Modeling and Performance Analysis of a Permanent Magnet Brushless DC motor using Instrumentation Technique

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Abstract – This paper deals with the controlling of a permanent magnet brushless DC motor which can be done using a sensor control and a sensor less control technique. The characteristics of a brushless DC motor involve high efficiency and reliability as compared to the other motors of the same rating. The duty cycle of the motor is calculated using a PWM technique for both the methods used in controlling of a PMBLDC motor. A PID controller is also used for the speed control of the motor for sensor control and sensor less control method.

Keywords - Permanent Magnet Brushless DC Motor (PMBLDC), Pulse Width Modulation (PWM) Technique, Proportional-Integral-Derivative (PID) Controller, Hall Position Sensors, Robust Sensor less Commutation Control.

I. INTRODUCTION

A Permanent Magnet Brushless DC motor uses electronic commutators which are replaced in place of brushes that are used in other motors. The principle of a PMBLDC motor is similar to that of a conventional DC motor but has better characteristics and performance as compared to the other motors. For a BLDC motor the graph between current-torque and voltage-rpm is a straight line which shows a linear relationship. A BLDC motor has wide industrial applications since industries require medium and high speed motors. Using a PMBLDC is more advantageous as it reduces mechanical losses, has high efficiency, noiseless operation and improved speed-torque characteristics. A PMBLDC motor can be controlled using a sensor control or sensor less control technique depending upon the type used. A PID controller is used for speed control which can be closed loop or open loop control method, which also amplifies the speed of the PMBLDC motor. A PWM technique is used to vary the duty cycle which hence controls the speed of the motor. For a sensor control technique knowledge of exact position of rotor is required whereas sensor less control is used to overcome the disadvantages of a sensor control technique.

II. MATHEMATICAL MODELLING FOR A PMBLDC MOTOR

Typically, mathematical model of a PMBLDC motor is similar to that of a conventional DC motor that are having same rating. The review of the modeling of a PMBLDC motor is done using some equations involved in the process

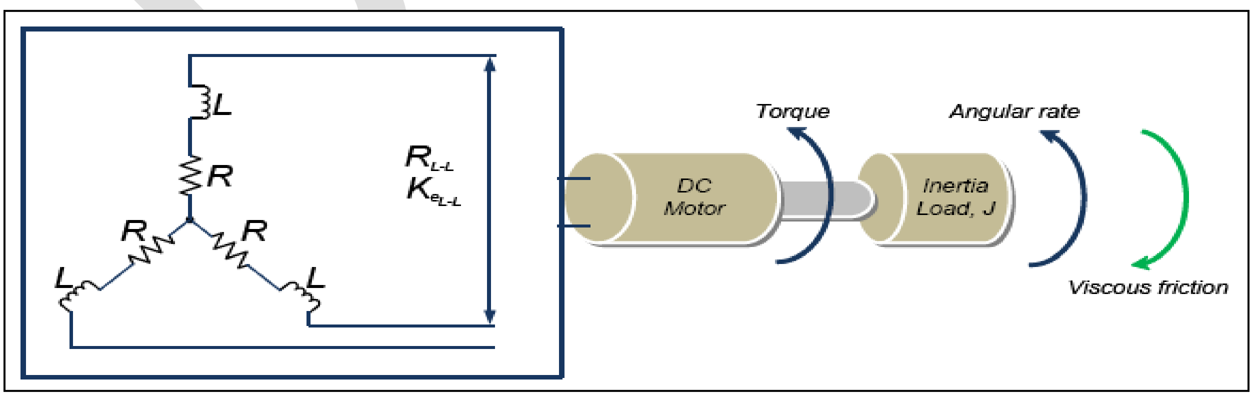


Fig. 1: Brushless DC motor schematic diagram

The phase voltage equations for a PMBLDC motor can be as follows:

$$V_a = R_a I_a + L(\frac{dI_a}{dt}) + E_a$$

$$V_b = R_b I_b + L(\frac{dI_b}{dt}) + E_b$$

$$V_c = R_c I_c + L(\frac{dI_c}{dt}) + E_c$$

Where, V_a,V_b,V_c are the phase voltages

I_a, I_b, I_c are the phase currents

E_a, E_b, E_c are the back EMF's

The back EMF's can be expressed as:

$$E_a = K_e \omega_\mathrm{m} \mathrm{F}(\theta_\mathrm{e})$$

$$E_a = K_e \omega_\mathrm{m} \mathrm{F}(\theta_\mathrm{e} - \frac{2\pi}{3})$$

$$E_a = K_e \omega_\mathrm{m} \mathrm{F}(\theta_\mathrm{e} + \frac{2\pi}{3})$$

Where, ω_m is the angular speed

θ_e is electrical angle of the rotor

$F(\theta_e)$ is the back EMF reference function of rotor position

III. CONTROL STRATEGY OF A BLDC MOTOR

A BLDC motor is referred to a bipolar drive where "bipolar" means that a winding is energized alternatively by both north and south poles. A bipolar drive strategy includes both sensor control technique and sensor less control technique for the smooth functioning of the motor. In a sensor based technique hall sensors and position sensors are used whereas in a sensor less control technique position encoders and back emf's are used.

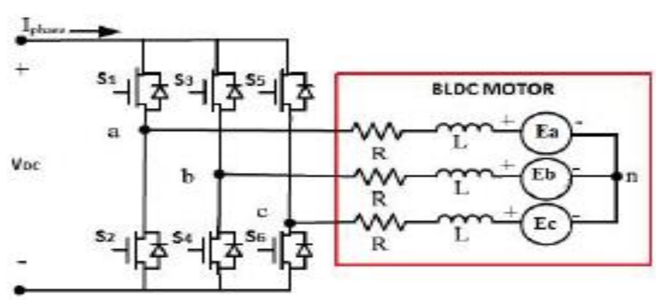


Fig. 2: A PMBLDC motor connected to inverter drive system

For a three phase PMBLDC motor application, a typical inverter drive operation is used which is divided into six modes according to the current conduction states and current sequence. The switches in an inverter drive system are operated for the phase currents of 120° when the back emf is constant and the commutation sequence is changed for the angle of every 60° electrical.

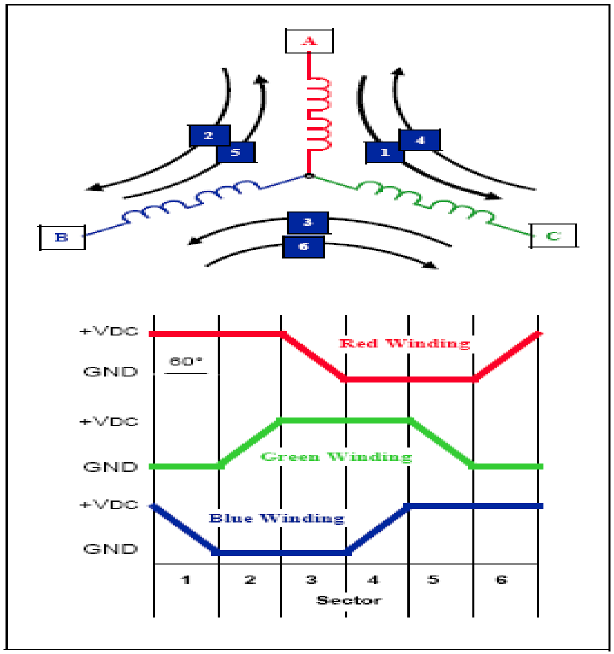


Fig. 3: Trapezoidal Back EMF waveform for a BLDC motor

A PWM control technique is used to adjust the duty cycle whose frequency is about 10 times to that of the maximum frequency of the circuit. The average output voltage is controlled through duty cycle of PWM control technique whose relationship is given by:

$$V_{avg} = D\ V_{input}$$

A PID controller is used for the speed control of a PMBLDC motor which incorporates two types of speed control techniques such as open loop speed control and closed loop speed control. A feedback path is given to the circuit which measures the actual speed and compared with the reference speed, the error speed signal generated is given as input to the PID controller and the output of the PID controller is subjected to the current limiter. The output of the PID controller is a DC square wave that is compared with a continuous triangular wave. The values of K_p, K_i, and K_d are calculated using a Ziegler Nicholas method.

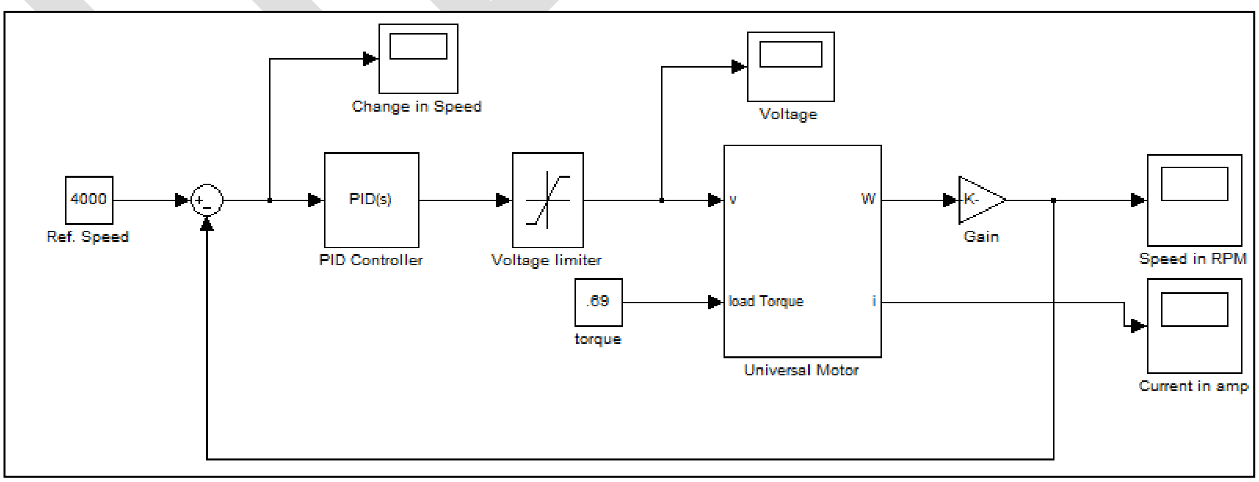


Fig. 4: Speed Control diagram through PID Controller

The figure shown above represents the simulink model for a PID control loop which is formed by the combination of Proportional-integral-derivative control.

IV. SIMULATION CIRCUIT AND RESULT ANALYSIS

A Matlab Simulation model of a PMBLDC motor for both sensor control method and sensor less control method is shown in the figure where a reference speed for both the control techniques has been set at 1650 rpm where a load torque disturbance is applied for a time period of 0.05 seconds. From the figure the two control techniques are compared with the simulink model and their waveforms.

The model shown below is of a PMBLDC motor with sensor control technique where reference speed is set at 1650 rpm. A PWM generator is used which adjusts the duty cycle and controls the speed of the motor. A decoder is used for the conversion of hall sensor signal to the equivalent EMF signal that is given to the PWM generator. A demultiplexer is used so that the pulses obtained are divided equally and given to the gate signals.

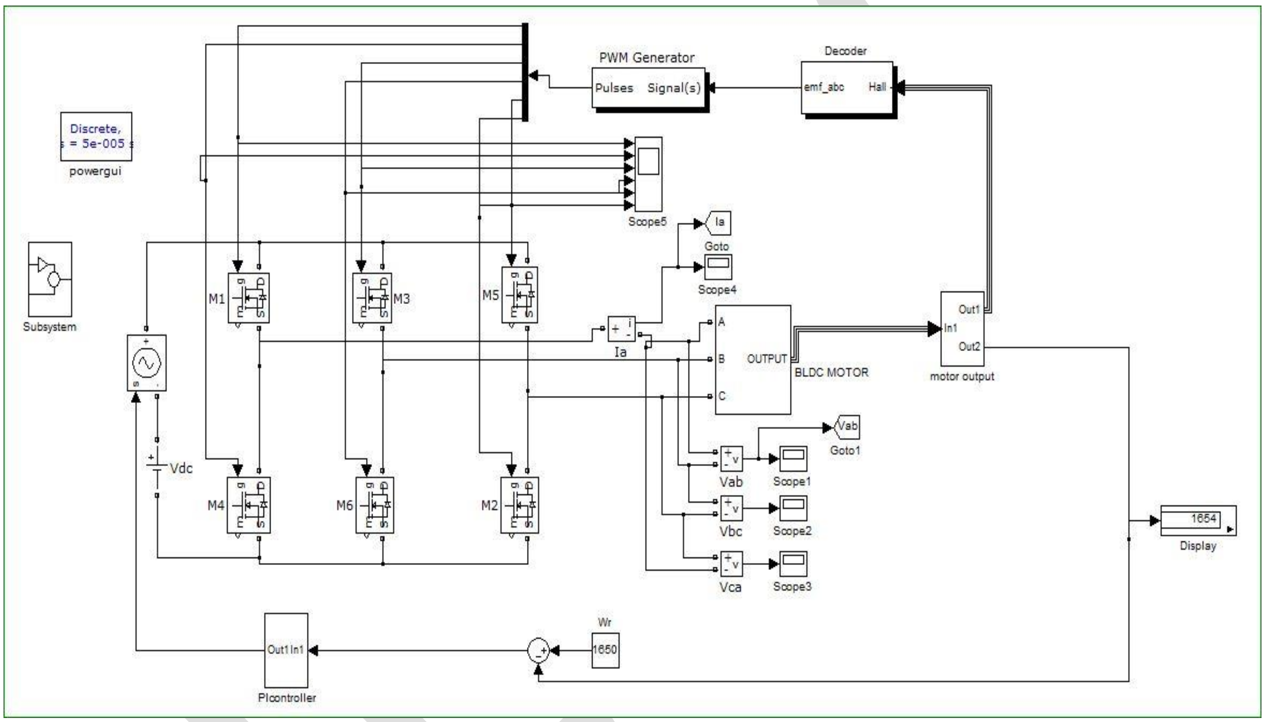
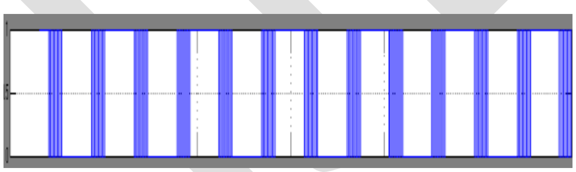
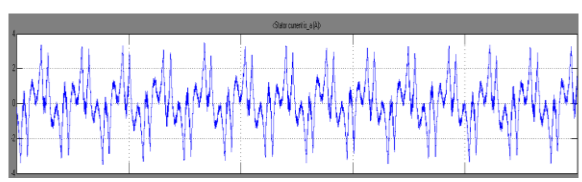


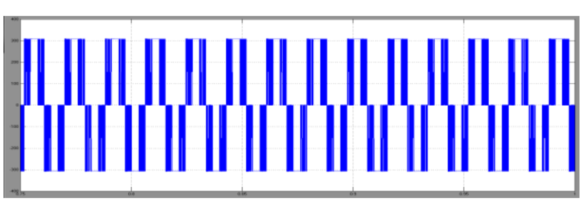
Fig. 5: Simulink model of a PMBLDC motor using sensor control



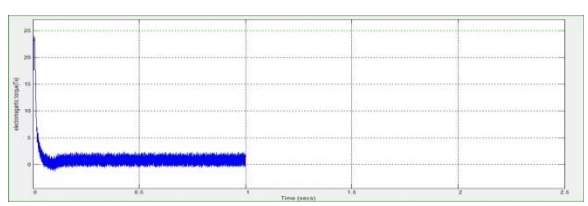
Gate Pulse for sensor control



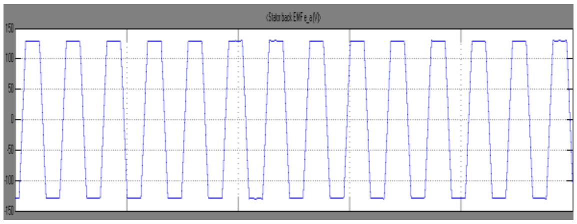
Phase Current Waveform



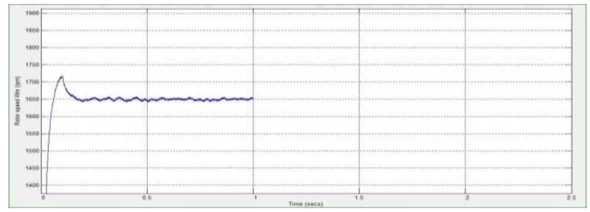
Line Voltage Pulses



Speed in rpm for sensor control



Back EMF Waveform



Electromagnetic Torque for sensor control

The model and the result analysis shown below is of a PMBLDC motor of a sensor less control technique where a motor torque has been divided into two parts that is stator back EMF and the motor output. The output from the stator back EMF is given to the PWM generator. Using demultiplexer the pulses obtained are equally divided and given to the gate pulse of the IGBT.

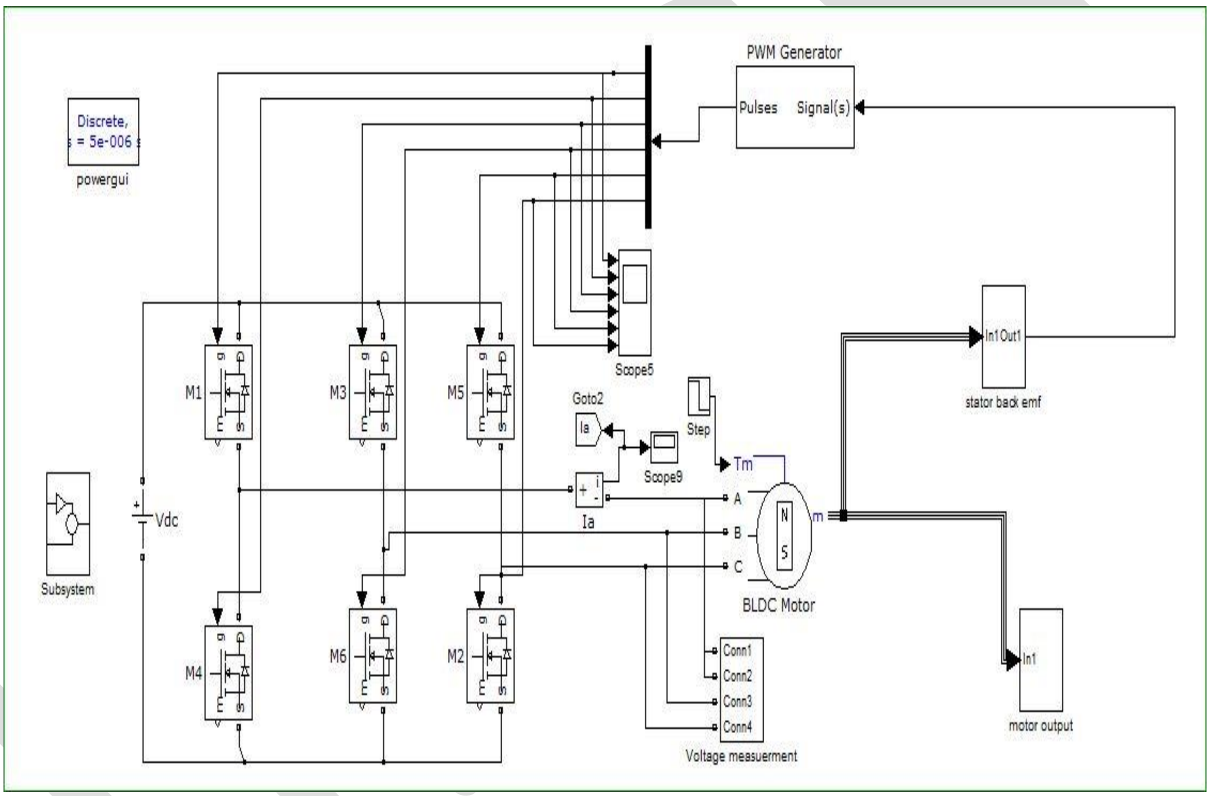
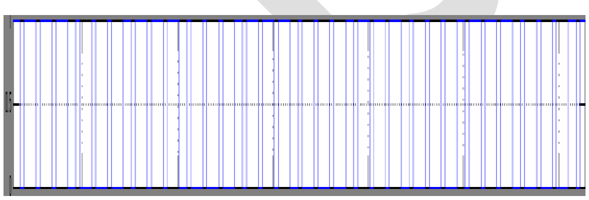
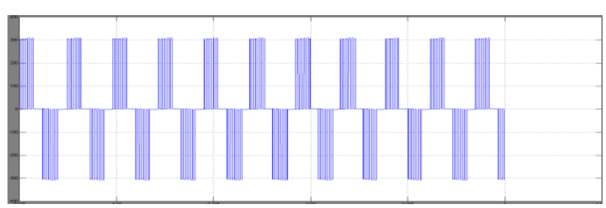


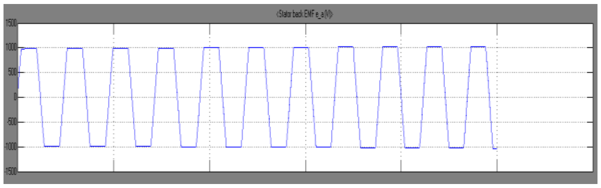
Fig. 6: Simulink model of a PMBLDC motor using sensor less control



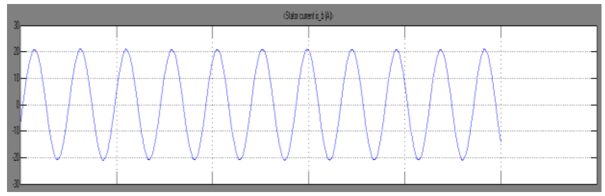
Gate Pulse for sensor less control



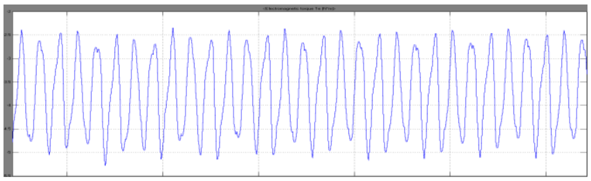
Line Voltage Pulses



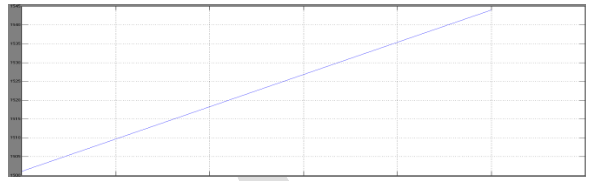
Back EMF Waveform



Phase Current Waveform



Electromagnetic Torque for sensor less control



Speed in rpm for sensor less control

V. CONCLUSION

This paper deals with the modeling and performance of a PMBLDC motor and comparison between the sensor control method and the sensor less control method using a PID control for speed analysis and current limiter and a PWM control for variation of duty cycle. From the calculation of the values and graphical analysis of voltages and currents it is found that a BLDC motor with sensor less control technique is more advantageous as compared to a BLDC motor with sensor control technique. In this paper controlling of a PMBLDC motor with different techniques is proposed, analyzed, and extended by overcoming the drawbacks of a BLDC motor over a conventional DC motor of same rating.

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