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Mathematical Modeling of Brushless DC Motor and its Speed Control using Pi Controller

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***Abstract*:-Electronically commutated Brushless DC motors are enormously used in many industrial applications This paper deals with development the mathematical model of the brushless dc motor and control the speed of the motor using PI controller. The difference between actual and required speeds is given as input to the controller. Based on this data pi controller controls the duty cycles of the PWM pulses which corresponds to the voltage change required to maintain the speed. The BLDC motor is driven by the AC supply from the 3-phase inverter that which is designed using six switches with appropriate sequence. The following hall signals produce back emf that the pulse is modulated by varying the duty ratio which is drawn from pi controller and given to inverter switches. The simulation of the proposed scheme was done using MATLAB software package in SIMULINK environment.**

Keywords: Brushless DC Motor(BLDCM),PI controller.

1. INTRODUCTION

A Brushless dc (BLDC) motor construction is similar to the synchronous motor with permanent magnets on rotor.In the dc motor, the current polarity is altered by commutator and brushes. However, in brushless dc motor there are no brushes and commutator. A Brushless dc motor is a rotating self-synchronous machine.The stator has usually a conventional three phase AC winding which is either star or delta connected and permanent magnets mounted on the surface of the rotor. The stator winding sequentially switched with dc voltage through three phase inverter.The inverter switching pattern and frequency are controlled by the rotor position and speed.Each switching pattern remains constant for 60 degrees electrical rotation of the rotor.The BLDC motor uses position sensors to sense the actual rotor position or the position can be detected without sensors. Brushless dc motors have high efficiency, silent operation, compact form, reliability and low maintenance as compared to conventional dc motor. But the speed control of these motors is not an easy task, the advancements in Microcontroller, power electronics and electrical drives over the decade have made reliable and cost-effective solution for adjustable speed application The BLDC motors are used in home Appliances, replacing the conventional motor applications.The major application includes washing machines, room air conditioner, refrigerator, vacuum cleaner, dish washer etc.

In this paper we developed the mathematical model of the brushless dc motor and control the speed of the motor using PI controller.

2. MATHEMATICAL MODEL OF BLDC MOTOR

A 3 phases, 4 poles, Y connected trapezoidal back-EMF type BLDC is modeled. Trapezoidal back-EMF is referring that mutual inductance between stator and rotor has trapezoidal shape. Therefore a b c phase variable model is more applicable than d-q axis. The following assumptions aremade.i.eMagnetic circuit saturation is ignored, Stator resistance, self and mutual inductance of all phases are equal and constant, Hysteresis and eddy current losses are eliminated, All semiconductor switches are ideal.

The electrical and mechanical mathematical equations of BLDC are:

Phase voltage equations of BLDC motor

$$V_a = Ri_a + (L-M)\frac{di_a}{dt} + E_a \text{..............................} (2.1)$$

$$V_b = Ri_b + (L-M)\frac{di_b}{dt} + E_b \text{..............................} (2.2)$$

$$V_c = Ri_c + (L-M)\frac{di_c}{dt} + E_c \text{..............................} (2.3)$$

Back emf equations of BLDC motor

$$E_a = K_e\omega_m F(\theta_e) \text{...} (2.4)$$

$$E_b = K_e\omega_m F(\theta_e - \frac{2\pi}{3}) \text{....................................} (2.5)$$

$$E_c = K_e\omega_m F(\theta_e - \frac{4\pi}{3}) \text{....................................} (2.6)$$

Torque equations are each phase of BLDC motor

$$T_a = K_t i_a F(\theta_e) \text{..} (2.7)$$

$$T_b = K_t i_b F\left(\theta_e - \frac{2\pi}{3}\right) \text{................................} (2.8)$$

$$T_c = K_t i_c F\left(\theta_e - \frac{4\pi}{3}\right) \text{................................} (2.9)$$

The electromagnetic torque is

$$T_e = T_a + T_b + T_c \text{..} (2.10)$$

$$T_e - T_l = J\frac{d^2\theta_m}{dt^2} + \beta\frac{d\theta_m}{dt} \quad \text{.....................................(2.11)}$$

$$\theta_e = \frac{p}{2}\theta_m \quad \text{...(2.12)}$$

$$\omega_m = \frac{d\theta_m}{dt} \quad \text{..(2.13)}$$

In the modeling equation K_e is back emf constant in volt/rad/sec and K_t=torque constant in N-m/Amp and ω_m is rotor angular speed.

3. PROPOSED CONTROL SCHEME:

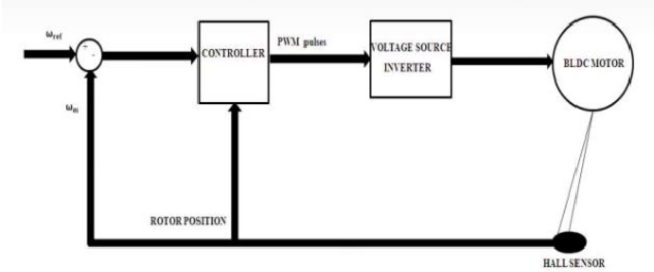

Fig3.1:Block diagram BLDCM drive system

The rotor position is measured using Hall sensors. By varying the voltage across the motor, we can control the speed of the motor. The speed and torque of the motor depend on the strength of the magnetic field generated by theenergized windings of the motor.The motor speed depends on the amplitude of the applied voltage. This can be adjusted using PWM technique. The required speed is controlled by a speed controller. This is implemented as a conventional proportional-Integral controller. The difference between the actual and required speeds is given as input to the controller. Based on this data PI controller controls the duty cycle of the PWM pulses which correspond to the voltage change required to maintain the desired speed.

In industrial system PI is a control loop feedback mechanism. Actually, between measured process variable and desired set point error exist. So, to correct that error Proportional integral controller is used in industries. The proportional mode and integral mode are two separate modes involved in proportional integral mode calculation. The reaction to the current error is calculated by Proportional mode and reaction to the recent error is calculated by integral mode. So, the sum of these two modes output is considered as corrective action to the control element and PI controller is implemented as

$$output(t) = K_p e(t) + K_I \int_0^t e(\tau)d\tau$$

e(t) =set reference value – actual calculated value.

The speed error is processed to PI controller after comparing the speed of the BLDC motor with its reference speed.

$$E(t) = \omega_{ref} - \omega_m(t)$$

Truth table to generate commutation signals via Back emf and duty ratio.The hall signals which are generated from the position of rotor generates the back emf which has the trapezoidal nature. This back emf is converted through a logic sequence that develops the model to generate appropriate commutation signal which is controlled by duty ratio.The corresponding truth table for this complete mechanism is shown below in table.

Hall Signals			**Back Emf**			**Commutation Signals (pulses)**					
H_a	H_b	H_c	E_a	E_b	E_c	Q1	Q2	Q3	Q4	Q5	Q6
1	0	1	+1	-1	0	1	0	0	1	0	0
1	0	0	+1	0	-1	1	0	0	0	0	1
1	1	0	0	+1	-1	0	0	1	0	0	1
0	1	0	-1	+1	0	0	1	1	0	0	0
0	1	1	-1	0	+1	0	1	0	0	1	0
0	0	1	0	-1	+1	0	0	0	1	1	0

4. MODEL OF SPEED CONTROL OF BLDC MOTOR

In this section, the MATLAB/SIMULINK implementation of the BLDC motor drive model is presented.

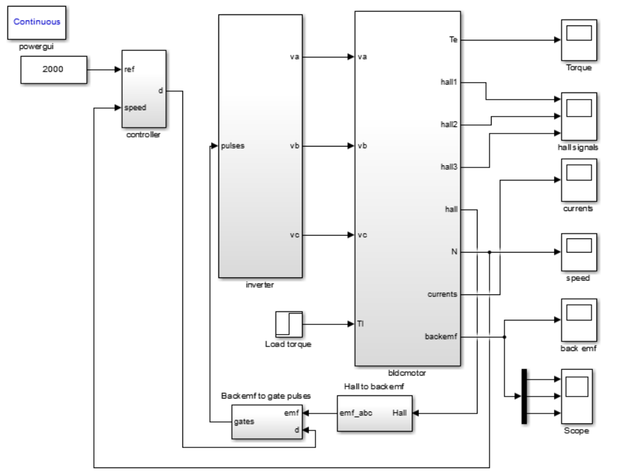

Fig 4.1: Complete model of speed control of BLDC motor drive

PI Controller:

The main reason why feedback is very important in systems is to be able to attain a set-point irrespective of disturbances or any variation in characteristics of any form. A proportional integral derivative is control loop feedback mechanism used in any applications to control the system. The PI controller attempts to correct that error between a tracked variable and reference set point and then the output is corrected which can adjust the process accordingly. The PI controller calculation involves two separate modes namely proportional mode, integral mode. The model of PI Controller is shown in figure

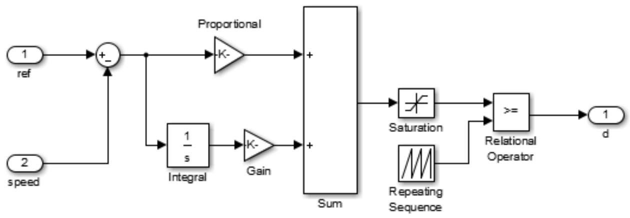

Fig 4.2: PI Controller block

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5. SIMULATION RESULTS

To verify the results of the proposed control strategy in MATLAB simulations,
BLDC Motor has the following constants and ratings:
Poles=4, DC input voltage=150v
R=0.7Ω,L=2.72mH, M=1.5mH, K_e=0.1128, K_t=0.049, J=0.0002 Kg-m^2
Controller gains: K_p= 1.5, K_i= 10

Rotor speed without load:

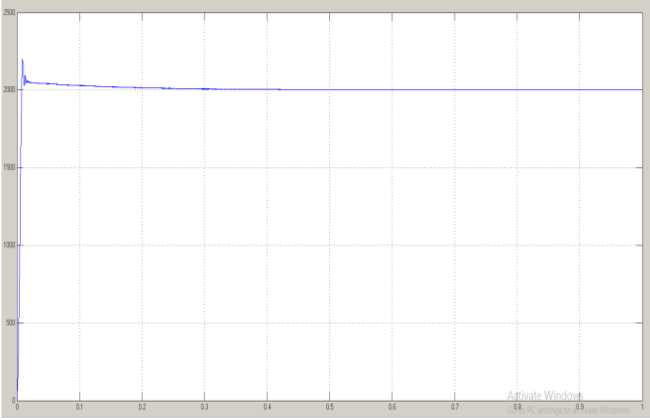

Fig 5.1 Rotor speed at no load condition

Electromagnetic torque at no load condition:

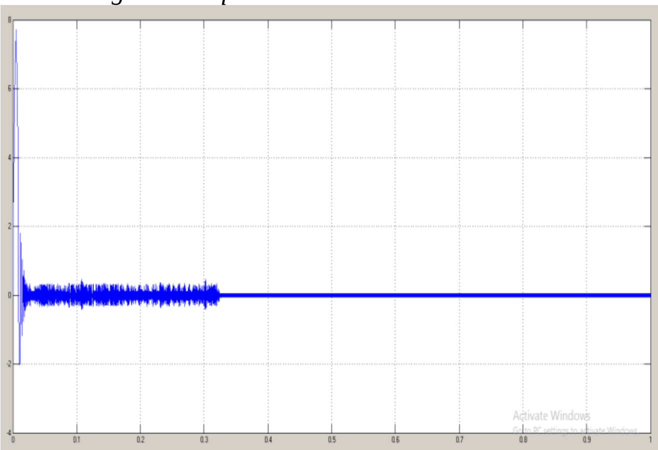

Fig 5.2 Electromagnetic torque at no load

Rotor speed at load condition at 2200 rpm:
The load torque of 1N-m at time 0.7 seconds and the corresponding speed of the rotor is at the reference speed of 2200 rpm

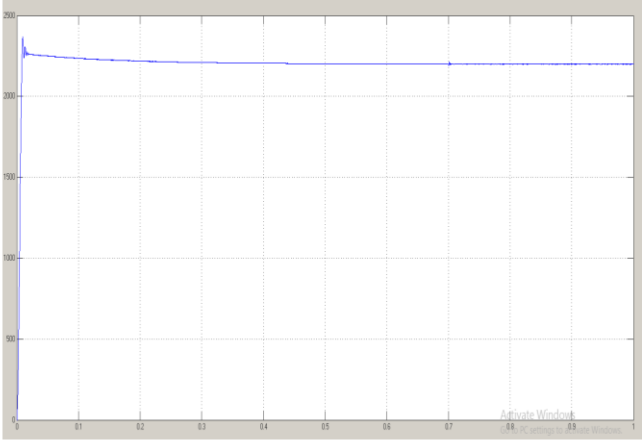

Fig 5.3 Rotor speed at T_l = 1N-m at set speed of 2200 rpm

Electromagnetic torque at load condition at 2200 rpm:
The load torque T_l of 1N-m at time 0.7 sec is applied to the motor and the corresponding electromagnetic torque is depicted at 2200 rpm

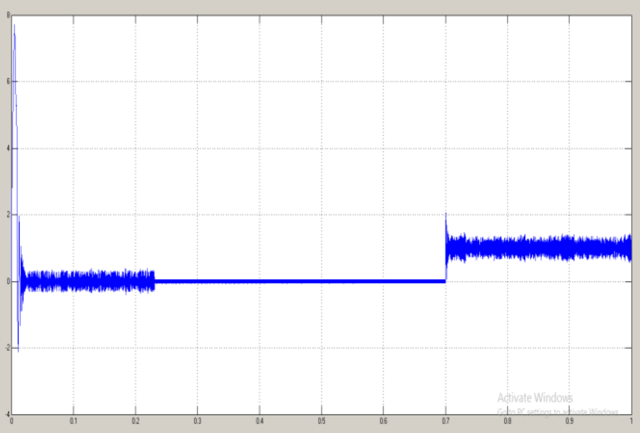

Fig 5.4 Electromagnetic torque at T_l = 1N-m at set speed 2200 rpm

Rotor speed at load condition at 2500 rpm:
The load torque of 1N-m at time 0.7 seconds and the corresponding speed of the rotor is at the reference speed of 2500 rpm

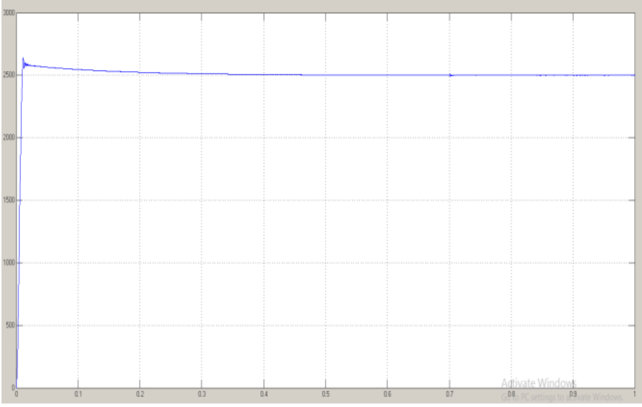

Fig 5.5 Rotor speed at T_l = 1N-m at set speed 2500 rpm

Electromagnetic torque at load condition at 2500 rpm:
The load torque T_l of 1N-m at time 0.7 sec is applied to the motor and the corresponding electromagnetic torque is depicted at 2500 rpm

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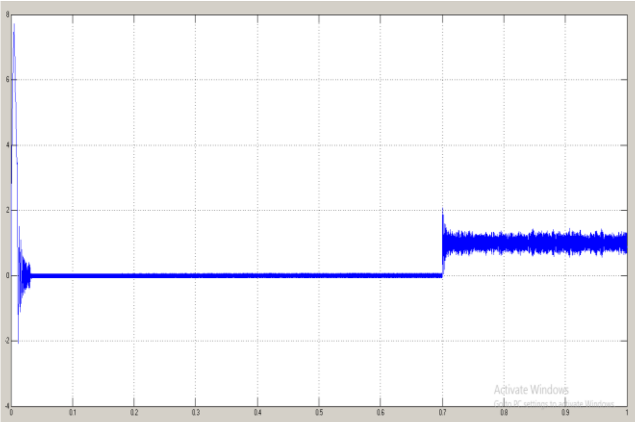

Fig 5.6 Electromagnetic torque at T_l = 1N-m at set speed 2500 rpm

Hall signals:

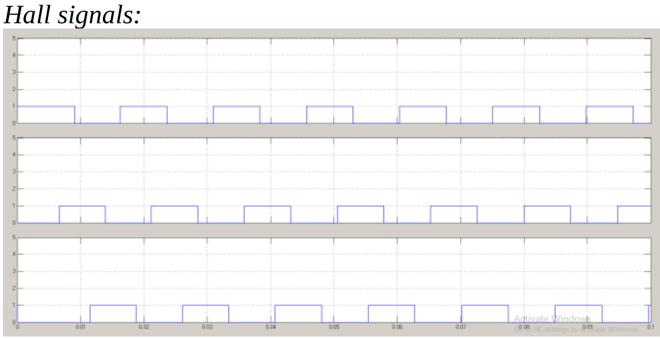

Fig 5.7 Hall signals

Phase voltage V_{an}:

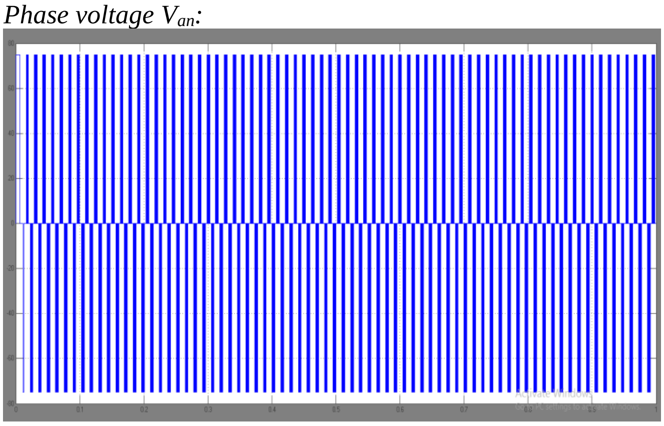

Fig 5.8 Phase voltage V_{an}

Line voltage V_{ab}:

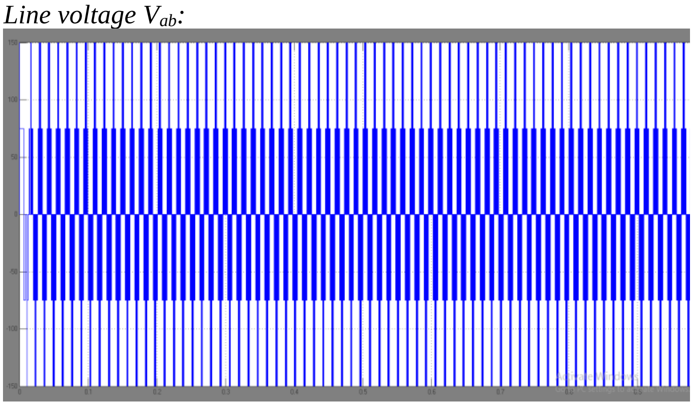

Fig 5.9 Line voltage V_{ab}

Back emf waveform:

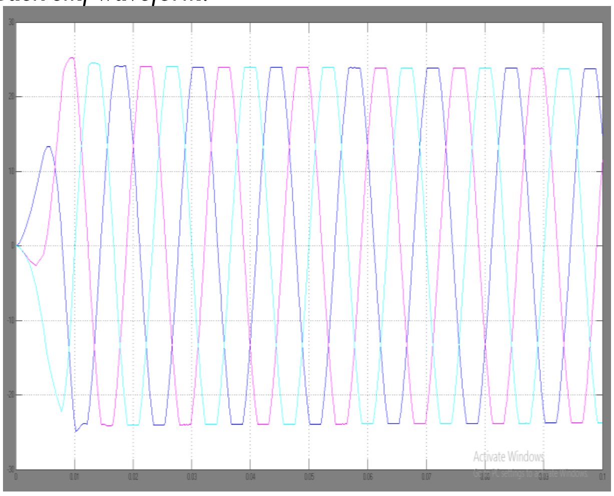

Fig 5.10 Back emf waveforms

6. CONCLUSION

In this paper mathematical model and the control scheme for speed control of BLDC motor using PI controller is proposed. It is shown that BLDC motor is a good choice in automotive industry due to higher efficiency, higher power density and higher speed ranges compare to other motor types. The performance of the BLDC motor is observed under no- load and variable load condition. The simulation of PI controller, using MATLAB/SIMULINK to control the speed of BLDC motor, proves that the desired speed is attained with in short time. From the results we observed that wide range of speed control is possible in BLDC motor using PI controller.

In future hysteresis current modulation technique can be used to control the speed of the motor and its performance characteristics compared with pi-based speed controlling technique.

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