Speed Control of BLDC Motor Drive for Various Applications

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Abstract:- **This paper exhibits a simplified way of controlling of the Permanent Magnet Brushless DC Motor (BLDC) using PI Controller with the comparative study & detailed performance analysis for different load applications in MATLAB environment using Sim Power System (SPS) toolboxes and Simulink in Discrete timespan. A various industrial application such as conveyors, pump load, elevators, lift, etc., in different operating condition like staring mode dynamics, braking mode dynamics, the step change in speed command, etc., have been tested. The choice of BLDC Motor has many advantages over brushed DC motors and induction motors which is of higher speed ranges, long life span, good speed versus torque characteristics, high dynamic response, long operating life, high efficiency, and noiseless operation.**

Keywords:- BLDC; MATLAB; PI Controller; Simulink.

I. INTRODUCTION

Brushless DC motor for a different mode of operation has dependably been a fascinating exploration zone in the field of electric drives due to the presence of major drawback of conventional DC motor. At brushes surface, a large amount of spark is produced which results in a large amount of loss of energy in the form of heat. This is considered as a major loss of energy and present due to the use of brushes and commutator. Because of this major disadvantage, the conventional DC motor faces the challenge of maintenance at a frequent interval of time and life of the motor is reduce [1]-[3].

The advancement in technology of power electronic along with the high-speed processor, self-commutating electronic devices and latest software helps to model, realize and analyze such control strategies. These types of complexity in control has not been an easy task. MATLAB software had provided a user-friendly environment to simulate such complex controlling and realized the dynamics of machine for a different mode of operation and their practical applications. In this work, the motor speed control is done with the help of a PI controller. The controlled output by the controller is then given to the inverter.

This paper presents analysis and modeling of BLDC motor drive subjected to a various operating condition like starting, braking, load perturbation, a step change in speed, etc., for the various practical application using different loads in MATLAB. Such an analysis provides an innovative approach through mathematically modeling practical

situations on a software platform. Speed control is done by the DC link voltage control method. DC link voltage control requires the knowledge of the rotor position and the mechanism to commutate the motor. The principle of torque hysteresis controller is to provide natural current protection, fast and reliable torque dynamic control. The dynamic performance of the drive under various operating conditions is studied and tested [4]-[5].
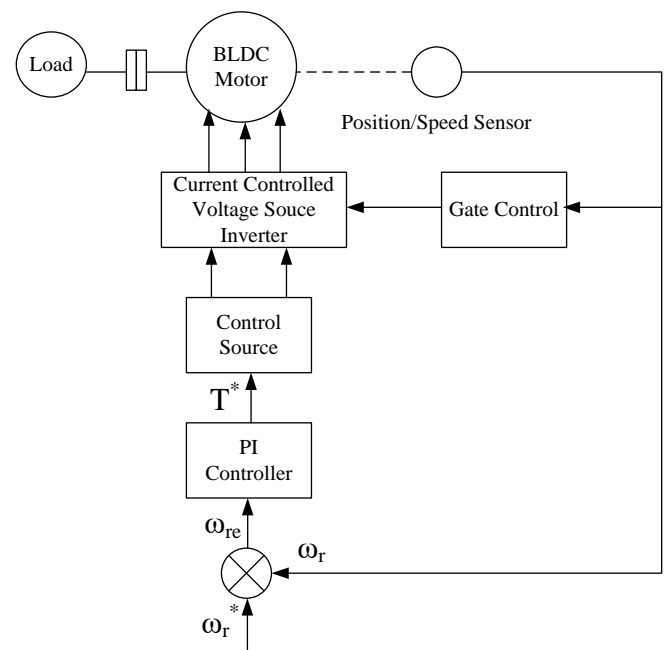

Fig 1:- Basic Block Diagram of Variable DC Link Voltage Controlled BLDC Motor Drive

II. CONTROL PHILOSOPHY

The basic block diagram of a BLDC motor drive is shown in Fig. 1. In BLDC motor the rotor position is known by the hall sensor. The speed control of the motor is done with the help of a PI controller. The reference speed ($\omega r*$) and actual motor speed (ωr) are compared and the speed error (ωre) is computed. The speed controller takes the speed error as input and using suitable logic, generates the reference torque command (T*). The output of the controller is given to the control DC voltage source which is fed into the voltage source inverter. The three-phase ac output generated by the inverter is fed to the BLDC motor.

There are mainly three types of controlling scheme of BLDC motor; hysteresis band control, PWM Control and Variable DC link voltage control as shown in Fig.2. In hysteresis band control, the value of the controlled variable

is forced to stay within certain limits (hysteresis band) around a reference value. The drawback of the hysteresis band control technique is its high and uncontrolled switching frequency when a narrow hysteresis band is used and have large ripples when the band is wider. In PWM control the motor is turned on and off at high rate. The chopping frequency is fixed but the length of the duty cycle depends on the control error. The fact that frequency is fixed makes a filter of acoustic and electromagnetic noise easier.

Use of variable dc voltage source to control the applied voltage is superior to Hysteresis and PWM methods. A linear power stage is cheaper than pulsed power stage (PWM). The Variable DC Link Voltage Control is considered in this work to control the motor speed. For controlling the gate pulse of the inverter carrier based controlling scheme and hysteresis current control schemes are used [6]-[7].
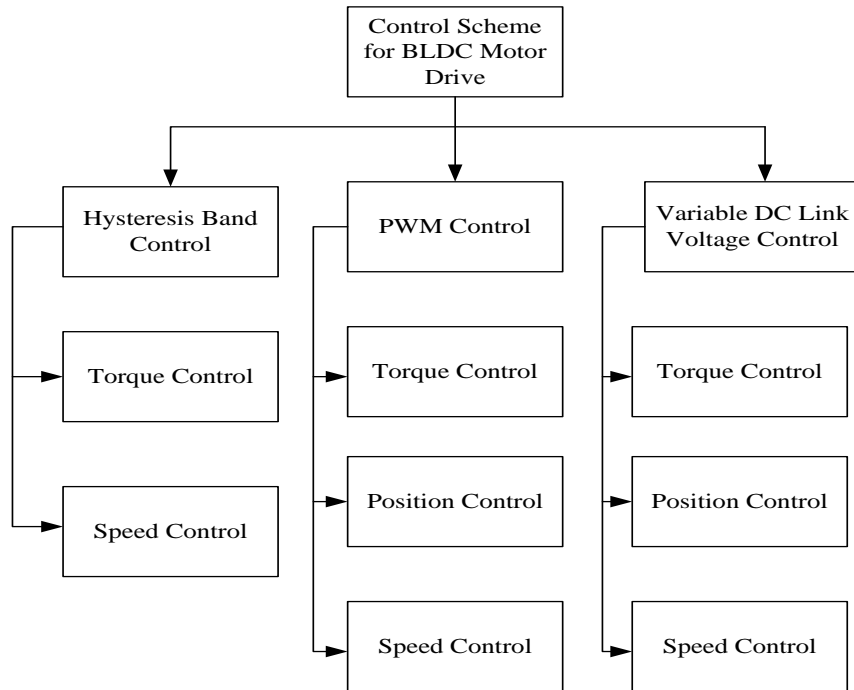

Fig 2:- Different Controlling Scheme of BLDC Motor

III. SYSTEM MODELING

The basic model of BLDC Motor Drive in MATLAB Simulink is shown in Fig. 3. Different parts of the device control structure are modeled using Simulink tool. The BLDC motors are aliased as permanent magnet synchronous motors with trapezoidal back EMF. This drive attributes closed-loop speed control through stator current control, employing Hall sensors. Based on the Hall sensor signals and the machine torque constant, the reference stator phase currents equivalent to the desired torque are derived. The required gate signals are obtained by the reference phase currents for the inverter through a hysteresis-band current control.
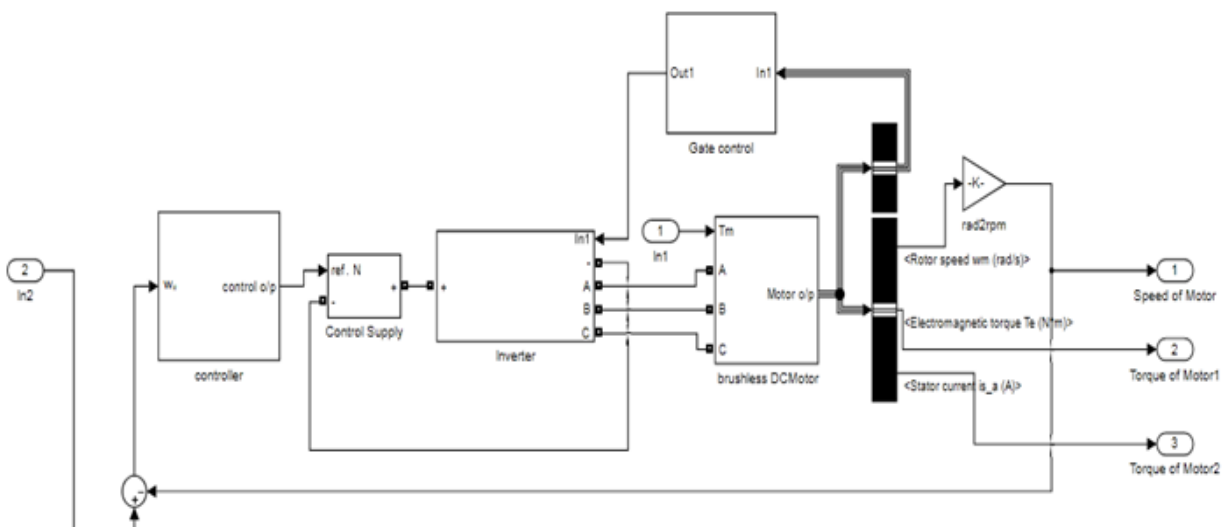

Fig 3:- Basic Model of BLDC Drive in MATLAB Simulink

A. Speed Controller

The difference between actual speed (ω_r) and the reference speed (ω_r^*) give rise to an error signal (ω_{re}). The error signal at that point goes into the PI control loop where it gets duplicated by the proportional (K_p) and integral (K_i) constant. The output signal equals to the sum of proportional and integration coefficients given by equation (1). The higher the value of Kp, the lesser is the output power with more error as given by equation (2) at an nth instant, which can be removed by introducing an integral part (K_i). The higher the value of K_i, the slower is the output. To adjust the PI controller, set the integration time equal to zero, and the given value to proportional time. By decreasing the coefficient of proportionality periodic oscillations are achieved in the system and then the value of k_i is adjusted. Fig. 4 shows a Simulink diagram of the PI control logic in the MATLAB environment. PI Controller parameters are given in TABLE II.

$$U(t) = K_p\, e(t) + K_i \int e(t)dt \qquad (1)$$
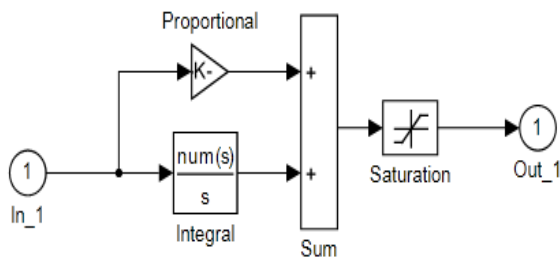$$\omega_{re(n)} = \omega^*_{r(n)} - \omega_{r(n)} \qquad (2)$$

Fig 4:- Simulink PI Speed Control Logic in MATLAB Simulink

B. Hall Sensor Decoder

PV Hall sensor detects the rotor position to generate the corresponding electrical signal. This is done by the hysteresis band control technique to generate the hall sensor output which is decoded into a back EMF signal of the motor. Hall sensors work on the principle of hall-effect that implies when a current-carrying conductor is subjected to the magnetic field, due to which a force is experienced by the charge carriers that are based on the voltage developed between the two sides of the conductor. On the reversal of the direction of the magnetic field, the voltage developed will also be reversed. Whenever rotor magnetic poles North (N) or South (S) comes near to the hall sensor, they stimulate a high or low-level signal, which can be applied to determine the current position of the shaft. [8]

The hysteresis band controller provokes the inverter's output current to keep tracking the reference signal within the hysteresis band. A hysteresis comparator is used which is fed by the output current of the inverter through a current sensor. Within the specific hysteresis band, the output current is compared to the reference signal. The output given by the comparator is forwarded to the decoder block. [9]

The Hall decoder Simulink diagram is shown in Fig. 5, which extracts the Back EMF information from the Hall Effect sensor signals. It represents the normalized ideal phase

currents to be injected in the motor phases. The figure shows the Back EMF of phase A and the output of the Hall decoder for phase A. There are upper and lower band limits. The signal generated by the gates is being compared to the feedback signal. When the value of the output signal becomes equal to the lower limit of the band switching takes place.
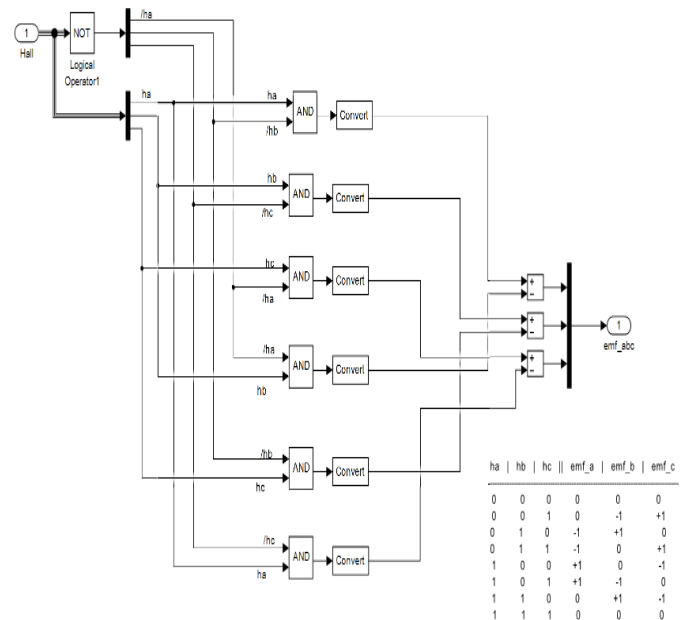

ha	hb	hc || emf_a	emf_b	emf_c
0	0	0	0	0	0
0	0	1	0	-1	+1
0	1	0	-1	+1	0
0	1	1	-1	0	+1
1	0	0	+1	0	-1
1	0	1	+1	-1	0
1	1	0	0	+1	-1
1	1	1	0	0	0

Fig 5:- Hall Sensor Decoder Logic in MATLAB Simulink

C. Gate Triggering Block

As per the signal generated by the Hall sensor, the decoder changes the input to respective emf which needs to change into different gate signal which controls inverter switches. Fig. 6 shows a Simulink diagram of the gate control logic in the MATLAB environment. Table I shows switching instant for the inverter.
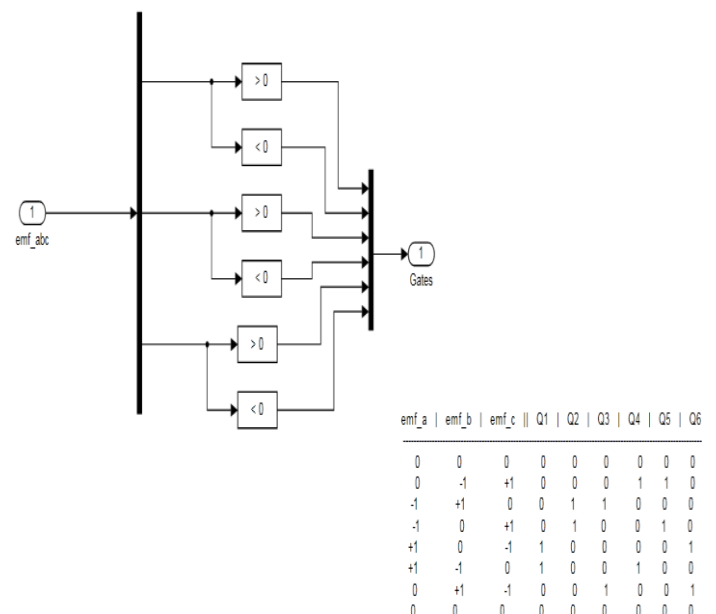

emf_a	emf_b	emf_c || Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0
0	-1	+1	0	0	0	1	1	0
-1	+1	0	0	1	1	0	0	0
-1	0	+1	0	1	0	0	1	0
+1	0	-1	1	0	0	0	0	1
+1	-1	0	1	0	0	1	0	0
0	+1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

Fig 6:- Gate Triggering Logic in MATLAB Simulink

Switching Interval	EMF			Operating Switches	
	A	B	C		
0º-60º	+	-	off	Q1	Q4
60º-120º	+	off	-	Q1	Q6
120º-180º	off	+	-	Q3	Q6
180º-240º	-	+	off	Q3	Q2
240º-300º	-	off	+	Q5	Q2
300º-360º	off	-	+	Q5	Q4

Table 1:- Switching Logic for Inverter Switches

D. Reference Speed and Torque

Signal builder block is used for generating the reference speed (ω_r*) and load torque (T) which is to be applied to the drive. The generated signal is shown in Fig. 7. These signals used to analyze the operation of the machine dynamics when different speed signals are fed to the drive-in changing load conditions.
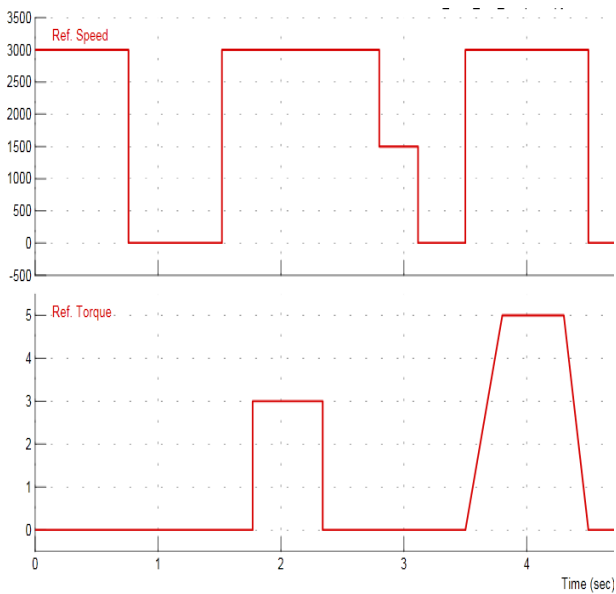

Fig 7:- Generated Reference Speed and Torque in MATLAB

IV.   RESULT & DISCUSSION

The developed model has been tested for a different mode of operation and application. The BLDC motor drive has been operated in Starting Mode, Braking Mode, Load Perturbation and some other different load applications. To check the sustainability of drive, various load torques have been applied.

A. Start Mode Dynamics

The BLDC motor is fed from a controlled voltage. Initially, the motor is started at no load with a reference speed of 3000 rpm with set torque limit. Due to the controller, initial starting current also remains within the limit. The motor attains its steady state speed within 0.02 sec. PI controller help in controlling the speed of the BLDC motor. The dynamics of the machine shown in Fig. 8.
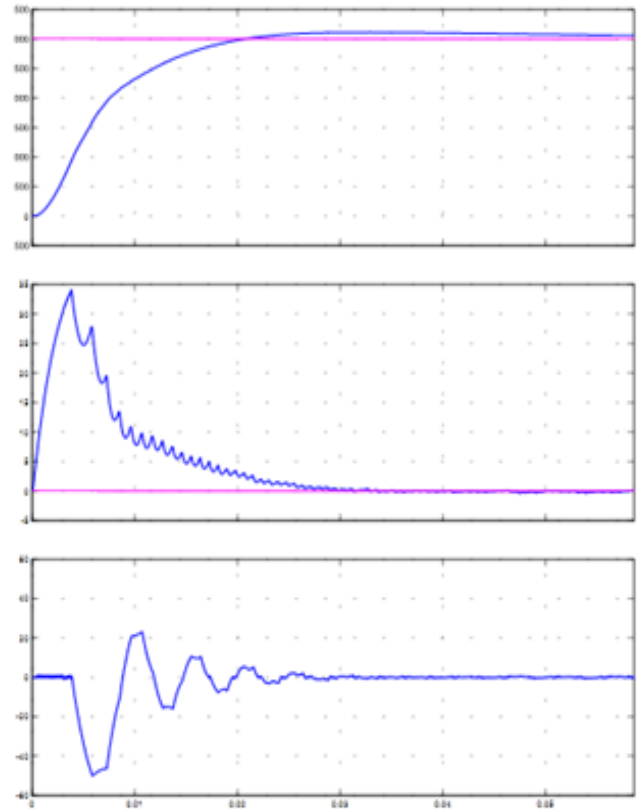

Fig 8:- Starting Mode Dynamics of the Motor (Speed, Torque and Current)

B. Braking Mode Dynamics

In braking mode, when the drive is running at a steady state speed of 3000 rpm, brakes are applied suddenly by changing the reference speed from 3000 rpm to 0 rpm as shown in Fig: 9 and motor come to rest after 0.02 sec. The stator current frequency is being reduced by the controller. With the reduction in motor current, a negative torque is produced by the motor with the positive speed, i.e. when regenerative braking takes place and the energy produce is feedback to supply. At the instant of speed fallen to zero the torque also become zero and motor come to rest position.

C. Load Perturbation Dynamics

When a machine is running at steady state speed, a sudden application and removal of the load are called Load Perturbation. With the sudden application of full load, the motor maintains its steady state speed after a small dip in speed to 2750 rpm from 3000 rpm. After removal of the load, machine speed increases from 3000 rpm to 3250 rpm for fractions of seconds. The result is shown in Fig. 10.
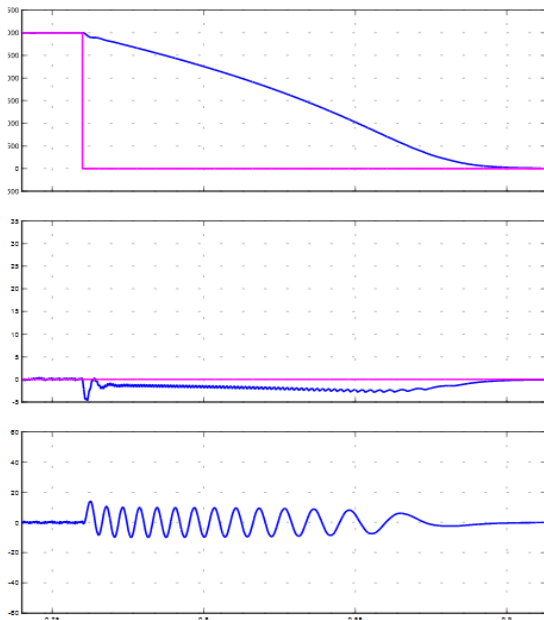
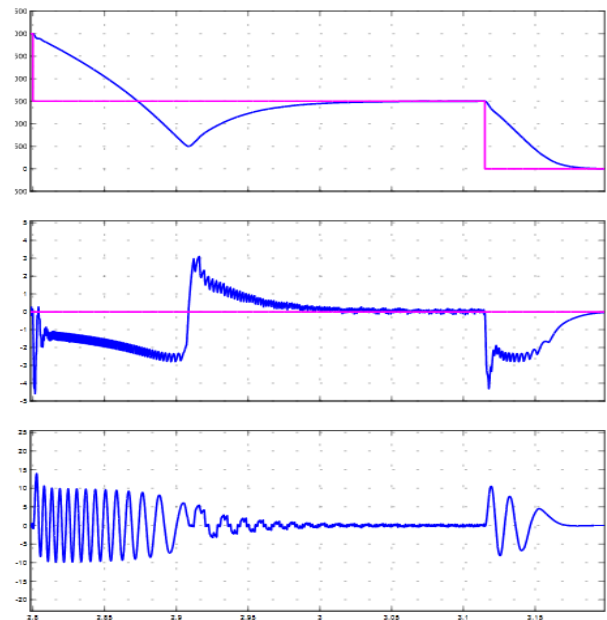Fig 9:- Braking Mode Dynamics of the Motor (Speed, Torque and Current)

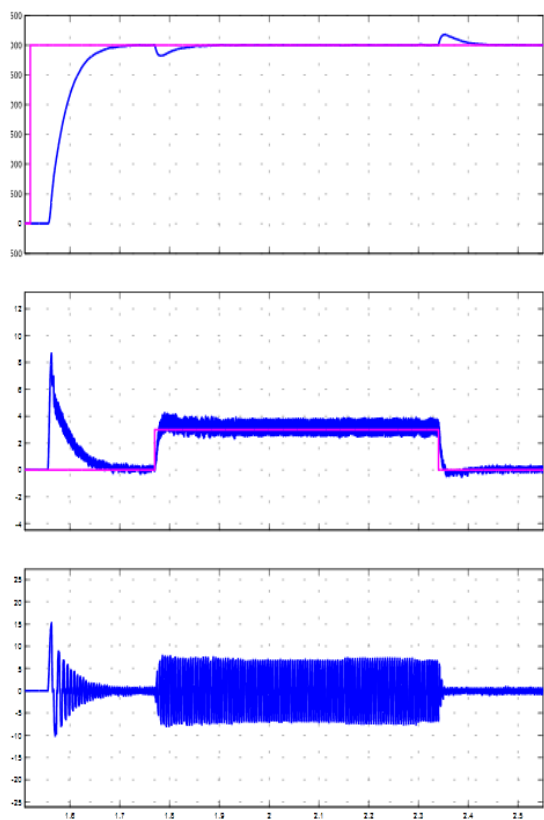Fig 11:- Step Change in the Speed of the Motor (Speed, Torque and Current)

E. Drive on Load for Various Applications

For various application in industries, a different load exists. Load like conveyors, feeders have a constant Speed-Torque characteristic while some of the loads (Mixer) have linearly varying Speed-Torque characteristics. In this work, these two types of Speed-Torque characteristics have been simulated and applied to the machine to check the performance of the modeled drive. These conditions are tested with the reference speed of 3000 rpm and machine return to its steady state under different load conditions. The observed dynamics are shown in Fig. 12.

Fig 10:- Load Perturbation Dynamics of the Motor (Speed, Torque and Current)

D. Step Change in Speed

To meet the speed required for a specific application, the machine can be operated at different speed levels. To check the performance of this drive under such conditions, a step change in speed from 3000 rpm to 1500 rpm is made and the dynamics observed which are shown in Fig. 11.
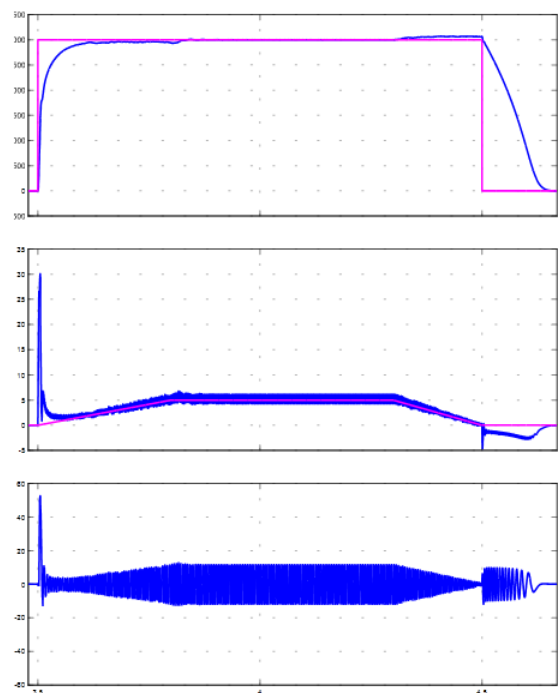

Fig 12:- Load Dynamics on the Linear Load of the Motor (Speed, Torque and Current)

PARAMETERS	VALUES
Proportional Gain Value	0.35
Integral Numerator Coefficient	12
Saturation Upper Limit	500
Saturation Lower Limit	-500

Table 2:- Pi Controller Parameter

PARAMETERS	VALUES
Rated Current	4.8 Amps
Rated Torque	5 Nm
Motor Stator phase resistance	2.875 ohm
Motor armature inductance	0.00085 h
Flux linkage	0.07147 wb
Inertia	$0.0008 kg.m^2$
Viscous damping	0.0003035 Nm.s
Pole pairs	4

Table 3:- BLDC Motor Rating and Equivalent Circuit Parameter

V. CONCLUSION

The simulation model of BLDC Motor drive having P-I controller is presented with a different operating condition like starting, breaking, load perturbation and for different industrial applications wherein the load torque is either constant or varies linearly with the speed is presented in this paper. The closed-loop system helps to achieve the reference speed even for different load condition. The motor attains its steady state speed in 0.02 sec during starting and after the break is applied machine comes to rest position after 0.02 sec. During load perturbation operation sudden change in operating condition lead to draw more current and torque which is higher than the rated parameter for fraction of seconds from the source. All the simulation results can also be verified on a practical system.

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