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Sensorless Rapidly Varying Rotor Speed Control of BLDC Motor through Fast Commutation Error Correction Method

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ABSTRACT

The sensorless control of a BLDC (Brushless DC) motor can be challenging due to the rapidly varying rotor speed, which can result in errors in the commutation process. In this context, a fast commutation error correction method is proposed to overcome this issue. The proposed method utilizes an estimation of the rotor position based on the changing voltage when the device is placed in a magnetic field of the motor, which is measured by a Hall effect sensor. The measured voltage is used to calculate the rotor position. To implement the proposed method, a current controlled pulse width modulation (PWM) technique which uses a PID (Proportional Integral Derivative) controller to adjust the commutation angle. The performance of the system is evaluated through simulation and experimental studies, which demonstrate its ability to achieve accurate sensorless control of a BLDC motor, even under rapidly varying rotor speed conditions. Overall, the fast commutation error correction method provides a viable solution for achieving sensorless control of BLDC motors under challenging conditions, such as those encountered in high-speed applications.

Keywords: sensorless, pulse width modulation technique, brushless DC motor, sensors, commutation.

I. INTRODUCTION

Brushless DC (BLDC) motors are widely used in many industrial applications due to their high efficiency, low maintenance, and reliable performance. They are used in many industries, including aerospace, automotive, and medical equipment [1]. The traditional method of controlling the speed of a BLDC motor involves using sensors to measure the rotor position and speed. However, sensorless control methods have become increasingly popular because they eliminate the need for additional hardware and reduce the cost and complexity of the system [2]. One of the challenges of sensorless control is accurately estimating the rotor position and speed. So, fast commutation error correction method is proposed.

This method uses a mathematical model of the motor to estimate the rotor position and speed, and a fast commutation error correction algorithm to adjust the commutation of the motor's phases [3]. The sensorless rapidly varying rotor speed control of a BLDC motor through the fast commutation error correction method involves estimating the rotor position and speed and adjusting the commutation of the motor's phases. The control system consists of a microcontroller, a power electronic converter, and the BLDC motor [4]. The mathematical model of the motor is used to estimate the rotor position and speed based on the electrical and mechanical characteristics of the motor and the applied voltage and current. The estimated rotor position is then used to control the commutation of the motor's phases. The commutation is adjusted rapidly to maintain the correct position and speed of the rotor. Any errors in the commutation are corrected using the fast commutation error correction algorithm, which continuously updates the estimated rotor position and adjusts the commutation accordingly [5]. The proposed method utilizes an estimation of the rotor position based on the changing voltage when the device is placed in a magnetic field of the motor, which is measured by a Hall effect sensor. PWM technique with current sensing controller in fast commutation error correction method is a common method used in sensorless control of BLDC motors [6]. This technique uses a combination of Pulse Width Modulation (PWM) and current sensing to control the motor speed and direction, while also implementing a fast commutation error correction method for improved accuracy. The PWM technique involves the use of a high-frequency pulse train to control the average voltage applied to the motor. The duty cycle of the pulse train is varied to control the speed of the motor [7]. The current sensing controller measures the current flowing through the motor and adjusts the PWM signal accordingly to maintain the desired current level. The fast commutation error correction method is used to improve the accuracy of the system by correcting for errors in the estimated rotor position. This method uses the Hall effect sensor to estimate the position of the rotor, which is then compared to the actual position. If there is an error, the commutation sequence is adjusted to reduce the error and improve the accuracy of the system [8-9]. Overall, the PWM technique with current sensing controller in fast commutation error correction method provides a reliable and accurate method for controlling the speed and direction of a BLDC motor without the need for external sensors [10]. This method can be used in a wide range of applications, including robotics, electric vehicles, and industrial automation. However, it does require a complex control algorithm and may require higher computational power compared to traditional sensor-based system. The sensorless rapidly varying rotor speed control of a BLDC motor through the fast commutation error correction method has several advantages. The first advantage is that it eliminates the need for sensors, reducing the cost and complexity of the system. This also increases the reliability of the system because there are fewer components that can fail. Another advantage is that the method provides accurate control of the motor's speed and position, even in rapidly varying conditions. This makes it suitable for applications where the motor speed needs to be quickly adjusted, such as in electric vehicles or robotics.

II. EXISITING SYSTEM

The traditional sensor-based principle for controlling a BLDC motor involves the use of external sensors, such as hall sensors or encoders, to measure the rotor position and speed. The sensor signals are then used to determine the appropriate commutation sequence to control the motor speed and direction. The basic operating principle of a BLDC motor is that a rotating magnetic field is generated by the stator windings, which interacts with the permanent magnets on the rotor to produce torque and rotation. The stator windings are energized in a specific sequence to produce a rotating magnetic field, which is synchronized with the rotor position. In a sensor-based system, the position of the rotor is detected by external sensors, such as hall sensors or encoders, which are mounted on the motor. These sensors provide feedback on the rotor position and speed to the control system, which uses this information to determine the appropriate commutation sequence. The hall sensors are typically mounted in the stator and detect the position of the rotor magnets as they pass by. The encoder is mounted on the rotor and provides a precise position and speed feedback by counting the number of rotations and the relative position of the rotor. The control system uses the sensor signals to determine the appropriate commutation sequence, which is the order in which the stator windings are energized. The commutation sequence is synchronized with the rotor position to produce the desired torque and rotation. Overall, the traditional sensor-based principle for controlling a BLDC motor involves the use of external sensors to detect the rotor position and speed and to determine the appropriate commutation sequence.

III.PROPOSED SYSTEM

Three phase inverters are important part in AC motor drives. A 3-phase 4-switch inverter (3P4S) and a 3-phase 6-switch inverter (3P6S) are both popular topologies used in industrial applications to convert DC voltage to AC voltage. The main difference between the two is the number of switches used to achieve the conversion. A 3P4S inverter uses four switches per phase, while a 3P6S inverter uses six switches per phase. The extra switches in a 3P6S inverter are used to create more voltage levels, resulting in a smoother output waveform and reduced harmonic distortion. However, this comes at a cost of increased complexity, cost, and losses. Since a 3P4S inverter has fewer switches, it is generally less expensive to build and maintain than a 3P6S inverter. This can be an important consideration in applications where cost is a key factor. A 3P4S inverter is simpler in design than a 3P6S inverter and therefore easier to troubleshoot and maintain. A 3P4S inverter has fewer switches, which means that there are fewer switching losses. This can result in higher overall efficiency, which is important in applications where power consumption is a concern. A 3P4S inverter has fewer components, which means that there are fewer potential failure points. This can result in higher overall reliability, which is important in applications where downtime is costly. However, it's worth noting that a 3P6S inverter can be a better choice in certain applications, particularly those that require a high-quality output waveform or low harmonic distortion. Ultimately, the choice between a 3P4S and a 3P6S inverter will depend on the specific requirements of the application. And for low power application 3P4S inverter is preferred. Scalar control and vector control are two methods for controlling the speed and torque of a brushless DC (BLDC) motor. Scalar control, also known as voltage-frequency control, is a simple and widely used control method for BLDC motors. It involves adjusting the voltage and frequency of the motor supply to control the motor speed and torque. In scalar control, the current and voltage are controlled together by varying the duty cycle of the pulse-width modulation (PWM) signal, which determines the amount of power delivered to the motor. However, scalar control does not take into account the rotor position or the magnetic field produced by the rotor, which can lead to less efficient operation and less accurate control.

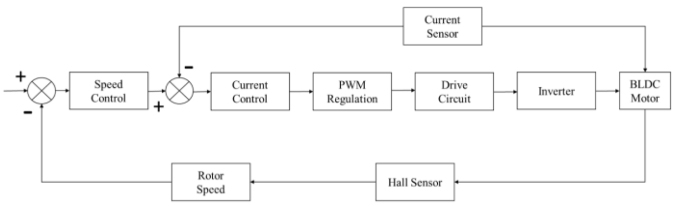

Figure 1: Proposed system

Vector control, also known as field-oriented control, is a more advanced and precise control method for BLDC motors. It involves controlling the magnetic field produced by the rotor and aligning it with the stator field to achieve optimal torque and speed control. Vector control requires a feedback sensor, such as an encoder, to determine the position of the rotor, and uses complex algorithms to calculate the optimal current and voltage values to achieve the desired performance. Vector control is more complex and expensive than scalar control, but it provides better control accuracy and efficiency, particularly at low speeds and high loads. Scalar control is a simpler and more cost-effective control method for BLDC motors, while vector control provides more precise and efficient control at the expense of greater complexity and cost. The choice of control method depends on the specific application requirements and cost considerations. And in this sensorless speed control vector control is preferred has it is more efficient than scalar control. And this sensorless speed control is based on closed loop control system principle where current sensing controller with PWM technique is used as feedback. Fuzzy logic control (FLC) is a type of control system that uses fuzzy logic, a mathematical concept that deals with uncertain and ambiguous information, to make decisions and control a system. In the context of sensorless speed control of BLDC motors, FLC can be used to improve the performance and efficiency of the motor control system. In sensorless speed control of BLDC motors, the position and speed of the rotor are estimated based on the back electromotive force (EMF) signals measured at the motor terminals. However, the back EMF signals are affected by various factors, such as the load and motor parameters, which can cause errors in the position and speed estimation. FLC can be used to compensate for these errors and improve the accuracy of the speed control. FLC works by using linguistic variables, such as "high," "low," "medium," etc., to represent the input and output variables of the control system. The linguistic variables are then mapped to fuzzy sets using membership functions that define the degree of membership of the input or output variable to each fuzzy set. The rules of the control system are defined in terms of fuzzy if-then statements that relate the input variables to the output variables. The fuzzy rules are then used to compute the output variable using fuzzy inference. In the context of sensorless speed control of BLDC motors, FLC can be used to adjust the current and voltage of the motor based on the estimated speed and position of the rotor. The FLC system can also take into account other factors, such as the load and motor temperature, to improve the performance and efficiency of the motor control system. FLC can be combined with other control methods, such as vector control, to further improve the performance of the motor control system.

IV. METHODOLOGY

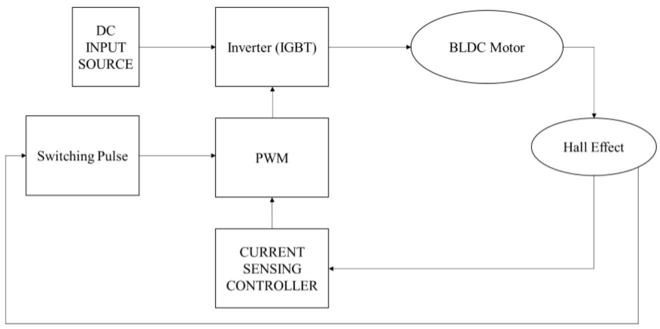

Figure 2: Block diagram

DC power Supply is the input voltage to the system which is used to power the motor. And 3P4S inverter is used for low power application which is an electronic circuit that converts the DC power supply into three-phase AC power for driving the BLDC motor. The BLDC motor is the device being controlled by the speed control system. With the help of hall effect sensor rotor position can be determined which provide switching pulses. In current sensing controller the current is converted from abc frame to dq0 frame in which signal seems to be appear as DC signal. So, that the controlling of signal becomes easy compared to when the signal is in AC. And in PWM technique, PID controller is used to calculate error value as the difference between a measured variable and a desired set-point. Then this error is going to be adjusted proportionally, integrally, and derivatively to compensate for input signal. The power losses in a conductor are the product of the square of the current and the resistance of the conductor

$$P_L = I^2 \times R$$

When transmitting a fixed power on a given wire, if the current is halved transmitted is equal to the product of the current

$$P_T = I \times V$$

Fuzzy logic can be used to control the motor's speed and torque. A fuzzy logic controller takes into account various input parameters such as motor speed, load, temperature, and voltage to determine the appropriate output voltage to be applied to the motor. By using fuzzy logic, a BLDC motor can be controlled more precisely and efficiently than traditional control methods. This is because fuzzy logic can take into account a wider range of input parameters, including those that may be difficult to measure accurately, and can adjust the output voltage in real-time to compensate for changes in the motor's operating conditions. Overall, the use of fuzzy logic in BLDC motor control can lead to improved performance, increased efficiency, and reduced wear and tear on the motor, ultimately resulting in a longer lifespan for the motor and lower maintenance costs for the user. Fuzzy logic is widely used in machine control in a proportional and integral controller output is directly proportional to the summation of proportional of error and integration of the error signal.

$$A(t) \propto \int_0^t e(t)dt + A(t) \propto e(t)$$

Removing the sign of proportionality we have,

$$A(t) = K_i \int_0^t e(t)dt + A(t) = K_p\, e(t)$$

Where, K_i and K_p proportional constant and integral constant respectively.

V. RESULTS AND DISCUSSION

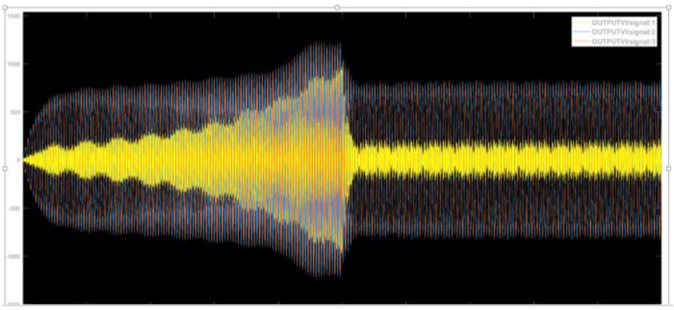

Figure 3: Voltage waveforms

The output waveform of a 3-phase 4-switch inverter consists of three sets of voltages that are out of phase with each other by 120 degrees. Each set of voltages corresponds to one of the three phases of the AC power. The waveform is created by switching the DC voltage on and off in a controlled manner using four switches. During each switching cycle, two switches are turned on at a time, allowing current to flow in one direction through the load. The switches are then turned off and another pair of switches is turned on, allowing current to flow in the opposite direction through the load. By repeating this process at a high frequency, a stable AC output waveform is generated. The waveform produced by a 3-phase 4-switch inverter is typically a square wave, which contains harmonic frequencies that can cause issues with some types of loads. To overcome this, additional filtering and control circuitry may be required to produce a pure sine wave output. Overall, the output waveform of a 3- phase 4- switch inverter is characterized by its 3 sets of voltages that are out of phase with each other and can be used to power 3- phase AC loads.

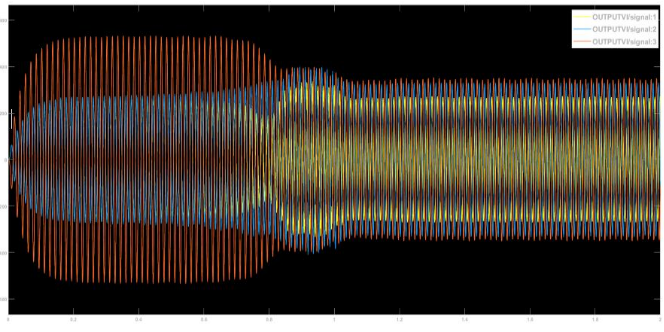

Figure 4: Current waveforms

The output waveform of a 3-phase 4-switch inverter depends on the switching pattern of the power switches. The most common switching pattern used is the sinusoidal pulse width modulation (SPWM) technique, which generates a high-quality sine wave output. The SPWM technique works by comparing a reference sine wave with a high-frequency carrier wave. The amplitude and frequency of the carrier wave determine the modulation index, which is used to control the output voltage magnitude. The phase angle of the reference sine wave is used to determine the phase angle of the output waveform. During each switching cycle, two of the four switches are turned on at a time. By controlling the timing and duration of the switch on/off times, the SPWM technique produces a 3-phase AC waveform with the desired frequency, amplitude, and phase angle. The output waveform of a 3-phase 4-switch inverter using SPWM technique is a high-quality sine wave with the desired frequency, amplitude, and phase angle, which is generated by controlling the switching pattern of the power switches. The output waveform of the sensorless speed control of a BLDC motor through the faster commutation error correction method depends on the specific implementation and the performance of the algorithm. The faster commutation error correction method aims to improve the accuracy and speed of the rotor position estimation, resulting in a smoother and more continuous waveform. Waveform of the motor will be synchronized with the input voltage waveform, which is typically a pulse-width modulated (PWM) signal. The faster commutation error correction method ensures that the commutation of the motor is stable and consistent, which results in a stable and consistent output waveform. The faster commutation error correction method also aims to reduce the torque ripple of the motor, which is the variation in torque output during each electrical cycle. Overall, the output waveform of the sensorless speed control of a BLDC motor through the faster commutation error correction method will have improved accuracy, speed, and consistency compared to other methods. And even though there is variation in torque the rotor speed is controlled.

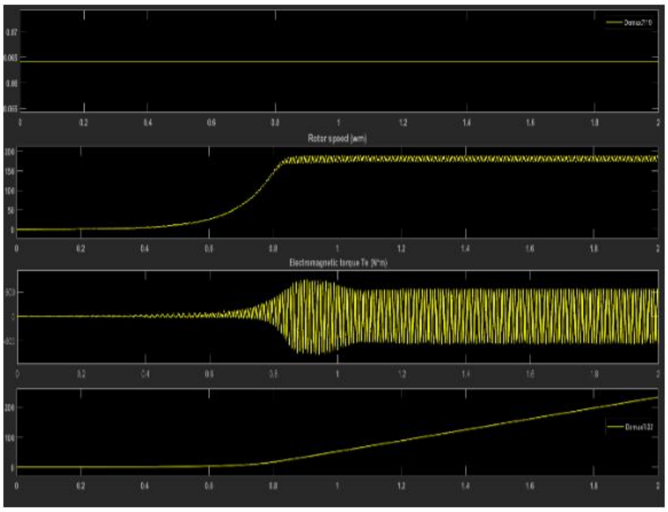

Figure 5: Output waveforms

VI. CONCLUSION

In conclusion, the sensorless rapidly varying rotor speed control of a BLDC motor through the fast commutation error correction method is a sophisticated control strategy that can provide precise control of the motor's speed and position without the use of sensors. The method uses a mathematical model of the motor to estimate the rotor position and speed, and a fast commutation error correction algorithm to adjust the commutation of the motor's phases. This method has several advantages, including reducing the cost and complexity of the system and providing accurate control of the motor's speed and position in rapidly varying conditions.

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