Design And Implementation of Sensor Less BLDC Motor Control Using PIC Microcontroller

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***Abstract*—BLDC motors are very efficient and reliable. Traditionally, BLDC motor drives apply position sensors (Hall sensors) to sense rotor position for effective commutation. Unfortunately, sensors introduce added cost and complexity, leading to reduced reliability. Sensorless control techniques are favored in order to address these limitations. This paper describes a design and implementation of an efficient sensorless BLDC controller with PIC microcontroller. This system estimates the rotor position based on the generated back Electromotive Force (BEMF) that appears in the windings of BLDC motors. Using these signals, the PIC microcontroller for electronic commutation of a motor controls the switching of three phase inverter. This decreases hardware complexity and costs while allowing for stable and efficient motor operation. Experimental implementation shows smooth motor control and consistent performance across varying operating conditions. The sensorless BLDC motor control method proposed in this paper offers an efficient, simple, and affordable solution that can be used for driving applications: electric vehicles, household equipment, industrial automation, etc.**

***Index Terms*—BLDC Motor, Sensorless Control, PIC Microcontroller, Back-EMF Detection, Electronic Commutation.**

I. INTRODUCTION

BLDC motors are very popular in modern electrical/electronic applications due to their high efficiency, high torque-to-weight ratio, long lifetime and low maintenance. Applications for BLDC motors include electric vehicles, cooling fans, robotics, and various types of industrial automation systems. Conventional BLDC motors employ Hall-effect sensors for rotor position detection for electronic commutation; however, using these sensors adds to the system's overall cost, size and complexity and may lead to decreased reliability under severe operating conditions. To alleviate these drawbacks, techniques for sensor less control have been developed for rotor position estimation without physical sensors. In this work, sensor less control of BLDC motors is achieved using a PIC microcontroller and employs the Back Electromotive Force (Back- EMF) detection methodology to implement control of a BLDC motor. The system utilizes the Back-EMF signal's zero-crossing point to ascertain the rotor position, thus generating the proper power switching. The aforementioned system reduces the complexity of the hardware and increases the overall system's performance and reliability.

II. PROBLEM IDENTIFICATION

BLDC motors are used across many applications due to their reliable performance and energy efficiency; however, the conventional method of implementing a BLDC motor control system typically requires the use of Hall-effect sensors to determine rotor position for commutation. The implementation of Hall-effect sensors often results in increased system costs, increased physical size of the system, and more complicated electronic circuitry to drive the motors as well as increased complexity associated with using Hall-effect sensors at high temperatures, when they may not work reliably or under harsh conditions. These problems indicate the need for an improved rotor sensing technique that does not rely on Hall effect sensors in order to increase overall reliability and reduce system cost. Therefore, there is a need for a sensorless technique for controlling BLDC motors that utilizes Back EMF sensing techniques.

III. OBJECTIVE

The primary goal of this study is to develop a sensorless BLDC motor control system using a PIC microcontroller. Instead of utilizing Hall sensors, the system will detect the position of the rotor by monitoring the Back-EMF signal. By employing this approach, the cost and complexity of the hardware will be significantly reduced. Additionally, an emphasis will be placed on providing efficient motor commutation, dependable operation, and enhanced performance of BLDC motors in applications including industrial drive systems and electric vehicles.

IV. SCOPE

This project scope includes creating and implementing a Sensorless Brushless DC (BLDC) motor controller with a PIC Microcontroller. The control system will use Back-EMF detection as a way to determine rotor position without the need for using Hall-effect sensors to determine the rotor position. This method has reduced hardware complexity and increased reliability. The developed controller can be used in many applications, such as Electric Vehicles; Cooling Fans; Robotics; Industrial Automation Systems; etc. In addition, the project provides an affordable solution for more efficient motor control and improved motor performance.

V. ABBREVIATIONS

BLDC: Brushless Direct Current Motor
PIC: Peripheral Interface Controller
BEMF: Back Electromotive Force
PWM: Pulse Width Modulation
MOSFET: Metal Oxide Semiconductor Field Effect Transistor

VI. APPLICATIONS OF THE PROPOSED SYSTEM

1. Electric Vehicles (EVs) Electric vehicles (also known as e-bikes and efficiency, speed control, and extended battery life. By eliminating position sensors through the Sensorless Control technique, both the cost of hardware and the reliability of systems increase.
2. Drones (UAVs) The use of BLDC motors in UAVs is prevalent for the rotation of UAV propellers. The sensorless operation provides a platform for reducing system weight and complexity, which impacts flight efficiency. Furthermore, fast speed response and stable operation during flight are enabled through the sensorless method.
3. Industrial Automation In industrial applications such as conveyor systems, robotic arms, and CNC machines utilize BLDC motors to achieve precise control over both speed and torque output. By adopting sensorless operation for BLDC motors, maintenance is minimized and reliability is enhanced; thus, ensuring continued industrial utilization.

VII. MERITS AND DEMERIT

Proposed Sensorless Control System for BLDC Motors- Great Perks!! No Position Sensor (No Hall Sensor), Low Hardware Level- Higher Reliability- Reduced Maintenance -More Mechanical Parts- Due to Compact Size-Excellent Efficiency- Used in Industrial/Automation, etc.

Drawbacks:
Back EMF at Low-Speed is Hard to Detect; Algorithm is More Complex; Accurate Signal Processing is Required; Electrical Noise May Impact BEMF Detection- Adequate Filter to Avoid Impact on BEMF Detection-Needs Properly Designed Electronics.

VIII. PROPOSED SYSTEM

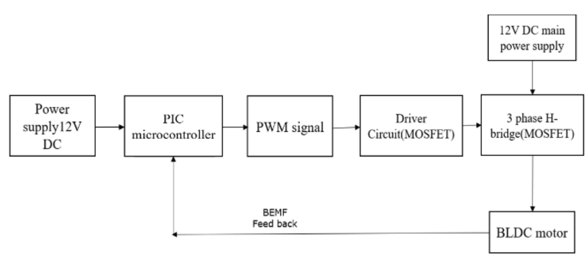

Figure 1. Block Diagram

The proposed system provides a method for controlling a brushless direct current (BLDC) motor using a sensorless controller implemented with a PIC Microcontroller. The system receives an input of 12 Volts DC and provides both the Function and Power for the controller and motor drive. The PIC

Microcontroller will act as the main controller for this system and will create Pulse Width Modulated (PWM) signals that will be derived from motor feedback. The PWM signals will then be used to control the switching of the MOSFET Driver circuit.

The Driver Circuit then takes the control signal and amplifies it to generate a three-phase signal to drive the three-phase MOSFET H- Bridge Inverter that will convert the DC Power from the power supply into the controlled AC Power (three-phase) needed to operate the BLDC Motor.

As the BLDC Motor is turning, each of the motor windings generate back EMF (BEMF) that is fed back to the PIC Microcontroller to allow the controller to determine the rotor position. Using this information, the controller can adjust the switching pattern of the MOSFET Driver circuit to provide appropriate commutation and efficient operation of the BLDC Motor. By eliminating the need for position sensors through the use of this sensorless control technique, the cost and complexity of the overall system will be reduced while also improving system reliability.

IX. POWER SOURCE (12 VOLT - DC)

The entire electrical system gets the necessary voltage for DC from a power supply block. In this case, the project's power supply is provided by either a 12V battery (not rechargeable) or by one with a typical rating to provide room to deliver this amount of current throughout the system. This supply voltage feeds different portions of the circuit (i.e., everything from the main control chip to the output drivers for the motors). If the controller uses a voltage regulator, the input voltage will be 12V but the regulator will output 5V to provide a stable voltage source for the controller. Proper regulation of the returning to a controlled source the application will ensure that every part of the operating system works as designed (e.g., clean signals (no noise), possibility of controlling enough power to operate motors).

X. PIC MICROCONTROLLER

The primary control unit within the overall system is the PIC microcontroller. This unit accepts input signals as well as generates the necessary control signals to operate the brushless DC (BLDC) motor. Through its operation in this project, the PIC microcontroller will utilize back electromotive force (BEMF) feedback from each of the motor phases to provide an estimate of the rotor position. Based on the rotor position estimates produced by the BEMF feedback, the motor controller will determine the appropriate sequence of switches for each of the motor phases. The PIC microcontroller also produces pulse width modulation (PWM) signals to control the speed and operation of the BLDC motor. The PIC microcontroller allows for efficient management of the brushless motor commutation and overall control of the system by incorporating built-in timers, analogue to digital converters, and a fast- processing speed.

XI. OPERATION INSIDE A PIC

In a sensorless BLDC motor control system, the microcontroller in the PIC is responsible for reading the motor's signals, determining the rotor's location, and generating switching signals for the MOSFET driver. The PIC has two significant internal tasks; it has an ADC (Analog to Digital Converter) that converts the BEMF (Back Electromotive Force) signals produced by the motor phases when the rotor turns from an analog value to a digital value, and the second task is to obtain a virtual neutral voltage. ADC The BLDC motor produces BEMF as it turns, which is an analog value generated by each motor phase. The PIC uses its built-in ADC to convert the analog phase voltage (BEMF) into a digital value. The PIC continually samples the phase voltages of the motor to collect digital value, and then pole position is identified (using the BEMF waveform zero crossing point) as the trigger to enable switching the next motor phase to continue the motor turning. Virtual Neutral Point-In many brushless DC (BLDC) motors there is no physical neutral point present for the three-phase winding. As a result, the system needs to establish a Virtual Neutral Voltage from the electrical potential of the three phases using RLC (Resistors, Inductors, or Capacitors) to create an average voltage representative of the three phases. Typically, this voltage will be set to approximately 1/2 of the DC Bus (Vdc Due to the fact that the BEMF (Back EMF) of the disconnected floating phase will continue to oscillate about this virtual neutral voltage, when it crosses this virtual neutral voltage, the PIC will recognize this as a zero-crossing event. The occurrence of a zero-crossing event indicates to the PIC where the rotor is located and when to subsequently perform the next commutation of the motor.

By using this approach for zero-crossing detection through ADC (Analog to Digital Converter) and virtual neutral voltage comparison; the PIC microcontroller is able to accurately control the BLDC motor without requiring Hall Effect Sensors, which results in a decreased cost and increased reliability of the overall system.

XII. SIGNAL GENERATION WITH PWM

This section explains how the PWM (Pulse Width Modulation) signal block controls the speed of a BLDC (Brushless Direct Current) motor. PWM signals generate variable duty cycles of a digital signal at a fixed frequency. The PIC (Peripheral Interface Controller) microcontroller will produce the PWM signals according to the speed required by the motor. When the duty cycle is increased, the motor receives more average voltage (Hertz), which results in greater speed. When the duty cycle decreases, this will reduce the motor's speed. Therefore, PWM controls are used extensively because they offer efficiency and limit power loss. By allowing for accurate and repeatable motor speed control, PWM also provides for a stable operating state, and increases the efficiency of the motor drive system.

XIII. THE DRIVER CIRCUIT (MOSFET DRIVER)

A driver circuit connects a PIC to the power MOSFETs in the inverter stage. The output of the PIC contains low-power logical signals that cannot drive the gate of a MOSFET without amplification. Therefore, the driver circuit amplifies the signals from the PIC and provides the necessary voltage and current to switch the MOSFETs properly. The driver circuit allows for fast switching and isolates the control circuit from the power stage. A MOSFET driver protects the microcontroller from overvoltage conditions and improves switching performance, resulting in lower power loss and increased overall efficiency of a BLDC motor control system.

XIV. THREE-PHASE H-BRIDGE (MOSFET INVERTER)

The power stage of the brushless DC (BLDC) motor driver is a three- phase H-bridge circuit with six (6) transistors made from metal oxide semiconductor field effect transistors (MOSFETs) being used in the configuration of a three-phase power supply inverter. The H-bridge circuit converts the energy supplied from the battery (or similar DC energy source) to create a controlled three-phase ac voltage to drive a BLDC motor. The H-bridge controller switches (turns ON or OFF) the MOSFETs in a specific sequence based on the output signals from the PIC microcontroller, thus creating the magnetic field necessary to rotate the rotor of the motor. One of the main functions of the H- bridge is to provide adequate power to the motor and deliver enough energy efficiently to ensure proper operation of the motor.

XV. BLDC MOTOR

Brushless DC Motors (BLDC) are one of the key output devices in the system that convert electric energy into motion by producing mechanical rotation. Unlike traditional brushed DC motors, BLDC motors do not use any kind of brush for the purpose of commutation. In BLDC motors, electronic switching is used to accomplish this task. In fact, the microcontroller controls this electronic switch, turning on and off the stator phase winding in an orderly manner to create an electromagnetic field that moves the rotor. BLDC motors are recognized for being very efficient, having very little maintenance required and their long working life span.

Therefore, they have been extensively used in Electric vehicles, High-performance RC vehicles, UAVs (Drones), Industrial Automation, and Domestic Household Appliances. This project will control the operation and speed of the motor using PWM signals and Sensorless Commutation techniques.

XVI. BACK EMF (BEMF) DETECTION AND ZERO CROSSING METHOD

The BEMF that is generated from each one of the three windings on a BLDC motor will act against the supplied voltage as the motor rotates. The result of these three windings generating BEMF is a 120° phase shift, just like the signals received from the hall effect sensors. The figure below shows how both the hall effect sensor signals and the BEMF signals relate to one another.

In the diagram above it can be seen that the BEMF signals do not line up with the hall effect sensor signals (30° phase difference). In normal operation (one of three possible phases is rotated through each time there is a 60-degree rotation of the motor) at all times two phases will be powered (one with positive and one with negative voltage) and the third phase will be open. The third phase will be used to determine when the BEMF crosses zero, so by using the combination of all three phases' zero crossing signals we can produce our energizing sequence. In total there will be 6 zero crossing occurrences. (For each phase A, B, and C there are two zero crossing occurrences, one as the voltage goes from positive to negative and the other from negative to positive.) Coil Frequency and Switch Timing: The PIC microcontroller produces the PWM signal for the MOSFET driver and the three-phase inverter in the suggested sensorless brushless DC motor control system. PWM frequency ranges from approximately 10 kHz to 20 kHz; this will allow for smooth motor operation, reduce the amount of switching noise, and result in improved motor torque production. The PWM signal provides control of the voltage that is applied to the motor and, therefore, controls the speed of the motor. The brushless DC (BLDC) motor uses electronic commutation to energize (turn on) the three windings of the motor, that is, the three windings are turned on in a sequential fashion. The rotor position is determined by the back electromotive force (BEMF) from the windings; thus, the timing of the switches in the motor is dependent upon the rotor position as detected by the BEMF feedback signal. The motor will go through a six-step commutation process or a complete electrical cycle is made every 60 EC degrees of rotation. As an example, if a motor is rotating at a speed of 3000 RPM, the electrical switch frequency would increase. The PIC microcontroller determines when to change switches by measuring when a zero-crossing occurs with respect to the BEMF signal. Once the zero-crossing has been detected, there is a 30 EC degree delay before the next MOSFET pair is changed from the previous MOSFET pair; the delay will ensure that the rotating magnetic field produced by the stator windings perfectly aligns with the magnets on the rotor and produces a smooth

XVII. HARDWARE IMPLEMENTATION

The implementation of a sensorless BLDC motor control system has been developed, and the components necessary for implementation are identified below. The implementation of the proposed control system will use Embedded C for programming, and development will take place in MPLAB IDE. The source code will be compiled and uploaded to a PIC microcontroller via a programmer. The PIC microcontroller will generate PWM signals to control the ON/OFF switching of power MOSFETs, ensuring correct commutation of the motor. The total hardware setup was designed to allow BEMF (back EMF) detection as a means of creating a sensorless BLDC control system.

The following is a list of the components that will be used for implementation:

- 12 V DC Power Supply/Battery
- PIC16F887 microcontroller
- MOSFET Driver Circuit (IR2101 or equivalent)
- Power MOSFETs (Three-Phase Inverter Bridge)
- BLDC Motor
- BEMF Detection Circuit (Comparator/Voltage Divider)
- Voltage Regulator (5V for Microcontroller)
- Passive Components (Resistors, Capacitors, etc.)

All of these components will combine to create a sensorless BLDC motor control system using BEMF for rotor position detection and PWM electronic commutation for motor control.

XVIII. RESULT AND DISCUSSION:

The inverter stage converts the DC supply into controlled three-phase signals required to operate the BLDC motor. The motor phases generate BEMF signals, which are sensed using a resistor network. Since the neutral point of the motor is not available, a virtual neutral voltage is created. The PIC microcontroller uses its ADC module to read the BEMF signals and detect the zero-crossing point, which indicates the correct switching time for the next phase.

Based on this detection, the controller performs six-step commutation to rotate the motor smoothly. The PWM duty cycle controls the motor speed. Experimental results show that the system operates efficiently with reduced hardware components and improved reliability. The proposed system is suitable for applications such as electric vehicles, drones, and industrial automation.

The inverter stage is responsible for converting the DC supply voltage into controlled three-phase voltages that are required to operate the BLDC motor. The three phases of the motor generate back EMF (BEMF) voltage signals, which are sensed by a resistor divider network. The neutral point of the motor is not available; therefore, a virtual neutral voltage is created to provide a reference voltage. The microcontroller (using its ADC module) reads the BEMF voltage signals and determines the zero-crossing voltage signal (when the BEMF voltage crosses zero). This signal provides information on when to switch the drive to the next phase of the motor. The controller will implement six-step commutation based on the detection of the zero-crossing signal, thereby allowing for smooth rotation of the motor. The PWM (pulse-width modulation) duty cycle also provides the ability to control the speed of the motor. The results of the experiments demonstrate the effective operation of the system based on reduced hardware components and increased reliability. Therefore, the proposed system is well suited for use in electric vehicle applications, drones, and industrial automation.

XIX. BRUSHLESS DC MOTOR CONTROL WITH PIC16F887 MICROCONTROLLER CIRCUIT

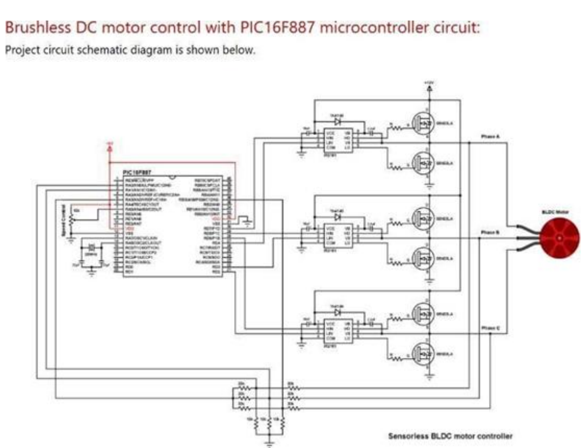

Figure2. Circuit Diagram

All ground terminals in the circuit are electrically common and connected together. A brushless DC motor operates using three phases, which are represented in the circuit as Phase A, Phase B, and Phase C. In this system, two separate power supplies are used. A 5 V supply powers the microcontroller, while a 12 V supply drives the three-phase inverter bridge and the BLDC motor.

Three 33 kΩ resistors are connected to the motor phases, and another set of three 10 kΩ resistors forms voltage divider networks. These dividers reduce the phase voltage because the microcontroller cannot directly handle the 12 V supply level. An additional set of three 33 kΩ resistors is used to create a virtual neutral point. This virtual midpoint is connected to pin RA3 (pin 5), which serves as the positive input of comparator 1 in the PIC16F887 microcontroller.

The PIC16F887 contains two analog comparators, but only comparator 1 is required in this design. Its positive input is connected to the C1IN+ pin (pin 5), while the negative input can be linked to any of the pins C12IN0 (pin 2), C12IN1 (pin 3), C12IN2 (pin 36), or C12IN3 (pin 34). In this configuration, the virtual neutral point is applied to the positive input of the comparator, while the back electromotive force (BEMF) signals from the motor phases are connected to the negative inputs. Specifically, the BEMF of Phase A is connected to pins 2 and 3, and the BEMF of Phase C is connected to pin 36.

The microcontroller continuously compares the virtual neutral voltage with the selected phase BEMF signal to determine the correct commutation timing. This approach reduces the need for additional hardware and simplifies the overall circuit design. The IR2101 driver ICs are used to control the high-side and low-side MOSFETs of each inverter phase. Switching between these MOSFETs is controlled through the HIN and LIN input signals, as illustrated in the timing diagram for both input and output signals.

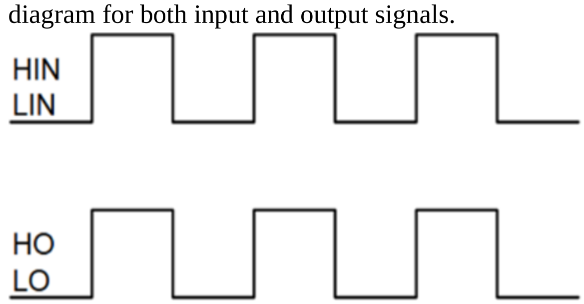

Figure 3. Timing Diagram

All three HIN lines of the IR2101 are connected to their respective pins: HIN phase A to P1D (RD7), HIN phase B to P1C (RD6), and HIN phase C to P1B (RD5), while the three LIN lines connect to their respective pins of: LIN phase A to RD4, LIN phase B to RD3, and LIN phase C to RD2. The PIC16F887 has one CCP module (Capture/Compare/PWM module) and one ECCP module (Enhanced CCP module). The functionality of the ECCP module allows you to create four PWM signal outputs displaying the same frequency and all controlled by a single duty cycle (however in this application we will use three of them). This project purposes to use three PWM signals for use in controlling the high side mosfets (only one PWM

The speed of the BLDC motor will be controlled by a potentiometer additive at a time). connected to analog input channel A4 (Pin #7). The PIC16F887 is running off a crystal oscillator (20 Mhz) and has a clock speed of 5 MIPS (100 nanoseconds per cycle). The function of the MCLR pin is disabled.

XX. SIMULATION

This Simulink model represents a sensor less control system for a Brushless DC (BLDC) motor. The speed control subsystem generates gate pulses based on the desired motor speed. A boost converter regulates the DC input voltage and supplies the inverter. The three-phase inverter, built with six switching devices, energizes the motor phases A, B, and C.

Instead of Hall sensors, sensor less commutation is achieved by detecting the trapezoidal back electromotive force (Back-EMF) from the stator windings. The controller compares the back-EMF signals to determine rotor position and timing for switching. Motor outputs such as speed (rpm), electromagnetic torque, and back-EMF are monitored to evaluate system performance and stability.

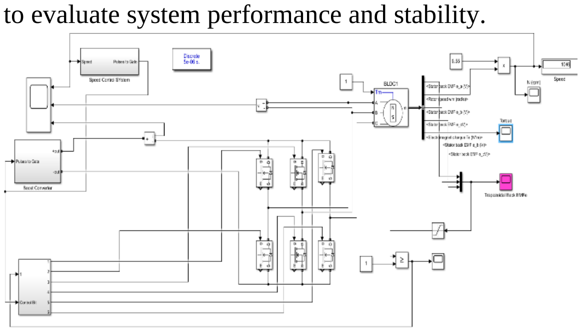

Figure 4. Schematic Diagram of BLDC Motor Controller

A. SWITCHING PULSES

The graph shows six switching gate signals used to drive the three-phase inverter of a BLDC sensor less motor controller. Each output corresponds to one transistor in the inverter. The pulses appear sequentially, creating a six-step commutation pattern. This switching sequence energizes motor phases properly, allowing rotor rotation using back-EMF–based position estimation.

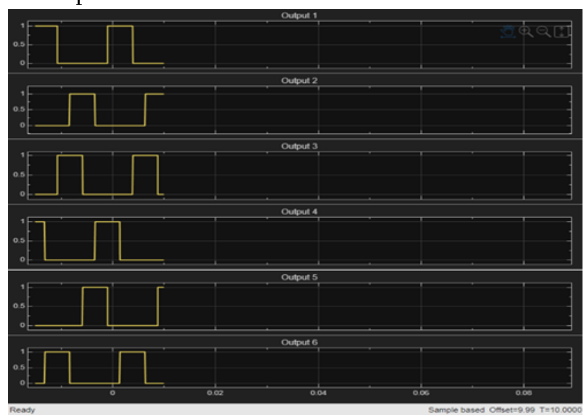

Figure 5. Six-Step Commutation Switching Signals for BLDC Motor

B. SIMULATION RESULTS OF BLDC MOTOR DRIVE PARAMETERS

The simulation output illustrates the electrical behavior of the proposed BLDC motor control system. The load current waveform shows dynamic variations corresponding to switching actions. The load voltage represents the supply applied across the motor phase. PWM pulses indicate the modulation used to control motor speed and switching sequence. The diode current demonstrates the freewheeling path during switching intervals, ensuring continuous current flow and protecting the inverter components from voltage spikes.

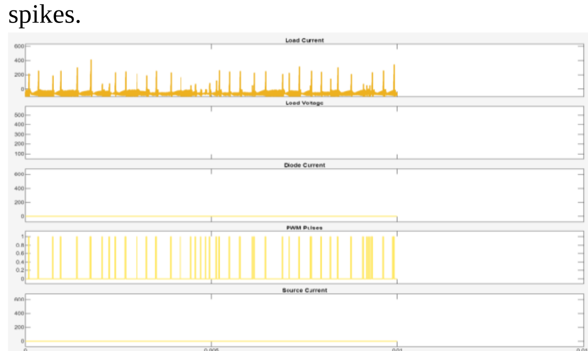

Figure 6. Simulated waveforms showing load current, load voltage, diode current, PWM pulses, and bus current in the BLDC motor control system

C. ELECTRO MAGNETIC TORQUE

The electromagnetic torque waveform illustrates the torque response of the BLDC motor during operation. The torque gradually increases with time while exhibiting small fluctuations due to switching effects. These variations are typical in BLDC drives and indicate the motor's dynamic response under the implemented control strategy.

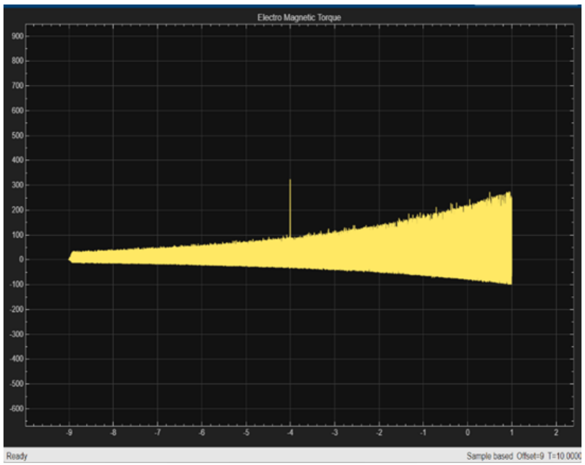

Figure 7. Simulated electromagnetic torque response of the BLDC motor.

D. ROTOR SPEED(RPM)

The rotor speed waveform shows the dynamic response of the BLDC motor during operation. Initially, the motor accelerates and stabilizes at a lower speed. Around the midpoint, a step change occurs, increasing the speed to a higher steady level. Minor fluctuations indicate switching effects and normal control system behavior.

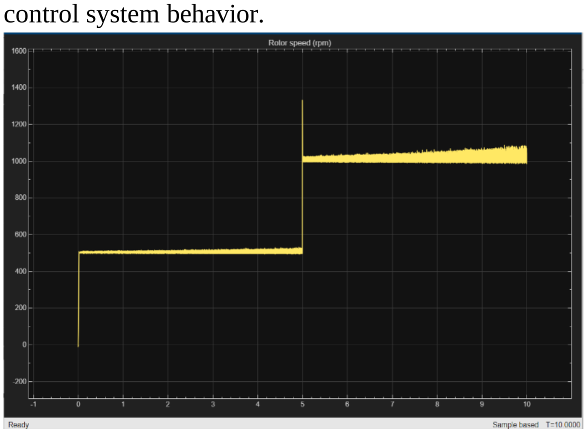

Figure 8. Simulated rotor speed response of the BLDC motor

E. TRAPEZOIDAL BACK EMF

The waveform represents the phase current variation of the BLDC motor during operation. Initially, the current remains within a moderate range while the motor runs at a lower speed. At approximately five seconds, the amplitude increases, indicating a higher operating condition. This change reflects the motor's response to increased load or speed demand.

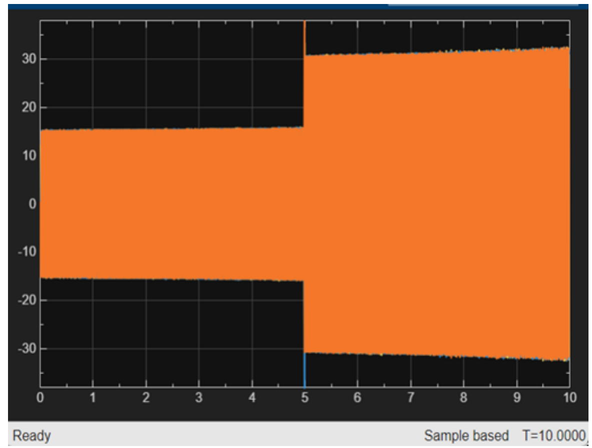

Figure 9. Trapezoidal Back EMF

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