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Implementation of BLDC Motor Drive for Automotive Water Pump

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Abstract

In order to save resources and prevent global warming, there has been a present need in recent years to reduce the volume of CO_2 emission and it improves the fuel consumption of automobiles. The trend in the automotive applications is to improve efficiency and to reduce volume and weight. Under these circumstances, the mechanical parts in the automobile industry are being replaced by electronics method. In this paper, the implementation of the integrated BLDC drive for water pump system for automotive application is carried out. MATLAB simulation is carried out for the proposed BLDC motor drive the speed and the rotor torque waveforms are analyzed for various reference speeds.

Keywords: *BLDC control, Inverter, Water Pump, Electric Drive.*

1. Introduction

As the interest in global environmental protection increases, there is growing interest in energy efficiency. Under these circumstances, the mechanical parts in the automobile industry are being replaced by electronic methods. Conventional mechanical water pump is directly connected by the engine belt. For this reason, regardless of coolant circulation, the conventional mechanical water pump is always operated [1]. In contrast, electric water pump is not directly connected and could operate at could reduce energy consumption. For this possible, integrated electric water pump is becoming more important.

In recent years, the brushless dc (BLDC) motor is receiving more interest for automotive applications. This issue to the total elimination of the brush/commutator assembly, which reduces audible noise and RFI problems various speeds. The way which the mechanical water pump is replaced by electric water pump as the interest [2]. For energy efficiency and small size, BLDC motor and drive are applied to the water pump.

Now-a-days Permanent Magnet Brushless DC (PMBLDC) motors are becoming more popular. They find applications in industries such as appliance, automotive, aerospace, consumer, medical and instrumentation. PMBLDC motors do not use brushes for commutation, instead they are electronically commutated. The stator of the PMBLDC motors consists of stacked steel laminations axially cut along the inner periphery. Though the stator resembles that of an induction motor, the windings are distributed in a different manner. The rotor is made up of permanent magnets and consists of alternate north and south poles. Ferrite magnets are traditionally used to make permanent magnets. Rare earth alloy magnets are gaining popularity due to their high magnetic density per volume. An alloy of neodymium, ferrite and boron has been used of late to make permanent magnets.

2. Construction and Operation

As their names suggest, the rotor is the rotational part of the motor while the stator is the stationary part. Structurally the stator assembly surrounds the rotor. Embedded into the side of the rotor are permanent magnets; external is the fan propeller blade. The motor coil is part of the stator assembly, and is placed inside the rotor. Brushless DC motors utilize Hall-effect sensors to provide positional and rotational information, which informs the LOGICAL INVERTER how to drive the motor coil. Brushless DC motors usually come in fixed voltage types, such as 5V, 6V, 12V, 24V, 48Vetc, with one of the most common ones in use being the 12V type. When the rated voltage is applied to the motor it will rotate with maximum speed, but by changing this applied voltage the motor speed can be controlled. Naturally, the voltage is higher and then speed is higher and vice versa.

In the brushless DC motor, the polarity reversal is performed by power MOSFETS, which must be switched in synchronism with the rotor position. The stator is normally 3-phase star connected. Each commutation sequence has one of the windings energized to positive power (current entering into the winding) and the second winding energized to negative power (current exits the winding) and third winding non-energized. Torque is produced by the interaction of the magnetic field produced by the stator windings and the permanent magnets.

2.1 Hall Sensors

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 embedded into 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.

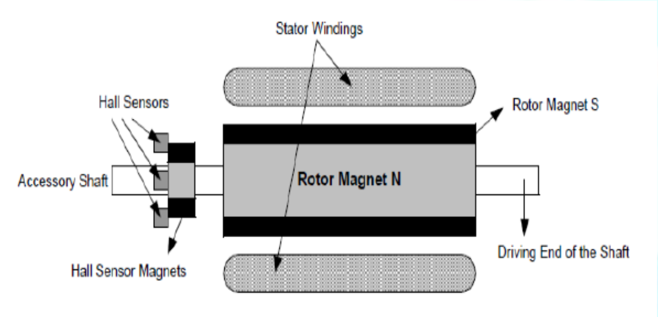


Fig. 1 Transverse section of BLDC

Above Figure 1 shows a 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. These are a scaled down replica version of the rotor. 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 PC 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 The Hall sensors may be at 60° or 120° phase shift to each other. Based on this, the motor manufacturer defines the commutation sequence, which should be followed when controlling the motor performance. Based on the physical position of the Hall sensors, there are two versions of output.

2.2 Features

The PMBLDC motors have many advantages over the dc commutator motor. They have better torque-speed characteristics due to the elimination of brush friction at higher speeds, which improves the useful torque output in the PMBLDC motor and has long operating life with less maintenance. The permanent magnet rotors have low inertia, which improves the dynamic response of the motor. The brushless motor provides noiseless operation with improved speed range. In addition, the ratio of torque developed to the size of the motor is higher, making it useful in applications where space and weight are critical factors. The use of permanent magnet rotor eliminates the rotor copper losses and provides considerable improvement in thermal characteristics.

2.3 Objective

The objective of this project work is to design a BLDC drive of water pump system for automotive applications .For reducing energy consumption, improved efficiency and reduced volume and weight mechanical water pump is replaced by electrical water pump. Conventional mechanical water pump is directly connected by the engine belt. For this reason regardless of coolant circulation the conventional mechanical water pump is always operated. Electrical vehicle do not have the internal combustion engine. Therefore, the EV (electric vehicle) needs an electric water pump for Cooling traction motor & inverter.

2.4 Basic Block Diagram

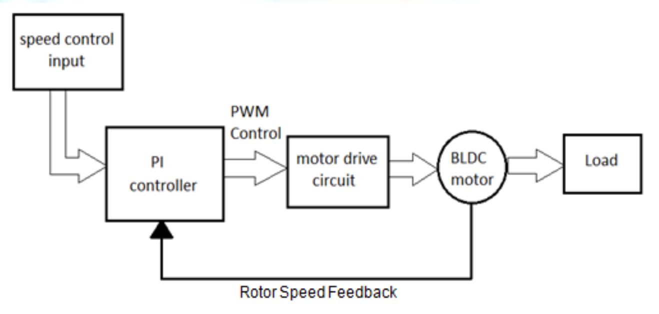


Fig. 2 Basic Block Diagram

The Speed Control Input unit provides motor speed input to the control system. This input can either be analog or digital. The actual motor speed is fed back to the closed-loop controller. The PI controller is used as the closed-loop control algorithm to track the actual motor speed and also apply the speed control input. Based on speed control input and present and past errors (proportional and integral values), the closed-loop control either increases or decreases the PWM duty cycle, which in turn controls the speed of the motor.

A PI controller is used to implement the closed-loop control that uses both the speed-control input and the actual motor-speed feedback to update the timer PWM duty cycle that, in turn, controls the motor speed.

The actual motor speed is calculated by tracking the time period between successive Hall events, which represents a part of the mechanical cycle of the motor. In a 3-phase BLDC motor control, one electrical cycle has six Hall states and, depending on the number of poles pairs in the motor, the electrical angle measured between successive Hall state changes can be translated to a respective mechanical angle. For example, for a 4-pole 3-phase BLDC motor with three Hall sensors, one mechanical revolution is equal to two electrical cycles; for an 8-pole 3-phase BLDC motor with three Hall sensors, one mechanical revolution is equal to four electrical cycles.

To boost the voltage to drive motors at higher voltage levels (V_{motor}), predrivers are used. The motor drivers also help protect the logic chips and isolate electrical noise. The outputs of the predrivers are fed to three half bridges as a part of the commutation loop.

3. Methodology

A BLDC motor is driven by voltage strokes coupled with the given rotor position. These voltage strokes must be properly applied to the active phases of the three-phase winding system so that the angle between the stator flux and the rotor flux is kept close to 90° to maximize torque. Therefore, the controller needs some means of determining the rotor's orientation/position (relative to the stator coils).

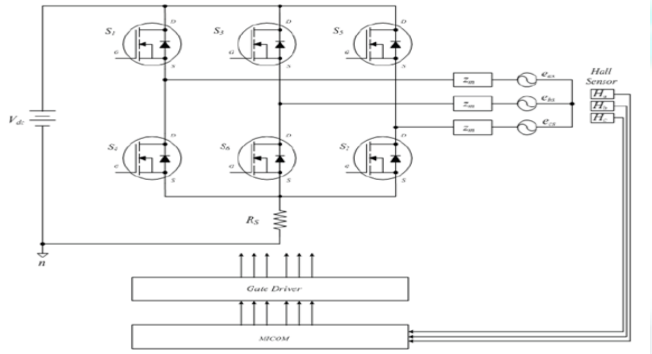
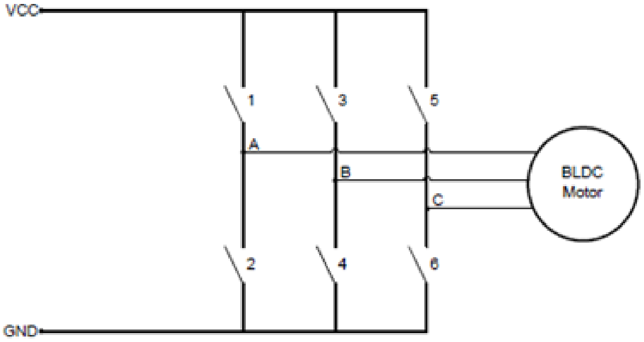


Fig. 3 Proposed Circuit diagram



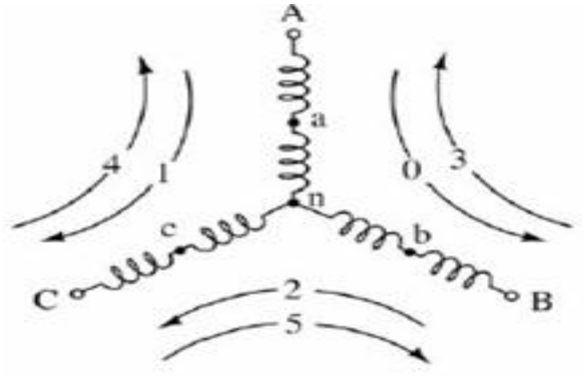


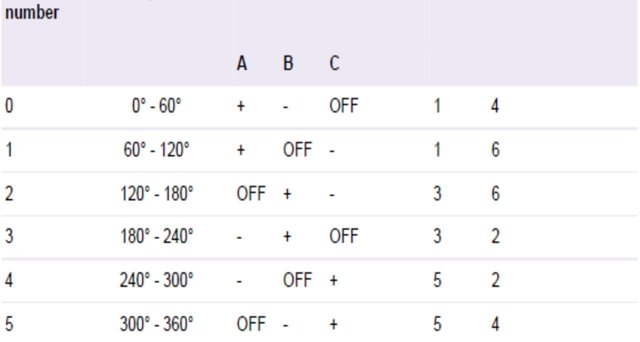
Fig.4 Three phase bridge and coil current direction

Fig 2 depicts a systematic implementation on how to drive the motor coils for a correct motor rotation. The current direction through the coils determines the orientation of the stator flux. By sequentially driving or pulling the current though the coils the rotor will be either pulled or pushed. A BLDC motor is wound in such a way that the current direction in the stator coils will cause an electrical revolution by applying it in six steps. As also shown in Fig 2 each phase driver is pushing or pulling current through its phase in two consecutive steps. These steps are shown in Table 1.This is called trapezoidal commutation. Fig 3 shows the relation between the definitions six-step commutation (six Hall sensor edges H1, H2 and H3), block commutation (i_a, i_b, i_c) and trapezoidal commutation (e_a, e_b, e_c).

Varying the voltage across the motor can simply control the rotor speed. This can be achieved by pulse width modulation (PWM) of the phase voltage. By increasing or decreasing the duty-cycle, more or less current per commutation step will flow through the stator coils. This affects the stator flux and flux density, which changes the force between the rotor and stator.

This means that the rotation speed is determined by the load of the rotor, the current during each phase, and the voltage applied.

Table 1: Switching sequence



Sequence number	Switching interval	Phase current			Switch closed	
		A	B	C		
0	0° - 60°	+	-	OFF	1	4
1	60° - 120°	+	OFF	-	1	6
2	120° - 180°	OFF	+	-	3	6
3	180° - 240°	-	+	OFF	3	2
4	240° - 300°	-	OFF	+	5	2
5	300° - 360°	OFF	-	+	5	4

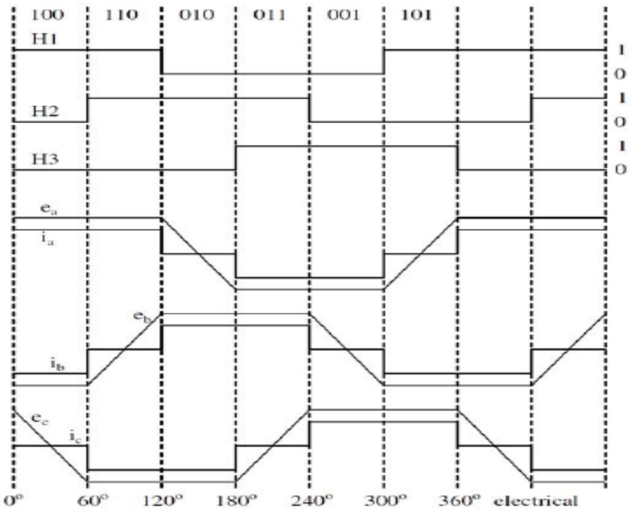


Fig. 5 Trapezoidal control with Hall sensor feedback

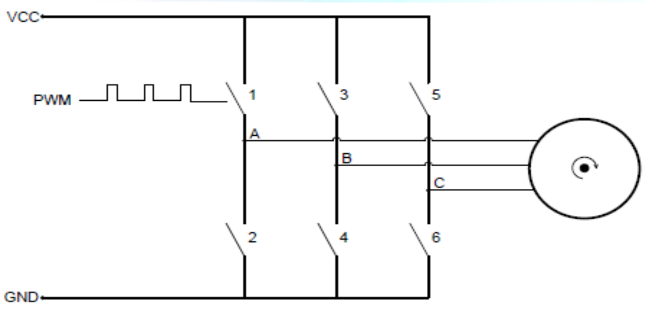


Fig. 6 Speed control through PWM

4. Equivalent Circuit and General Equations of BLDC Motor Drive

For Steady state conditions, assuming v and e are sinusoidal at frequency ω, the equivalent circuit becomes the one shown in Fig. Where X= ω L, and V, I, E, and λm are phasors with rms amplitudes. The steady state circuit equation can be written as

$$V = E + (R + j \omega L) I$$

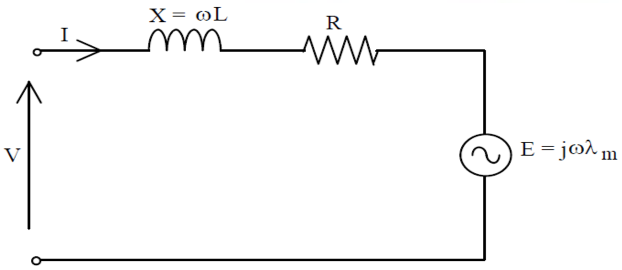


Fig.7 Steady state per phase equivalent circuit of brushless dc motors

For a maximum mechanical power at a given speed, *I* and *E* are in phase. This also gives maximum torque/ampere (minimum current/Nm). A BLDC motor has position feedback from the rotor via Hall devices, optical devices, encoder etc. To keep a particular angle between *V* and *E*, since *E* is inphase with rotor position and *V* is determined by the inverter supply to the motor. Assuming that, $\omega L << R$, when I is in phase with *E*, *V* will also be in phase with *E*. Thus the circuit can be analyzed using magnitudes of *E*, *V*, and *I* as if it were a dc circuit.

But first note that when *E* and *I* are in phase, the motor mechanical power output (before friction , windage and iron losses) .ie, the electromagnetic power output .

$$P_{em} = m |E| |I| = m \omega |\lambda_m| |I|$$

Where m is the number of phases, $|E|$, $|I|$, and $|\lambda_m|$ are the amplitudes of phasor *E*, *I*, and λ_m and the electromagnetic torque is

$$T_{em} = P_{em} / \omega_r = m \omega | \lambda_m | |I| / \omega_r$$

Where $\omega_r = 2 \omega / p$ is the rotor speed in Rad/s and p the number of poles.

Therefore,

$$T_{em} = (mp/2)(|\lambda_m| |I|)$$

The actual shaft output torque is

$$T_{load} = T_{em} - T_{losses}$$

T_{losses} is the total torque due to friction, windage , and iron losses.

Dropping the amplitude (modulus) signs, we have

$$T_{em} = (mp/2)(\lambda_m I)$$

And in terms of rotor speed, $E = (p/2)(\omega_r \lambda_m)$

Still assuming $\omega L << R$ and position feedback keeps V and E (and hence I) in phase .The voltage equation can be,

$$V = E + RI$$

Substituting relations of $E \sim \omega_r$ and $T \sim I$, we obtain,

$$V = (p/2)(\omega_r \lambda_m) + (2RT_{em}/mp \lambda_m)$$

Therefore,

$$\omega_r = (V/(p\lambda_m/2)) - (R T_{em}/m(p\lambda_m/2)^2$$

The corresponding $T \sim \omega$ curve is shown in Fig for a constant voltage

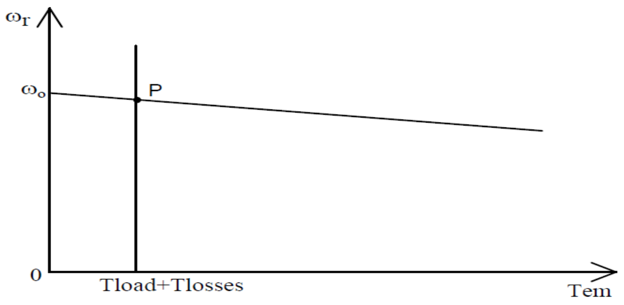


Fig 8 T~ ω curve of a brushless dc motor with a constant voltage supply

5. Simulation Result

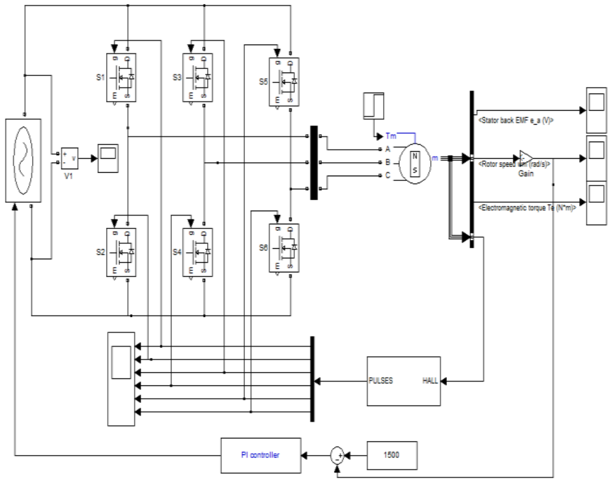


Fig. 9 Simulation diagram

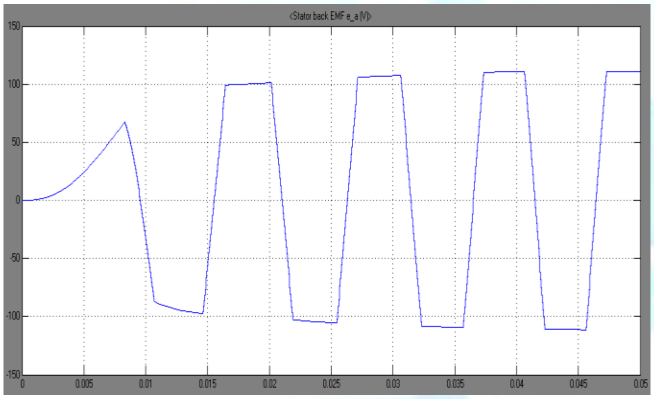


Fig. 10 Back EMF Wave Form

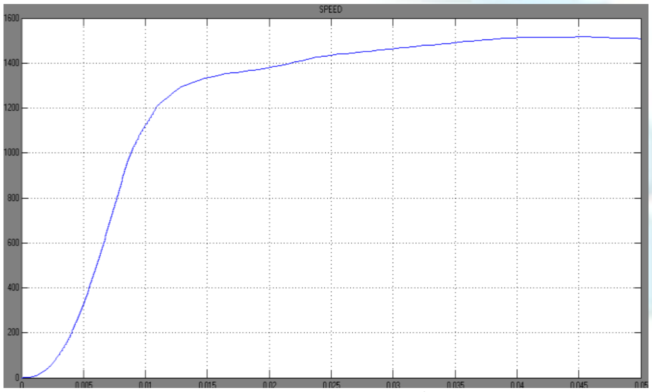


Fig. 11 Rotor Speed Waveform

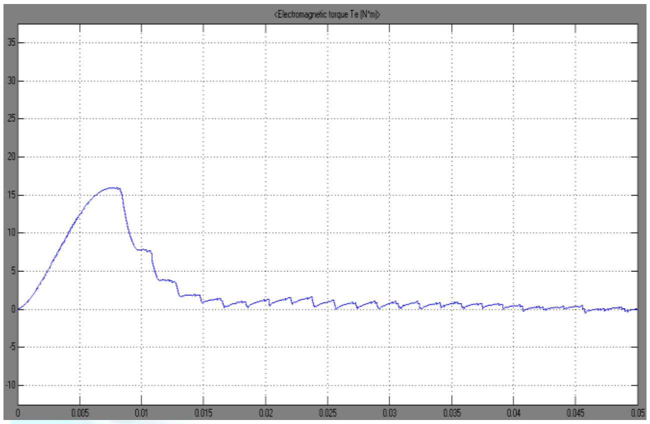


Fig. 12 Torque Waveform

6. Conclusion

This project present implementation of BLDC motor drive for automotive water pump. For the operation of a water pump, for automobile application, it is important to consider not only performance but also reliability. In order to enhance reliability , all parts of the drive , which the operating temperature range is over 125 degree, was chosen .The drive was simplified for reducing the overall cost.

MATLAB simulation is carried out for the proposed BLDC motor drive and analyzed the speed and the rotor torque waveforms for various reference speed.

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