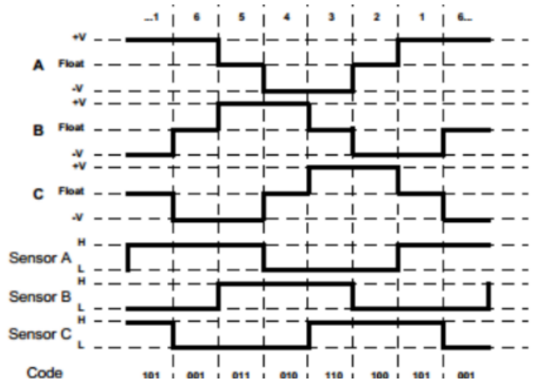

Fig -1: Phase voltage and sensor output waveforms [3]

It involves dividing the electrical cycle into six equal intervals and energizing the stator windings in pairs during each interval to create a rotating magnetic field. The switching sequence used in this method is typically determined based on the position of the rotor. This position can be sensed using either Hall-effect sensors or encoders. While the six-step commutation method offers reliability and simplicity, it may not always yield optimal efficiency. Another control method for BLDC motors is field-oriented control (FOC), which is also known as vector control. FOC is considered a more advanced method that enables precise control of BLDC motors. It achieves this by decoupling the electrical and magnetic axes of the motor. To control the motor, FOC utilizes feedback from Hall-effect sensors or encoders to adjust both the amplitude and phase of the current applied to the windings. This approach maximizes the efficiency and torque output of the motor. Space Vector PWM (SVPWM) is often used in conjunction with FOC for achieving precise control of BLDC motors. This technique involves optimizing the selection of voltage vectors to maximize the motor's performance and efficiency. In SVPWM, rotor position detection is typically done using Hall sensors. These sensors play a crucial role in accurately executing the PWM control strategy.

Sensorless control is an alternative method for controlling BLDC motors that offers a cost-effective solution. It eliminates the need for encoders or Hall-effect sensors, thereby reducing component costs. In sensorless control, the rotor position and speed are estimated using the motor's back electromotive force (back-EMF). As the rotor rotates, the motor generates a back-EMF voltage in the windings, and this voltage varies with the rotor's position. By analyzing the waveform of the back-EMF and employing complex algorithms, the controller can deduce the precise position of the rotor.

One of the advantages of sensorless control methods is their reduced component cost and increased reliability. However, implementing sensorless control methods accurately can be more challenging, particularly at lower speeds and during startup. This is because these methods require sophisticated algorithms and careful tuning to ensure precise control. Despite these challenges, sensorless control methods have gained popularity in various applications, especially in situations where sensor placement is impractical or cost-prohibitive.

3. SELECTION OF CONTROLLER AND DRIVER

Choosing the appropriate motor driver and controller is of utmost importance when aiming to achieve optimal performance with a BLDC motor. The process of selection primarily relies on the specific specifications of the motor, encompassing voltage, rated current, and power. Let us delve into how these factors exert an influence on the decision-making regarding the driver and controller:

The voltage rating assumes a significant role in this regard as the driver and controller ought to be compatible with the motor's voltage rating. It is crucial to carefully choose the components that regulate the power demands of the motor in order ensure safe operation. Moreover, the driver should possess a current rating that coincides with or surpasses the motor's rated current. This particular criterion ensures that the driver is fully equipped to supply the indispensable current to effectively drive the motor, all the while avoiding the perils of overheating or overloading. Furthermore, the power rating of the motor plays a pivotal role in determining the type of driver and controller that is necessitated. In instances where the power rating of the motor is relatively high, it may be imperative to employ more robust and capable drivers and controllers, as they are proficient in handling the augmented power demands. Lastly, the chosen control method, whether it be sensored or sensorless, should impeccably align with the motor's specifications and application requirements.

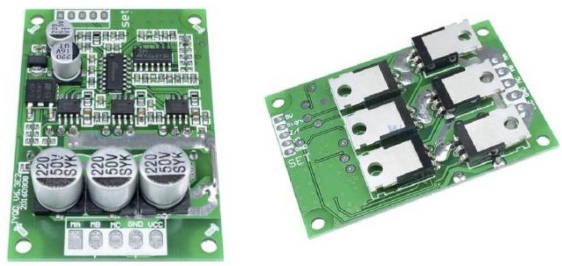

Fig -2: Brushless Motor Controller DC 12-36V 500W PWM Driver Board (Sensorless)

The process of selecting the most suitable motor driver and controller is undeniably intricate, as it necessitates thorough consideration of various factors such as voltage rating, rated current, power rating, and control method.

4. WORKING

The functioning of a brushless DC (BLDC) motor is a complex and synchronized process that involves a meticulously coordinated sequence of signals to the motor windings. This sequence is made to ensure that the rotor spins in the desired direction and at the desired speed. To understand the working of a BLDC motor, it is important to examine each step of the process in detail.

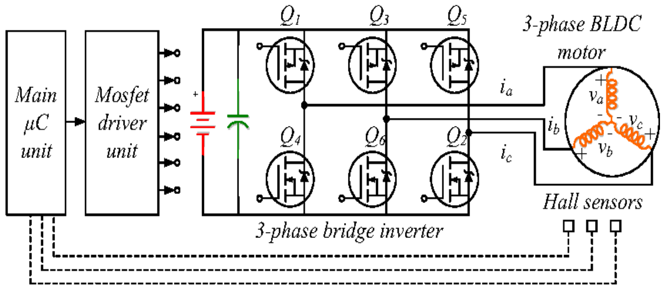

Fig -3: BLDC Motor Control diagram [3]

In a sensored BLDC motor control system, position sensors, such as Hall-effect sensors, play a crucial role in providing feedback on the rotor's position. This information is essential for determining the appropriate phase sequence that needs to be energized in the stator windings. By accurately sensing the position of the rotor, the controller can effectively calculate the optimal timing for commutation.

Commutation is a fundamental aspect of BLDC motor operation. It involves the controller determining the precise timing for energizing the stator windings in the correct sequence. This sequence of energizing the windings creates a rotating magnetic field, which interacts with the permanent magnets on the rotor. This interaction is what ultimately leads to the generation of torque and the rotation of the rotor. To facilitate the commutation process, the motor controller generates gate signals for the power electronic switches, typically six MOSFETs, in the three-phase inverter. These gate signals are responsible for controlling the timing and duration of current flow through the motor windings. By carefully manipulating these signals, the controller can effectively switch the MOSFETs in the inverter, directing the current through the stator windings.

The torque production in a BLDC motor is a result of the interaction between the magnetic field and the rotor's permanent magnets. By switching the MOSFETs in the inverter, the controller will direct the current through the stator windings such that it generates a torque, causing the rotor to turn. This torque production is a crucial aspect of BLDC motor operation, as it is what enables the motor to perform useful work. Throughout the operation of the BLDC motor, the controller continuously monitors the motor's characteristics. This monitoring allows the controller to make necessary adjustments to the commutation and timing to maintain the desired speed and torque. Feedback mechanisms, such as back-EMF voltage, play a vital role in fine-tuning the motor's operation. By utilizing these feedback mechanisms, the controller can make precise adjustments to ensure optimal motor performance.

In certain applications, speed control is a significant requirement. To achieve speed control in a BLDC motor, the duty cycle of the Pulse-Width Modulation (PWM) signals sent to the motor can be varied. By effectively regulating the average voltage thereby the power delivered to the motor through the manipulation of the PWM signals, the speed of the motor can be controlled. This speed control capability adds advantage to the operation of BLDC motors, making them suitable for a wide range of applications. Understanding the details of these processes is crucial for maximizing the performance and functionality of BLDC motors in various applications.

5. SPEED CONTROL USING IOT

In this particular segment, the primary focus revolves around the remote manipulation and regulation of the rotational velocity of a Brushless Motor encompassing state-of-the-art Internet of Things (IoT) technology. This cutting-edge technology encompasses the integration of an Arduino Uno, an ESP8266 ESP-01 Wi-Fi module, and the Brushless Motor Controller DC 12-36V 500W PWM Driver Board. The ultimate objective is to establish a wireless connection between the motor controller and the aforementioned components through the ESP8266 Wi-Fi module, allowing the regulation and alteration of the motor's speed through the manipulation of the Pulse Width Modulation (PWM) signal's duty cycle. This intricate process comprises a series of pivotal steps, each holding significant importance in the overall functionality and success of the project.

In order to ensure efficient operation of the motor, it is of utmost importance to connect it in strict accordance with the manufacturer's specifications. This entails providing the motor with the appropriate power supply and establishing the necessary connections, although specific details regarding these procedures are not explicitly mentioned within this context.

Within the motor controller, a designated pin is specifically allocated for the purpose of regulating the motor's rotational velocity. This particular pin is linked to one of the Arduino Uno's PWM pins, thereby enabling the user to adjust the duty cycle of the PWM signal, consequently facilitating the desired changes in the motor's speed. The seamless integration of the ESP8266 ESP-01 Wi-Fi module with the Arduino Uno serves as a pivotal enabler in establishing a stable and reliable connection between the motor controller and the Blynk IoT application via Wi-Fi. This amalgamation ultimately paves the way for the realization of remote speed control, thereby enhancing convenience and accessibility.

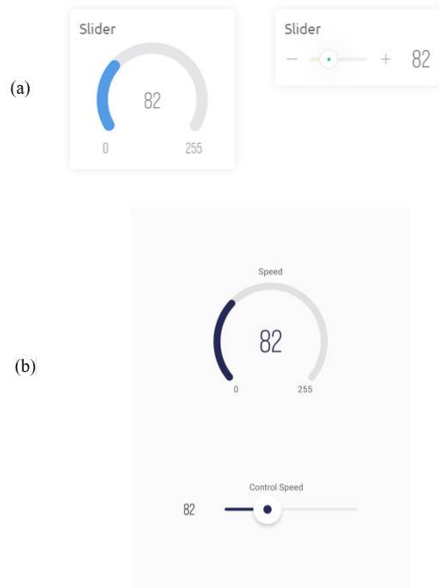

Fig -4: Blynk IoT Dashboard in (a) Website (b) Mobile Application

The effective utilization of the Blynk IoT application represents a crucial aspect of this project. This user-friendly application serves as a platform for creating a highly intuitive and visually appealing user interface that facilitates the regulation of the motor's speed. The provided source code establishes seamless communication between the Blynk IoT app and the motor controller, thereby granting the user the ability to effortlessly control the motor's speed through the utilization of a slider interface.

The successful execution of the project necessitates the development of the Arduino code and uploading them onto the Arduino Uno. This code is specifically designed to configure the hardware components and establish a stable connection with the Blynk application. Upon execution, the code effectively maps the position of the slider within the Blynk IoT app to the desired motor speed, subsequently adjusting the PWM duty cycle in a precise and efficient manner. It is important to note that the Wi-Fi-connected ESP8266 module acts as a vital communication bridge between the Blynk application and the motor controller, thereby effectively translating the user's slider inputs into precise and accurate speed adjustments through the utilization of PWM control.

6. SETUP AND CIRCUIT DIAGRAMS

The process of setting up the hardware components for the motor begins with providing a regulated power supply within the specified voltage range of 12-36V. This ensures that the motor receives the appropriate amount of power. To establish the connections, the VCC and ground (GND) pins of the motor controller should be connected to the corresponding voltage and ground terminals. This ensures the proper flow of electricity. Additionally, the MA, MB, and MC pins of the motor controller need to be connected to each phase of the motor.

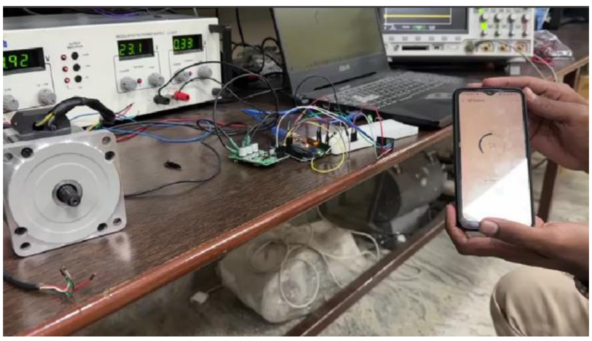

Fig -5: Demonstration of Speed Control using Blynk IoT Mobile Application

The Arduino Uno, a widely used microcontroller board, plays a crucial role in controlling the motor's speed. To enable speed adjustments, the VR (speed control) port of the motor controller should be connected to one of the Arduino Uno's PWM pins, such as Pin 9. This connection allows the Arduino Uno to regulate the speed of the motor by utilizing pulse-width modulation (PWM) techniques. By varying the width of the pulses, it can effectively control the amount of power delivered to the motor, thereby adjusting its speed accordingly.

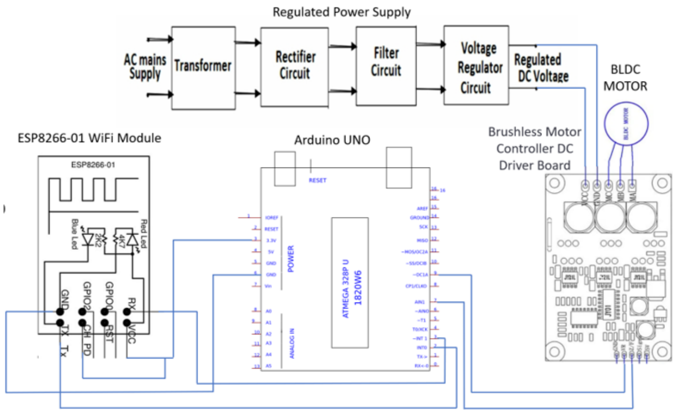

Fig -6: Diagram representing circuit connections for speed control of motor using IoT

The ESP-01 module serves as the key component responsible for enabling Wi-Fi connectivity, which allows for remote control of the motor. To establish communication with the ESP-01 module, several pins need to be properly connected. The TX pin and RX pin of ESP-01 should be connected to digital pins of Arduino UNO board to enable communication between the Wifi Module and the controller. Lastly, the EN pin (Enable) of the ESP-01 module is utilized to enable or disable the module.

To create a user-friendly dashboard for controlling the motor's speed, the Blynk IoT app can be used. This app is available for download on various app stores, making it easily accessible to users. By configuring the hardware and establishing a connection with the Blynk app using the Blynk AUTH token, users can effectively control the motor's speed. The code implemented in the Arduino Uno maps the slider values from the Blynk IoT app to control the motor's speed. By uploading the code to the Arduino Uno, users gain remote control over the motor's speed, allowing for convenient and flexible adjustments. The Wi-Fi-connected ESP8266 module facilitates the communication between the Blynk app and the motor controller. It serves as a bridge, translating the slider inputs from the app into precise speed adjustments through the implementation of PWM control. This seamless communication and control process ensures a smooth and efficient user experience.

7. CONCLUSION

This paper successfully demonstrated the precise control of a Brushless DC (BLDC) motor using a sensorless method, thereby eliminating the requirement for external position or speed sensors. Moreover, using the Internet of Things (IoT) technology, specifically an Arduino Uno and an ESP8266 ESP-01 Wi-Fi module, grants the ability to remotely control the speed of the motor through the Blynk IoT application. This innovative amalgamation of sensorless BLDC motor control and IoT connectivity opens up a vast array of possibilities for automation, particularly within the realm of computer-integrated manufacturing. By employing coding and classification systems such as DCLASS, MCLASS, and the OPTIZ coding system, it can be made possible to customize the motor's speed according to specific code of the material which is based on the material properties. This capability proves to be particularly advantageous in tapping applications, as it facilitates the adjustment of the motor's speed based on the properties of the material, thereby optimizing efficiency and precision.

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