International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I9P133

Volume 72 Issue 9, 361-366, September 2024

Original Article

Sensor-Less Back-EMF Integration for Control of Brushless DC Motors for Electric Vehicles

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Received: 15 September 2023 Revised: 09 January 2024 Accepted: 26 August 2024 Published: 28 September 2024

***Abstract** - In order to regulate the rotational speed of a Brushless DC (BLDC) motor for an electric vehicle, an AC-DC converter is shown here. There are two steps to the converter. A diode bridge rectifier is used in the first stage, followed by a DC-DC buck converter in the second. A DC-link capacitor couples the two stages and smooths down the ripple at the rectifier's output. Knowing the rotor location is crucial for speed regulation in BLDC motors. This project presents the use of an EMF-based sensor-less control technique for rotor position detection. To manage the rotational velocity of the BLDC motor, a feedback control system based on Pulse Width Modulation (PWM) has been developed for the DC-DC buck converter. This technique has been implemented for the speed control of brushed DC motors, but nowadays, there is a vast number of applications for the BLDC motor. So, an efficient speed control system is necessary. Sensor-less speed control technique overcomes the shortcomings of the sensored control technique, such as temperature sensitivity and higher costs. Hence, this project presents the implementation of sensor-less control for the speed control of BLDC motors for electric vehicles using MATLAB/SIMULINK.*

***Keywords** - Brushless DC motor, Sensor-less back-EMF integration, Commutation points, AC-DC converter, Continuous conduction, DC-DC converter, Feedback control, Pulse width modulation*.

1. Introduction

The benefits of Brushless DC (BLDC) motors include increased efficiency, dependability, and a greater operating speed range. Because of these distinguishing features, BLDC motors are increasingly being used in fields as diverse as the automotive, aerospace, biomedical, and robotics industries[1]. Due to its effectiveness in lowering the price and dimension of the motor while simultaneously raising the consistency of the method, sensor-less control of Brushless Direct-Current motors (BLDCs) has attracted significant attention as a research topic[2]. Using techniques like zero-crossing detection of the back-EMF, integration of the third harmonic voltage [3] [4], detection of the conduction of the free-wheeling diodes, and integration of the back EMF, sensorless controllers for BLDC motors have been developed. In this case, a DC motor's rotational speed is regulated by a two-phase, unidirectional AC-to-Direct Current converter.

The buck converter's output is required to be controlled in order to control the speed of the motor, and this may be done with a good response control loop. The performance of a feedback loop is very sensitive to disturbances, making it difficult to design an effective loop. The switching actions of semiconductor strategies such as MOSFETs, diodes, and transistors induce these disturbances via load fluctuations, input voltage changes, and electromagnetic interference. The capacity of the feedback control system to reject disturbances is crucial for achieving the targeted output voltage. The performance of feedback control systems has improved because of the work of several researchers who have suggested many control schemes, including predictive control [5], adaptive control, sliding mode control[6], and fuzzy logic control [7].

1.1. Problem Definition

Increasing demands for DC power are driving the increased use of single-phase AC-Direct Current conversion systems [8] [9] [10]. The standard operating voltage for most devices is between 12 volts and 400 volts DC. Brushless DC motors are used in a wide variety of contexts. As a result, a reliable mechanism for transforming energy is essential.

1.2. Objectives

- This project presents the implementation of the PWM control technique because of its lower complexity. Also, in order to control the speed of the brushless Direct Current motor, it is necessary to locate the position of the rotor so that the supply can be given to the respective phase according to the position of the rotor. For this, Hall sensors are used generally, but because of the high sensitivity of hall sensors to temperature, they may misbehave at higher loads as temperature increases.

- Hence, this project presents the implementation of a sensor-less control technique, which is based on the EMF induced in the motor.
- In order to achieve highly efficient conversion, the rectifier and Direct Current - Direct Current converter should be efficient. As a BLDC motor is used in the project, the noise obtained is very low compared to when a normal DC motor is used.

2. Description of Topology

Figure 1 shows the control strategy for the BLDC motor.

2.1. Sensor-Less BLDC Motor Control

Back EMF is used in sensor-less BLDC motor control, also known as sensor-less trapezoidal control of BLDC motors, to determine where the rotor is in relation to the stator. The rotor of an electric motor will spin when a voltage is supplied across its winding. Similar to the action of a generator, a motor not only accepts an input voltage but also generates its voltage when the rotor passes through the magnetic field of the motor. This voltage is related to the rotational speed of the motor and is called reverse electromotive force (or back EMF). Back EMF may be used on its own, without any other sensors, to determine a motor's rotor speed and position. A microcontroller, digital signal processor, or dedicated driver IC controls the majority of sensor-free BLDC motors because driving a motor with back EMF is not an easy process.

In Figure 2, a PI controller is used for the converter's closed loop operation, which is closer to the two stage AC-DC converter block. AC-DC converter, VSI, which is integrated into the BLDC motor, converts DC input to AC output, and IGBTs are used as switches for the inverter of the Three-Phase BLDC motor. These are the components that are used in the proposed model.

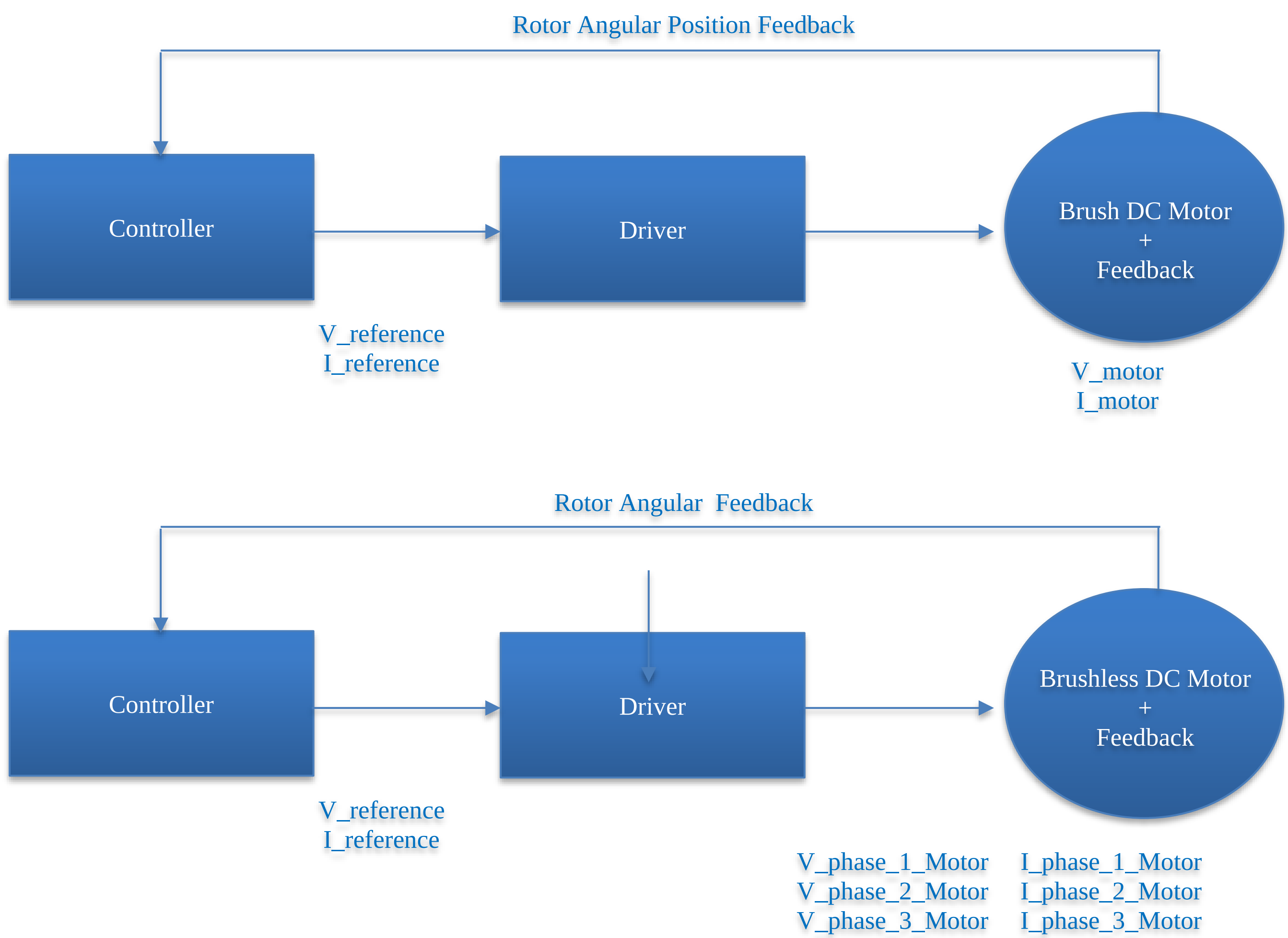

Fig. 1 Speed control strategy for brushless DC motor

2.1.1. Block Diagram

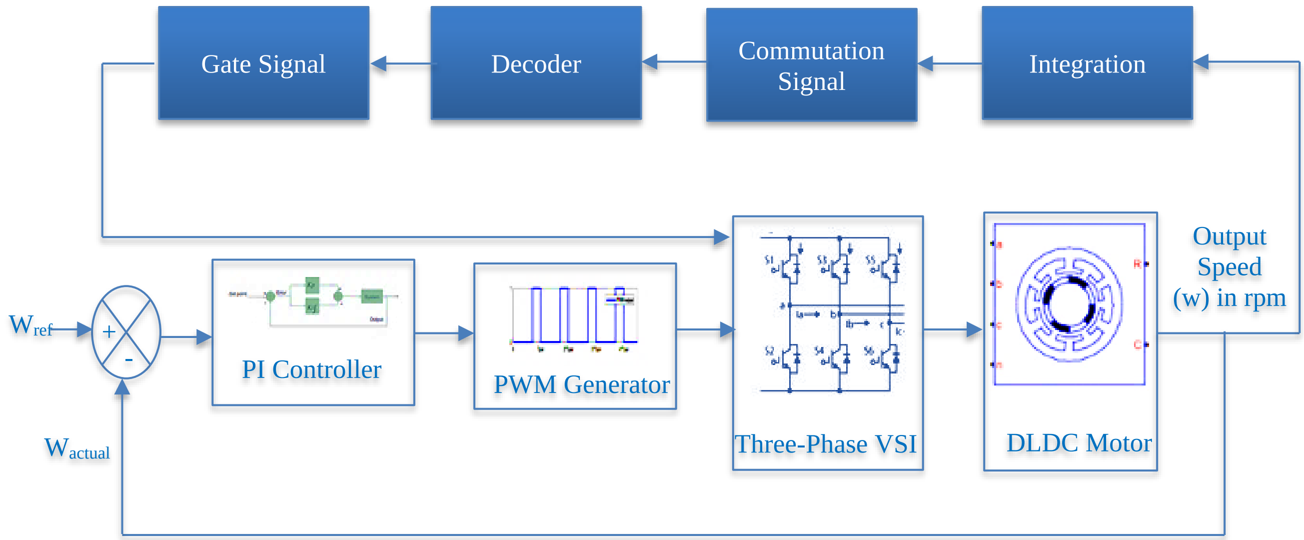

Fig. 2 Block diagram of proposed system

2.2. PI Speed Controller Design

A PI controller is used in the proposed method. The 3-phase BLDC drive's swift and precise response characteristics can be obtained using this controller. The following is the description of PI controller functions: The relative part reduces the aggravation from the plant, while the integral part reduces steady-state error in the system. Error is proportional to the proportional part:

$$U = Kpe(t)$$

The integral part will vary in proportion to the area under the error curve:

$$U = KI * \int e(t)dt \quad (1)$$

Then, the PI controller can be represented as

$$U(t) = Kpe(t) + KI \int e(t)dt \quad (2)$$

Where,
e(t) = speed reference – actual speed

2.3. Front End AC-DC Converter

The AC-DC conversion block described in this paper essentially involves two stages. The first stage is an AC-Direct Current converter, which is a full bridge rectifier. Since the rectifier operates at the power frequency of 50 Hz, switching loss is not a problem. By attaching a capacitor to the rectifier's output, ripples in the rectifier's output are reduced to a minimum.

2.4. DC-DC Converter

The second phase is the Direct Current - Direct Current converter, which converts fixed DC into variable DC, which is nothing but a buck converter [9]. An inductor (L), a capacitor (C), a switch (S), and a diode (D) make up the components. The DC motor receives the converter's output. The converter can be operated in continuous conduction mode by proper selection of the diode with a proper switching frequency and a duty cycle of D. The size of the inductor can be found by using the formula given below:

$$L_{(Buck\ converter)} \geq DT / 2T * (V_{input} - V_{output}) \quad (3)$$

2.5. The BLDC Motor and Speed Control

The amount of error is obtained from its reference value and the actual speed of the motor.

$$e(t) = \omega(\text{ref}) - \omega(\text{actual}) \quad (4)$$

Where,
$e(t)$ = error obtained
W(ref) = reference speed
W(actual) = speed of the motor

The error obtained is given to the PI controller, which reduces the error; hence, the speed of the motor is controlled.

2.6. Integrator

The output speed of the motor is integrated to find the rotational angle. Using this rotational angle, the position of the rotor can be found, and according to that position, the gate pulses will be given to the respective phases of the 3-phase inverter.

2.7. Commutation Signals

The mechanical angle obtained from the integrator is converted into an electrical angle inside this block, and after finding the electrical angle, the phase to be fired will be known.

2.8. Decoder

In this block, the output from the commutation signals block is decoded. According to that output, the direction of the back EMF can be known.

2.9. Gates

Once the EMF direction is known, according to the direction, the gate signals which will be given to the switches of the inverter are generated. According to the gate pulses, the phase to which the input voltage is to be given will be decided.

3. Result and Discussion

Figure 1 shows the Simulink diagram. Here, the actual speed is compared with the reference speed. By comparing the actual speed with the reference speed. An error is obtained if they are not equal. The pi controller reduces that error.The output of the PI controller is given to the input of the PWM generator. From that, it is given to the subsystem. The subsystem consists of a 3-phase power supply, diode bridge rectifier, DC-DC buck converter [11-13] and inverter. 400Vrms value is given to the 3-phase power source. That input is given to the rectifier, which converts AC to DC. A DC link capacitor is connected to the rectifier to reduce the ripple content. That DC output is given to the buck converter, which steps down the voltage with respect to speed. Next, there will be an inverter. Gate pulses coming from the sensor-less strategy are used to switch the inverter. The sensor-less strategy contains an integrator block, commutation signal, decoder, and gate subsystems. The integrator is used to integrate the speed in rad/sec to convert it into the mechanical angle. This angle is then converted into an electrical angle.

According to this angle, output from the commutation signals subsystem is obtained, which resembles that of the output of hall sensors. Then, these output signals are decoded inside the decoder block to obtain the direction in which back EMF is induced. Then, back EMF direction signals obtained from the previous block are converted into 6 signals, which will be the gate pulses that will be given to the switches of the inverter. In this way, the speed of the motor is controlled. The input voltage given to the rectifier is 550 volts. When this voltage is given, the output of the buck converter that is obtained is 130 volts, as shown in Figure 5. Figure 3 shows the Stator current I_a of the BLDC Motor, and Figure 4 shows the electromagnetic torque.

3.1. Comparison of the Existing and Proposed Model

From the above Figures 6 and 7, the transient period that the DC motor went through before reaching the reference speed is 1 sec, and that of the BLDC motor is 0.08sec. Hence, it can be proved that the operation of the BLDC motor is smooth and efficient and as the BLDC motor is used in place of the normal DC motor, noise in the motor will be reduced, and the performance of the motor in terms of speed has been improved. Also, as sensor-less control is implemented instead of using hall sensors, the motor's inefficiency at high temperatures due to high loads will be decreased. Hence, the performance of the motor is increased.

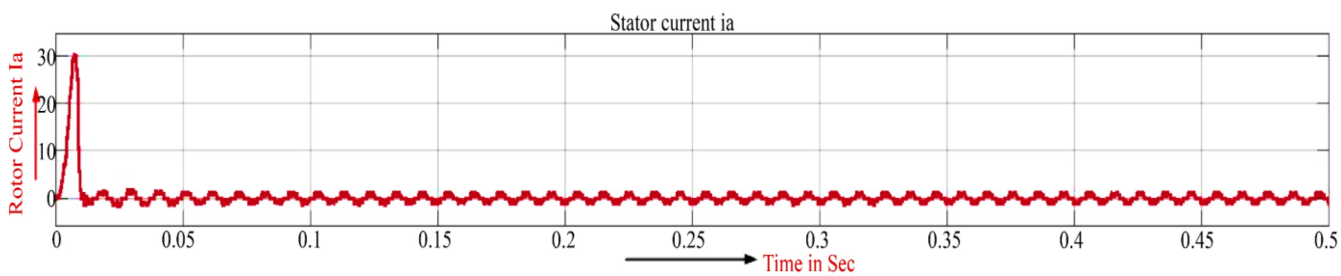

Fig. 3 Stator current I_a of BLDC motor

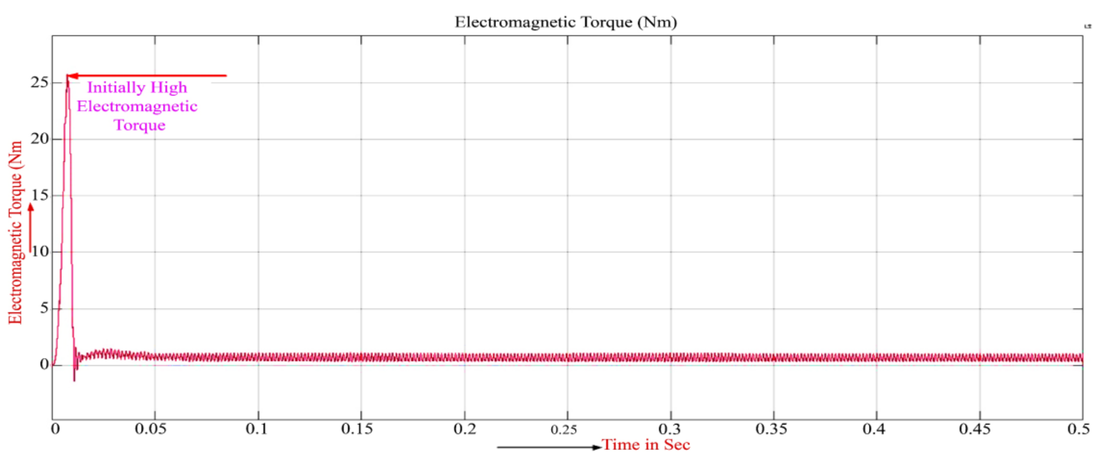

Fig. 4 Electromagnetic of BLDC motor

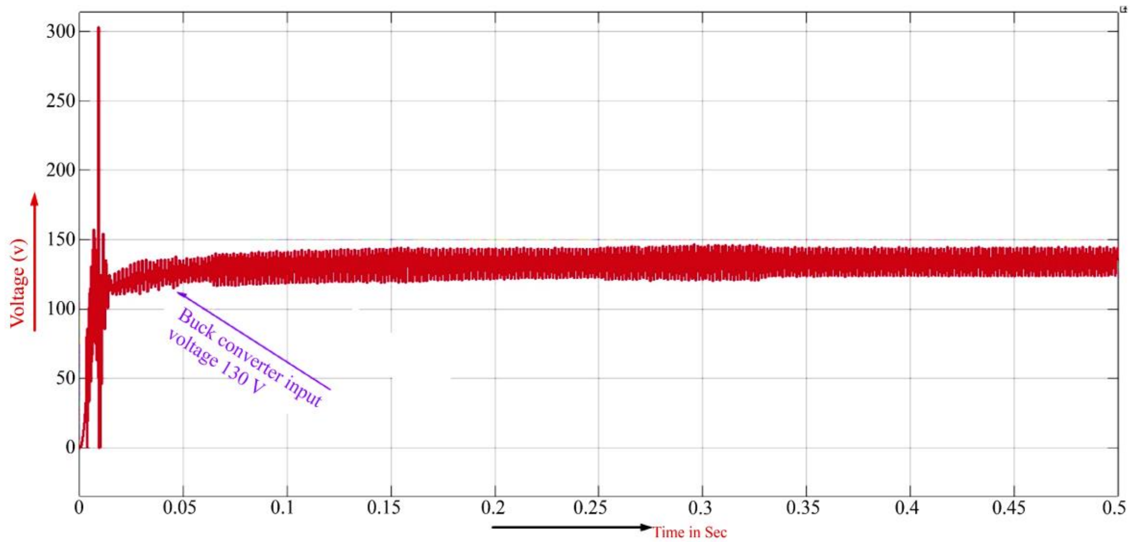

Fig. 5 Buck converter voltage

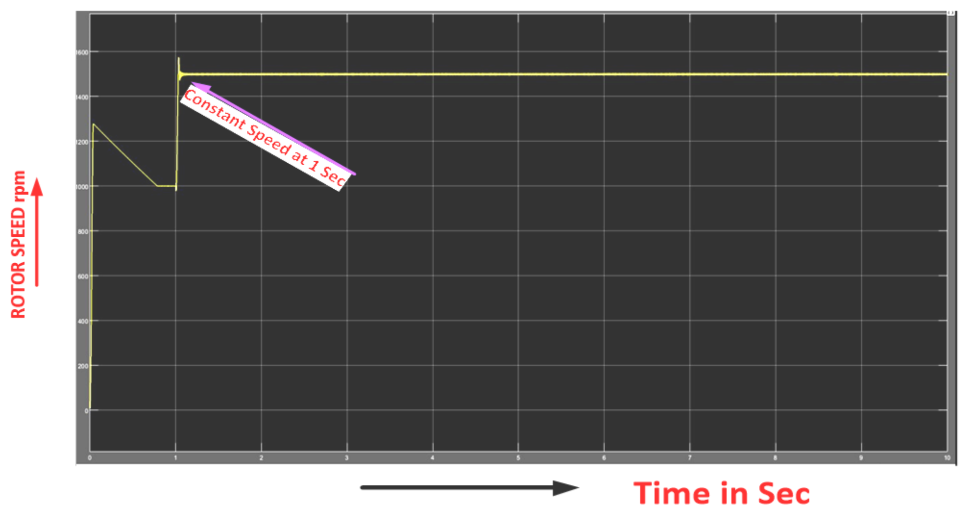

Fig. 6 Speed control of BLDC motor using PWM

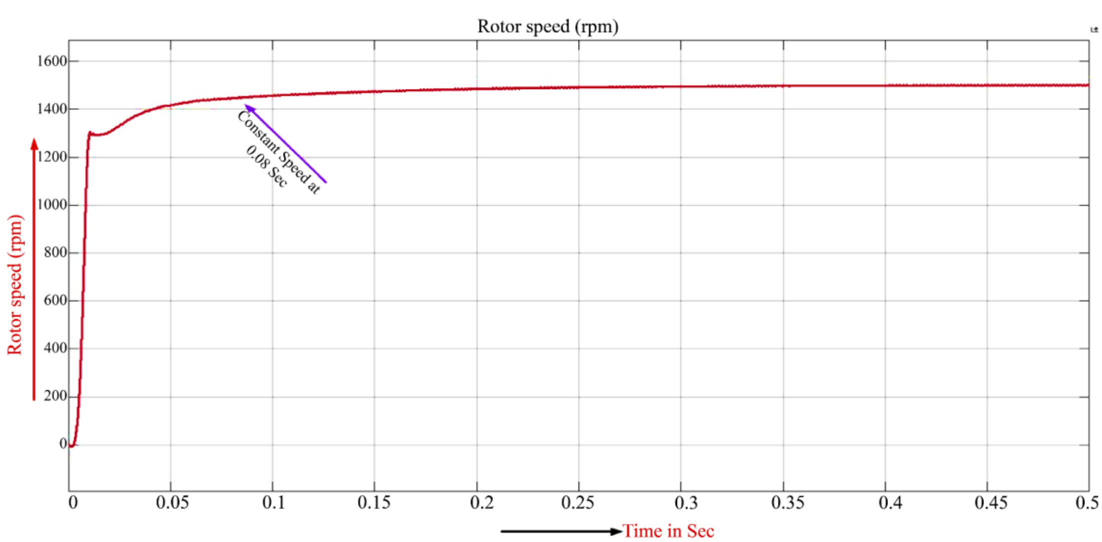

Fig. 7 Speed control of BLDC motor using sensor-less Back-EMF

4. Conclusion

In this study, we implement a sensor-less back-EMF integration technique for control of the BLDC motor that is robust against variations in rotor velocity. Even though the suggested method's angular velocity ripples are initially bigger than those of the control using a position sensor, they eventually disappear when the motor is charged, making the overall response adequate. Although current ripples are often caused by synchronization with commutation points, they may be reduced by adjusting the switching thresholds or using a controller.

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