SPEED CONTROL OF BLDC MOTOR

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Abstract— *This paper is to control the speed of a BLDC motor using some control technique. Efficiency and Reliability are the key features for the development of advanced motor drives. Residential and commercial appliances such as refrigerators and air conditioning systems use conventional motor drive technology BLDC motor has various application used in industries like in drilling, lathes, spinning, electric bikes etc.. This proposed system provides a very precise and effective speed control system. The user can enter the desired speed and the motor will run at that exact speed.*

1. Introduction

A brushless DC (BLDC) motor drive is characterized by higher efficiency, lower maintenance, and higher cost. Therefore, it is necessary to have a low-cost but effective BLDC motor controller.
Brushless DC (BLDC) motor is a type of synchronous motor that consists of a rotor that has a surface mounted permanent magnets and stator with polyphase armature windings. As compared with conventional DC motor, it doesn't contain brushes, but the an electronic drive to energize the stator commutation is performed electrically usingwindings.

Fig.1.1 BLDC motor

Mostly BLDC motor stator winding is placed in slots with stacked steel laminations as shown in fig.1.1along with inner periphery, which is connected in a star-like fashion.Numerous coils in the slots are interconnected to form a winding and to form an even number of poles, and these windings are distributed along the stator periphery. This motor winding rating is chosen depending on the controller power supply.With alternate North and South poles , the rotor is made with permanent magnets with a certain number of poles, that varies from 2 to 8 pole pairs. Traditionally ferrite materials are used as permanent magnets.

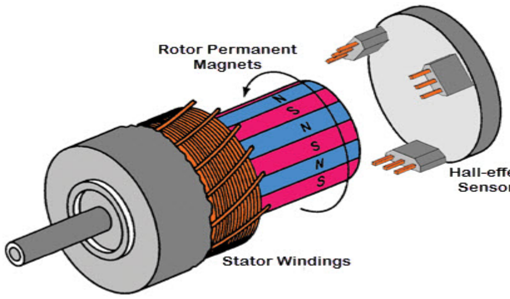

Fig.1.2 working of BLDC motor

Generally a BLDC motor construction is done in two ways: either by placing windings in the core and rotor outside of it or by windings outside the core. In the first arrangement, the rate of heat dissipation gets reduced as the rotor magnets act as an insulator. So, it is typically used in fans. But in case of latter arrangement, heat dissipation in the motor is more and widely used in hard disk drives.

The principle of the working of a brushless DC motor is the mechanical torque development due to the interaction of the magnetic field produced by rotor magnets and stator coils as shown in fig.1.2. The electronic switching or commutation circuit switches the supply to the stator windings such that one winding is energized with positive power, and the second winding with a negative power and the third is non-energized to develop the torque. So the peak torque occurs when these two fields are at 90 degrees to each other and get reduced when they move together.

In BLDC motor, the feedback is achieved using multiple sensors, mostly hall-effect sensors which are mounted either on the stator or rotor. Thus, the rotor shaft position is determined by continuous high and low signals from these hall sensors as the rotor magnetic poles (North and South) pass to their vicinity. Thus, based on the signals from these sensors, the winding to be energized is decided

2. SPEED CONTROL OF BLDC MOTOR

Since the brushless DC motor is used to run the loads at the desired speed, controlling its speed is essential with suitable controller. BLDC motor speed is controlled at the base, above and below rated speeds by armature voltage and flux weakening methods. By controlling the applied voltage, we can run the DC motor at the base and below-rated speeds, whereas by flux weakening above rated speed control is possible. Control unit design can be implemented with the use of several analog controllers to digital. In many of the cases, digital-integrated circuits with Pulse Width Modulation technique (PWM) are implemented to have control of this motor. This speed control can be open or closed-loop control.

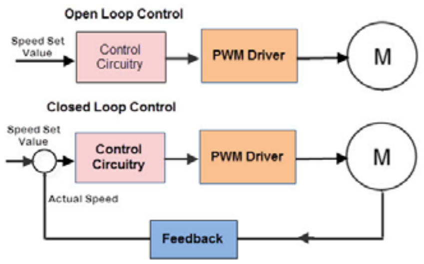

Fig.2.1. open and closed loop control

In an open-loop control, the input voltage applied is controlled to get the variable speed using different type of controllers like current limiters, potentiometers, chopper circuits, etc as shown in fig.2.1.

In closed-loop control, the supply voltage is controlled by taking actual speed of the motor as a feedback signal. And depends on the error between desired and the actual speed motor voltage applied is varied or controlled. The closed-loop control consists of three basic elements: PWM circuit, sensing circuit and motor driver. PWM circuit can be implemented with timer or programmablelike microcontroller as shown in fig.2.1. Actual speed sensing is possible with different sensors like hall-effect sensors, optical encoders, IR sensors, etc. and motor driver drives the BLDC motor based on signals from the controller.

3.SPEED CONTROL USING PWM

Pulse-width modulation (PWM) is acommonly used technique for controlling power to an electrical device, made practicalby modern electronic power switches. Theaverage value of voltage (and current) fed tothe load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared tothe off periods, the higher the power supplied to the load as shown in fig.3.1. The PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power. The switching's have to bedone several times a minute in an electric stove, 120 Hz in a lamp dimmer, from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies. The term duty cycle describes the proportion of on time to the regular interval or period oftime; a low duty cycle corresponds to low power. Duty cycle is expressed in percent,100% being fully on.

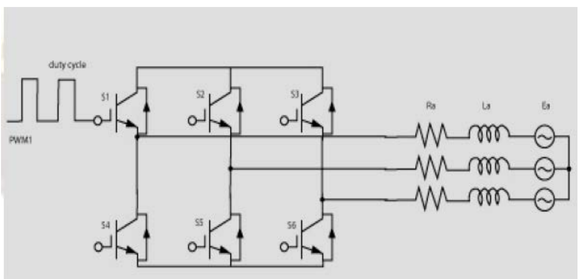

Fig.3.1.PWM drive circuit

The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically nocurrent, and when it is on, there is almost novoltage drop across the switch. Power loss,being the product of voltage and current, isthus in both cases close to zero. PWM worksalso well with digital controls, which, becauseof their on/off nature, can easily set the neededduty cycle. PWM has also been used in certaincommunication systems where its duty cyclehas been used to convey information over acommunications channel.The desired speed can be obtained by changingthe duty cycle. The PWM in microcontroller isused to control the duty cycle of DC motor.

Average Voltage=D * Vin (1)

4. OPTIMIZED SPEED CONTROL

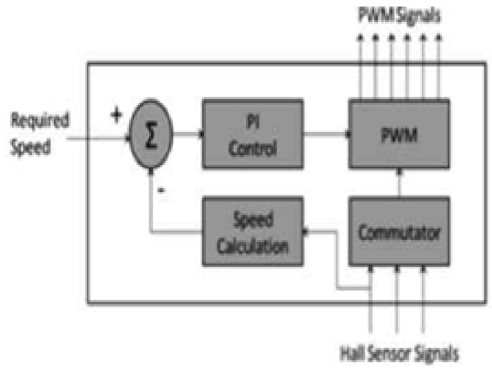

Fig.4.1. Block diagram of optimized speed control

Motor speed, then, depends upon the amplitude of the applied voltage. The amplitude of the applied signal is adjusted by using pulse width modulation. By controlling the duty cycle of the PWM signal, the amplitude of the applied voltage can be controlled, which in turn will control the speed of the motor.fig.4.1. The difference between the required speed and the actual speed is input into the PI controller, which then modulates the duty cycle of the PWM based on the error signal obtained by the difference between the actual speed and required speed.

A. SPEED CONTROL USING SENSORS

a) 5.1.Hall-effect sensors

These kinds of devices are based on Hall-effect theory, which states that if an electric current- carrying conductor is kept in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers that tends to push them to one side of the conductor. A build-up of charge at the sides of the conductors will balance this magnetic influence producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall-effect because it was discovered by Edwin Hall in 1879.

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall-effect sensors embedded into the stator.

Most BLDC motors have three Hall sensors inside the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors they give a high or low signal indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. Transverse section of a BLDC motor with a rotor that has alternate N and S permanent magnets. Hall sensors are embedded into the stationary part of the motor. Embedding the Hall sensors into the stator is a complex process because any misalignment in these Hall sensors with respect to the rotor magnets will generate an error in determination of the rotor position.

To simplify the process of mounting the Hall sensors onto the stator some motors may have the Hall sensor magnets on the rotor, in addition to the main rotor magnets. Therefore, whenever the rotor rotates the Hall sensor magnets give the same effect as the main magnets. The Hall sensors are normally mounted on a printed circuit board and fixed to the enclosure cap on the non-driving end. This enables users to adjust the complete assembly of Hall sensors to align with the rotor magnets in order to achieve the best performance.

Nowadays, because miniaturized brushless motors are introduced in many applications, new position sensors are being developed, such as a three branches vertical Hall sensor depicted in figure. The connecting principle between the brushless motor and this sensor is reminiscent of the miniaturized magnetic angular encoder based on 3-D Hall sensors. A permanent magnet is fixed at the end of a rotary shaft and the magnetic sensor is placed below, and the magnet creates a magnetic field parallel to the sensor surface. This surface corresponds to the sensitive directions of the magnetic sensor. Three-phase brushless motors need three signals with a phase shift of 120° for control, so a closed-loop regulation may be used to improve the motor performance.

Each branch could be interpreted as a half of a vertical Hall sensor and are rotated by 120° in comparison to the other. Only a half of a vertical Hall sensor is used since little space is available for the five electrical contacts (two for the supply voltage and three to extract the Hall voltages). This sensor automatically creates three signals with a phase shift of 120°, which directly correspond to the motor driving signals, to simplify the motor control in a closed-loop configuration.

A drawing of this device's use as angular position sensor for brushless motor control is given in figure. A first alignment is between the rotor orientation and the permanent magnet, and a second alignment is between the stator and the sensor. This alignment will allow the motion information for the motor and the information about its shaft angular position.

b) 5.2.Variable reluctance (VR) wheel speed sensors

This kind of sensor is used to measure position and speed of moving metal components, and is often referred as a passive magnetic sensor because it does not need to be powered. It consist of a permanent magnet, a ferromagnetic pole piece, a pickup coil, and a rotating toothed wheel. This device is basically a permanent magnet with wire wrapped around it. It is usually a simple circuit of only two wires where in most cases polarity is not important, and the physics behind its operation include magnetic induction.

As the teeth pass through the sensor's magnetic field, the amount of magnetic flux passing through the permanent magnet varies. When the tooth gear is close to the sensor, the flux is at maximum. When the tooth is further away, the flux drops off. The moving target results in a time-varying flux that induces a voltage in the coil, producing an electrical analog wave. The frequency and voltage of the analog signal is proportional to velocity of the rotating toothed wheel. Each passing discontinuity in the target causes the VR sensor to generate a pulse. The cyclical pulse train or a digital waveform created can be interpreted by the BLDC motor controller.

The advantages of the VR sensor can be summarized as follows: low cost, robust proven speed and position sensing technology (it can operate at temperatures in excess of 300 °C), self-generating electrical signal which requires no external power supply, fewer wiring connections which contribute to excellent reliability, and a wide range of output, resistance, and inductance requirements so that the device can be tailored to meet specific control requirements.

Due to the fact that these sensors are very small, they can be embedded in places where other sensors may not fit. For instance, when sealed in protective cases they can be resistant to high temperatures and high pressures, as well as chemical attacks. Through the monitoring of the health of running motors, severe and unexpected motor failures can be avoided and control system reliability and maintainability can be improved. If the VR was integrated inside a motor case for an application in a harsh environment, sensor cables could be easily damaged in that environment. Then, a wireless and powerless sensing solution should be applied using electromagnetic pulses for passing through the motor casing to deliver the sensor signal to the motor controller.The Hall-effect sensor explained before is an alternative but more expensive technology, so VR sensors are the most suitable choice to measure the rotor position and speed.

B. ADVANCES IN SENSORLESS CONTROL

Position sensors can be completely eliminated, thus reducing further cost and size of motor assembly, in those applications in which only variable speed control (*i.e.*, no positioning) is required and system dynamics is not particularly demanding (*i.e.*, slowly or, at least, predictably varying load). In fact, some control methods, such as back-EMF and current sensing, provide, in most cases, enough information to estimate with sufficient precision the rotor position and, therefore, to operate the motor with synchronous phase currents. A PM brushless drive that does not require position sensors but only electrical measurements is called a sensorless drive.

The BLDC motor provides an attractive candidate for sensorless operation because the nature of its excitation inherently offers a low-cost way to extract rotor position information from motor-terminal voltages. In the excitation of a three-phase BLDC motor, except for the phase-commutation periods, only two of the three phase windings are conducting at a time and the no conducting phase carries the back-EMF. There are many categories ofsensorless control strategies; however, the most popular category is based on back electromotive forces or back-EMFs.

Sensing back-EMF of unused phase is the most cost efficient method to obtain the commutation sequence in star wound motors. Since back-EMF is zero at standstill and proportional to speed, the measured terminal voltage that has large signal-to-noise ratio cannot detect zero crossing at low speeds. That is the reason why in all back-EMF-based sensorless methods the low-speed performance is limited, and an open-loop starting strategy is required.

Generally, a brushless DC motor consists of a permanent magnet synchronous motor that converts electrical energy to mechanical energy, an inverter corresponding to brushes and commutators, and a shaft position sensor. In this each of the three inverter phases are highlighted in a different colour, including the neutral point: red phase A, green phase B, blue phase C, and pink neutral point N.

The stator iron of the BLDC motor has a non-linear magnetic saturation characteristic, which is the basis from which it is possible to determine the initial position of the rotor. When the stator winding is energized, applying a DC voltage for a certain time, a magnetic field with a fixed direction will be established. Then, thecurrent responses are different due to the inductance difference, and this variation of the current responses contains the information of the rotor position. Therefore, the inductance of stator winding is a function of the rotor position.

1) 7.SPEED CONTROL BY PWM GENERATED USING MICROCONTROLLER

In recent years, with the development of mixed-signal integrated circuit technology, many system-on-chip (SOC) devices have become available. High-throughput microcontrollers with imbedded programmable memory as well as other precision analog and digital peripherals can be incorporated into a single integrated circuit. SOC devices have many advantages, including lower overall system cost and reduced board space, as well as superior system performance and reliability. Taking all these features into account, a dedicated sensorless BLDC controller implementingback-EMF zero-crossing detection circuit as one of its peripherals, can be developed.

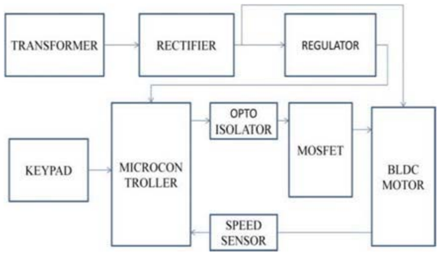

Fig.7.1. Block diagram pwm generated using microcontroller

A back-EMF sensing method that requires neither a manufactured neutral voltage nor a great amount of filtering can be implemented using a microcontroller reducing the total system cost. A usual microcontroller model is the ST72141 (STMicroelectronics) which integrates the analog detection circuit and other motor control peripherals with a standard microcore. In this figure 7.1 , the true back-EMF zero crossing point can be extracted directly from the motor terminal voltage by properly choosing the PWM and sensing strategy.
The motor terminal voltage is directly fed into the microcontroller through current-limiting resistors. The resulting feedback signal is not attenuated or filtered. As a result, a sensorless BLDC driver with a much wider speed range from start-up to full speed is obtained. This microcontroller-based sensorless BLDC drive system could be successfully applied to automotive returnless fuel pump applications, in which a BLDC motor life span is typically around 15,000 h, extending the life of the motor almost three-fold. Once a microcontroller is used to perform the brushless commutation, other features can be incorporated into the application, such as electronic returnless, fuel system control, fuel level processing, and fuel tank pressure. These added features simplify the vehicle systems as well as drive overall system cost down.

8. CONCLUSION

BLDC motor is a good choice for various applications due to higher efficiency, higher power density and higher speed ranges compare to other motor types. The Output characteristics and simplicity of model make it effectively useful in design of BLDC motor drives with different control algorithms in different applications.

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