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Speed Control of Brushless DC Motor Using Proportional Integral Controller

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Abstract: Ease control and high power density are the two main reasons for using brushless DC motor in wide range of industrial applications. In general the brushless DC motors are controlled using power Semiconductor bridge. So the rotor position sensors are used in the inverter bridge for starting and to provide proper commutation sequence to the power switches. In building inverter bridge power switches are used due to high reliability and performance. In this paper the three phase brushless DC motor model is designed with proportional integral controller and tested in MATLAB software. The PI controller is used to control the speed of the brushless DC motor. On the other hand parameters like Back EMF, current, speed and torque are evaluated for the designed models of BLDC motor. Due to the easy implementation and simple control structure the convectional PI controller are used in industries.
Keywords: Brushless DC motor, PI controller, PMBLDC.

I. INTRODUCTION

The replacement for conventional DC motor is BLDC motor in many cases. The characteristic of DC motor is retained by BLDC motor except brushes and commutator. To provide large amount of torque for a wide range of speed BLDC motor suits the most with high performance. Actually for applications that require high power, high reliability and high efficiency BLDC motor is the ideal choice.

A small BLDC motor is used in hard disk drives and large BLDC motor is used in electric vehicles. In BLDC motor physical commutator is not necessary because the electric current powers the permanent magnet that causes rotation in motor. So current commutation takes place because of solid state switches. In this case commutation happens electronically. Most commonly used BLDC motors are three phases rather than two phase BLDC motor. Due to the rotor rotation voltage is induced in the stator winding called back-EMF of BLDC motor. So torque is primarily influenced by back-EMF of BLDC motor. In case size of the motor and torque delivered ratio is higher so the critical factors are space and weights in certain application to make it useful. When practical speaking the torque ripple exit mainly due to imperfection emf, ripple current and phase current commutation. Due to the magnet size and shape of the BLDC motor the imperfection emf is occurred. On the other side hysteresis and PWM control generates ripple in current. The Bimbra [1] has explained the generalized machine theory.

II. BLOCKING DIAGRAM OF PROPOSED METHOD

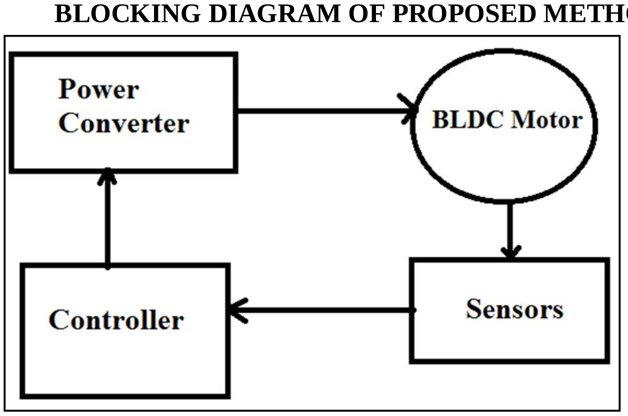

Figure 1: Block diagram of BLDC motor's Speed control

The block diagram of brushless dc motor with its speed controller is shown in [Figure.1].It consist of four main parts they are

BLDC motor, sensors, controller and power converters. The power is transformed from source to BLDC motor through converter. So the BLDC motor in turn converts electrical energy in to mechanical energy. To the power converter gate signal is applied on the basis of rotor position.

III. WORKING PRINCIPLE OF BLDC MOTOR

One after another the BLDC motor's electronic commutator energizes the stator coils and generates a rotating electric field that 'drags' the rotor around with it. N "electrical rotations" equates to one mechanical rotation, where N is the number of magnet pairs. To indicate the relative position of stator and rotor to the controller three phase effect sensors are embedded in the stator of the three phase brushless DC motor. The hall sensor helps brushless DC motor to energize the winding in a correct sequence and at the correct time.Constructionally the all sensor is mounted on the non driving side of the system [Figure.2].

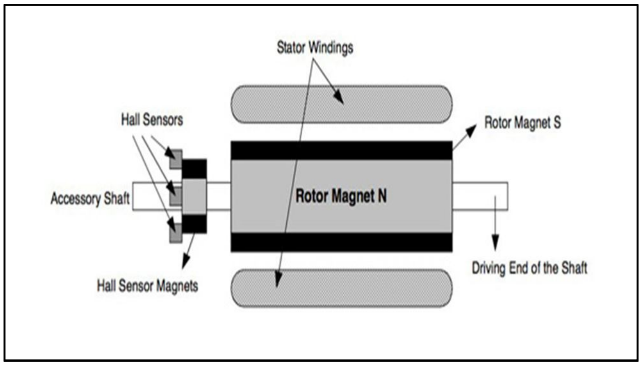

Figure 2: Hall sensors are embedded in the stator of a BLDC motor

The high or low signal is generated during the rotor magnetic poles passes the hall sensors by combining the signals from the three sensors. Due to the movement of the winding through the associated magnetic field the potential voltage is generated by the electrical motors and it can be called as electromotive force. As per Lenz's law the magnetic field which opposes original change in flux will give rise in winding current. In general this means electromotive force tends to resist the rotation of the motor and referred as back electromotive force.

The Baldursson [2] has developed brushless DC motor modelling and control. Padmaraja [3] has developed the fundamentals of brushless DC motor. A new simulation model is developed by Jeon [4].For complete MATLAB modelling Simulink user's guide is helpful [5].

IV. DESIGN OF PI SPEED CONTROLLER

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 basic model of permanent magnet brushless DC motor is shown in figure.2. In that model it consist of BLDC motor, position sensor, pulse width modulation current controller, voltage source inverter, reference current generator and PI controller. The speed error is processed to PI controller after comparing the speed of the BLDC motor with its reference speed.

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

$$T_{ref}(t) = T_{ref}(t-1) + K_p[e(t) - e(t-1)] + K_1 e(t)$$

K_p & K_I -gain of speed controller

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The reference torque is nothing but output of the controller. The three phase reference current i_a, i_b, i_c is generated by reference current generator with the limits of peak current magnitude decided by the controller and position sensor. The switching commands are generated to drive the inverter devices by comparing motor current and its reference current. KO [3] has implemented the control of BLDC motor using PI controller.

V. MATHEMATICAL MODELLING OF THE BLDC MOTOR

$$V_a = i_a R_a + L_a \frac{di_a}{d_t} + M_{ab} \frac{di_b}{d_t} + M_{ac} \frac{di_c}{dt} + e_a \rightarrow Eq.(1)$$

$$V_b = i_b R_b + L_b \frac{di_b}{d_t} + M_{ba} \frac{di_a}{d_t} + M_{bc} \frac{di_c}{dt} + e_b \rightarrow Eq.(2)$$

$$V_c = i_c R_c + L_c \frac{di_c}{d_t} + M_{cb} \frac{di_b}{d_t} + M_{ca} \frac{di_a}{dt} + e_c \rightarrow Eq.(3)$$

Where, R_a, R_b, R_c - Stator resistance of phase a, b and c.

L_a, L_b, L_c - Stator inductance of phase a, b and c.

i_a, i_b, i_c -Stator current of phase a, b and c.

V_a, V_b, V_c -Voltages of phase a, b and c.

$R_a = R_b = R_c = R$ -Mutual inductance between phases

L_a, L_b, L_c -Stator self inductance of phase a, b and c.

In this case, $L_a = L_b = L_c = L$

$M_{ab} = M_{ac} = M_{bc} = M_{ba} = M_{ca} = M_{cb} = M$

Assuming three phase balanced system, all phase resistance are equal.

$R_a = R_b = R_c = R$

Let us rearrange the above equations 1, 2 and 3. We get,

$$V_a = i_a R + L \frac{di_a}{d_t} + M \frac{di_b}{d_t} + M \frac{di_c}{dt} + e_a \rightarrow Eq.(4)$$

$$V_b = i_b R + L \frac{di_b}{d_t} + M \frac{di_a}{d_t} + M \frac{di_c}{dt} + e_b \rightarrow Eq.(5)$$

$$V_c = i_c R + L \frac{di_c}{d_t} + M \frac{di_b}{d_t} + M \frac{di_a}{dt} + e_c \rightarrow Eq.(6)$$

Let us neglect mutual inductance in equations 4, 5 and 6. We get,

$$V_a = i_a R + L \frac{di_a}{d_t} + e_a \rightarrow Eq.(7)$$

$$V_b = i_b R + L \frac{di_b}{d_t} + e_b \rightarrow Eq.(8)$$

$$V_c = i_c R + L \frac{di_c}{d_t} + e_c \rightarrow Eq.(9)$$

VI. TORQUE GENERATION

Theoretical motor constant ‘K_t’ is the product of torque and supply current ‘I’.

$$T_a + T_b + T_c$$

$$K_{t(motor)} = K_{t(a)} + K_{t(b)} + K_{t(c)}$$

$$i_{motor} = i_a = i_b = i_c$$

θ -Angle

T_a, T_b, T_c -Total torques

$$\frac{d\theta}{dt} = \left(\frac{P}{2}\right) * \omega$$

The generated electromagnetic torque is given by,

$$T_e = \frac{[e_a i_a + e_b i_b + e_c i_c]}{\omega} \text{ in N-M}$$

$$T_e = K_t \{ f_a(\theta) i_a + f_b(\theta) i_b + f_c(\theta) i_c$$

$$J\left(\frac{d\omega}{dt}\right) + B\omega = T_e - T_1$$

The relation between angular velocity and angular position is given by,

$$\frac{d\theta}{dt} = \left(\frac{P}{2}\right) * \omega$$

T_1 -load torque

ω -Motor inertia

B-Damping Constant

P-Number of poles

VII. SIMULATION MODEL OF THE BLDC MOTOR

TABLE I

Voltage (V_{dc})	160 volts
Damping constant (T_{load})	0.02 N-M/rad/sec
Resistance (R)	0.7 ohms
Inductance (L)	2.72 mH
Moment of inertia (J)	0.000284Kg-m/sec^2
Number of poles	4
Number of phases	3

Table.1. Specification of BLDC motor

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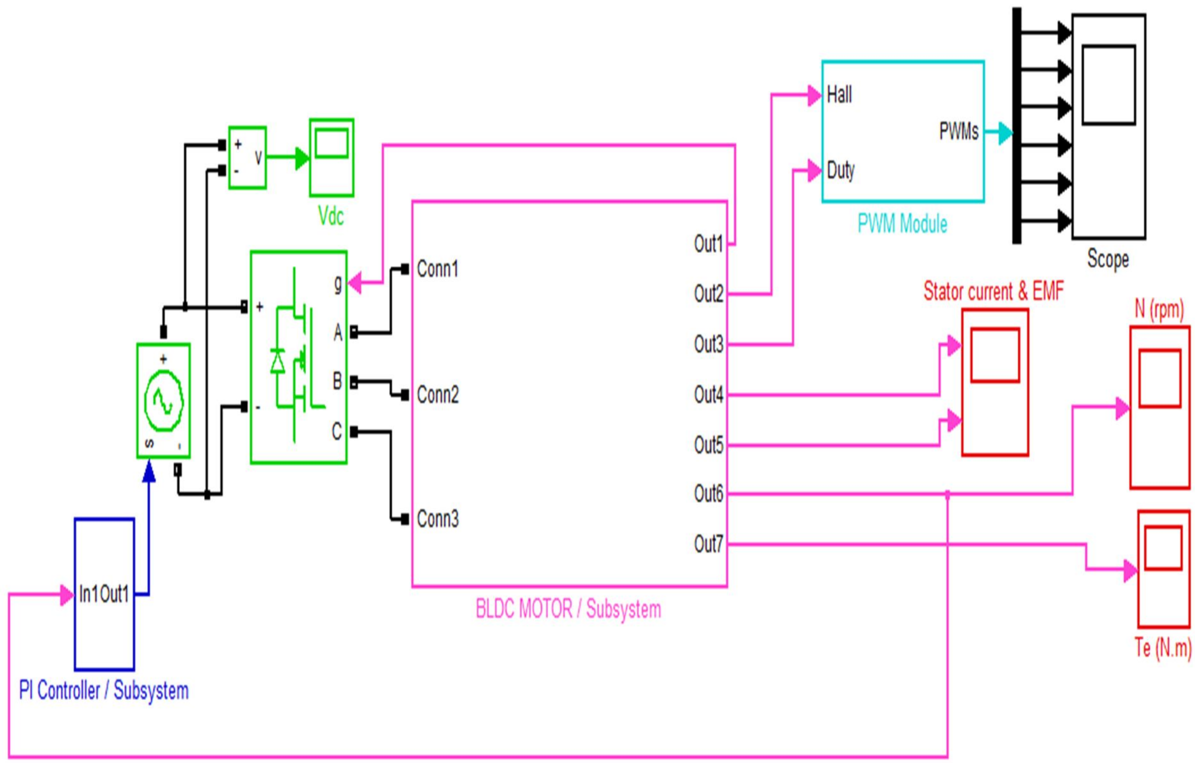

Figure 3: MATLAB Simulink model of BLDC motor

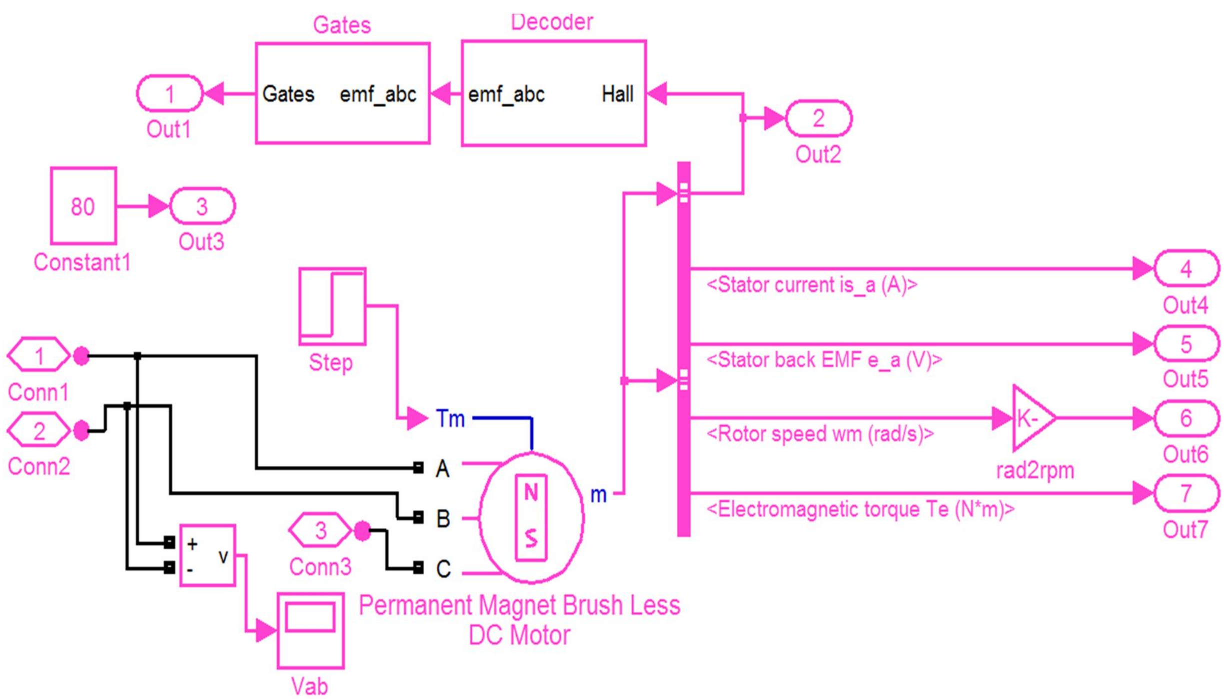

Figure 4: MATLAB Simulink Sub system model of BLDC motor

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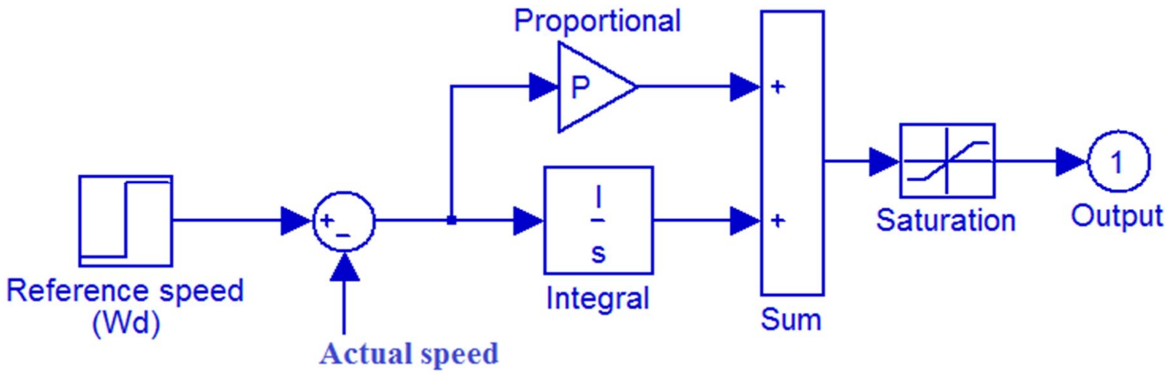

Figure 5: MATLAB Simulink Sub system model of PI controller

VIII. SIMULATION RESULTS

A. Current

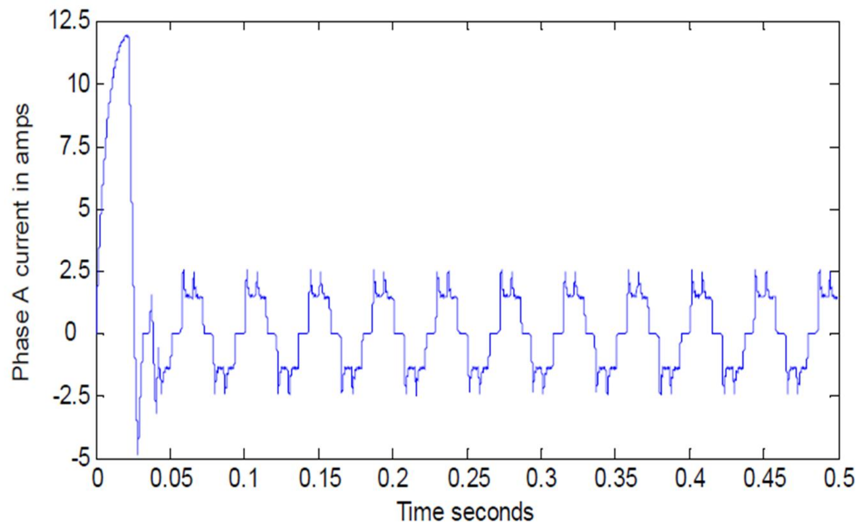

Figure 6: Current Phase A in amperes

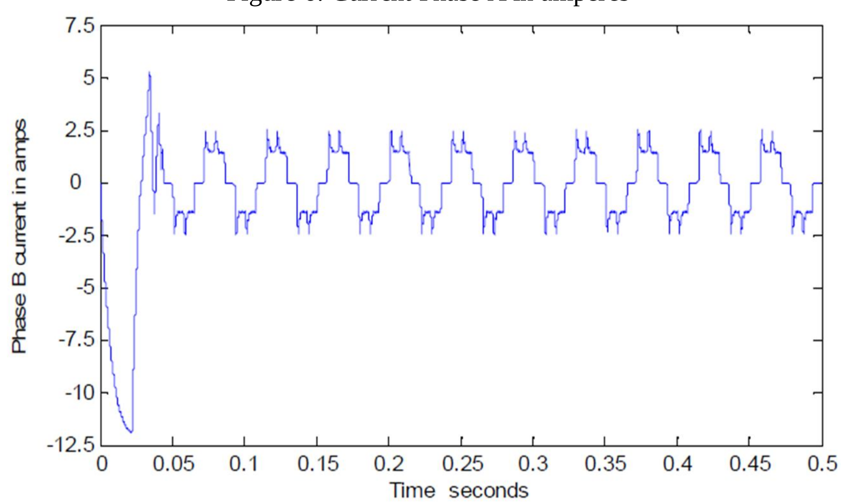

Figure 7: Current Phase B in amperes

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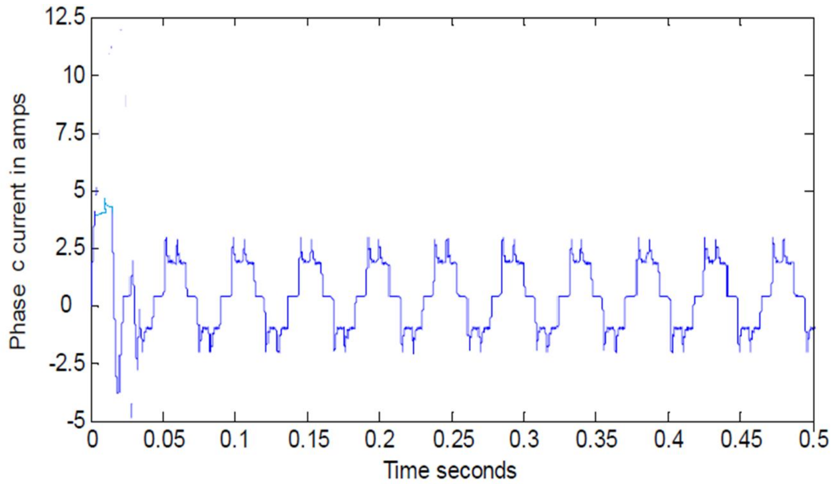

Figure 8: Current Phase C in amperes

B. Back EMF

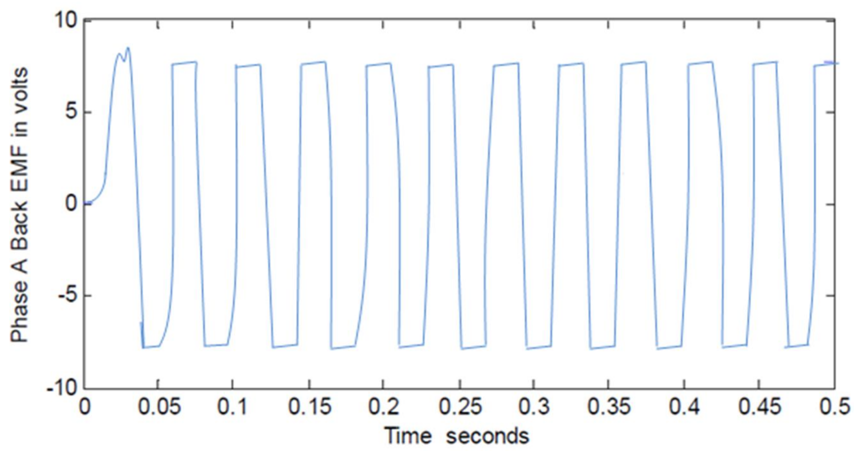

Figure 9: Back EMF Phase A in Voltages

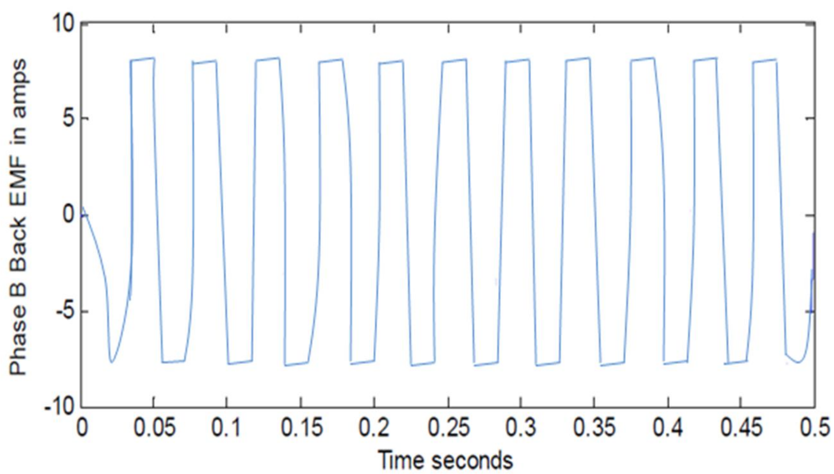

Figure 10: Back EMF Phase B in Voltages

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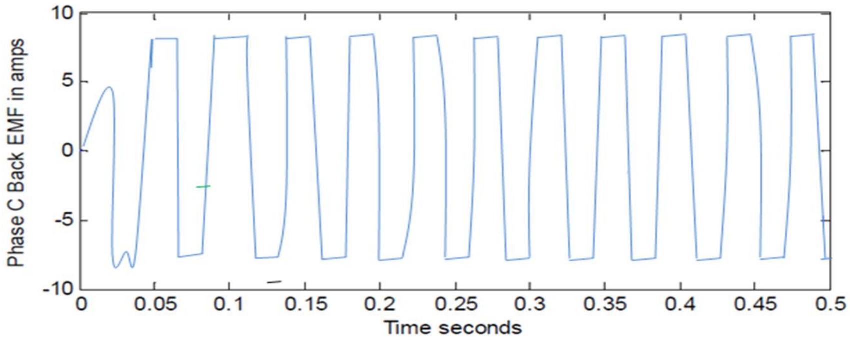

Figure 11: Back EMF Phase c in Voltages

C. Speed

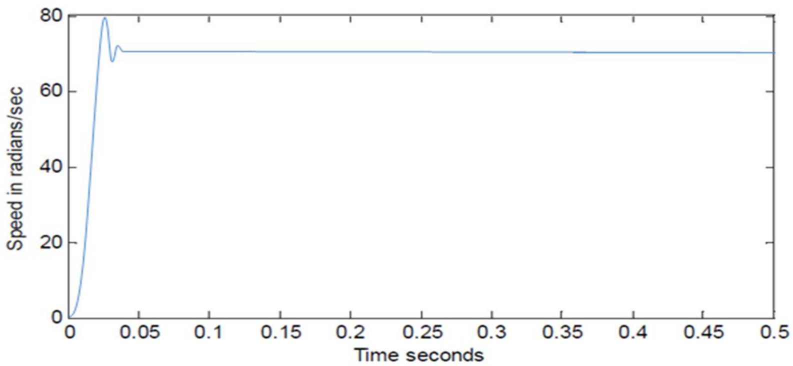

Figure 12: Speed in radian / second

D. Torque

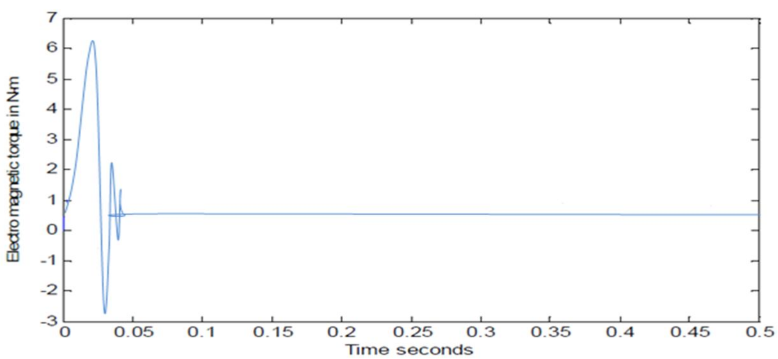

Figure 13: Torque in Newton meter

IX. CONCLUSION

The speed control of Proportional integral controller is shown in [Figure.12].The Proportional integral controller the motor reaches the reference speed with a percentage overshoot of 6.23.Initially the reference speed is set as 700rpm with 0.005 seconds at rest. At the same time the initial phase back electromotive force of the BLDC motor is zero. Therefore the phase current at the time of starting is transient but once the speed reaches its reference speed. Then the current also reach its reference speed the conduction period of current is 120 degree as shown in [Figure.6]. In general to provide mechanical work in industry and generate electric power in power plants electrical machines are used. Due to high efficiency and good dynamic response the permanent magnet brushless DC motor gains attractiveness in the recent years. Because of low cost and high reliability the brushless DC drives are preferred. In this mission speed control of permanent magnet brushless DC motor is achieved using Proportional integral controller in MATLAB software and also tested successfully by evaluating the parameters like back EMF, current, torque and speed.

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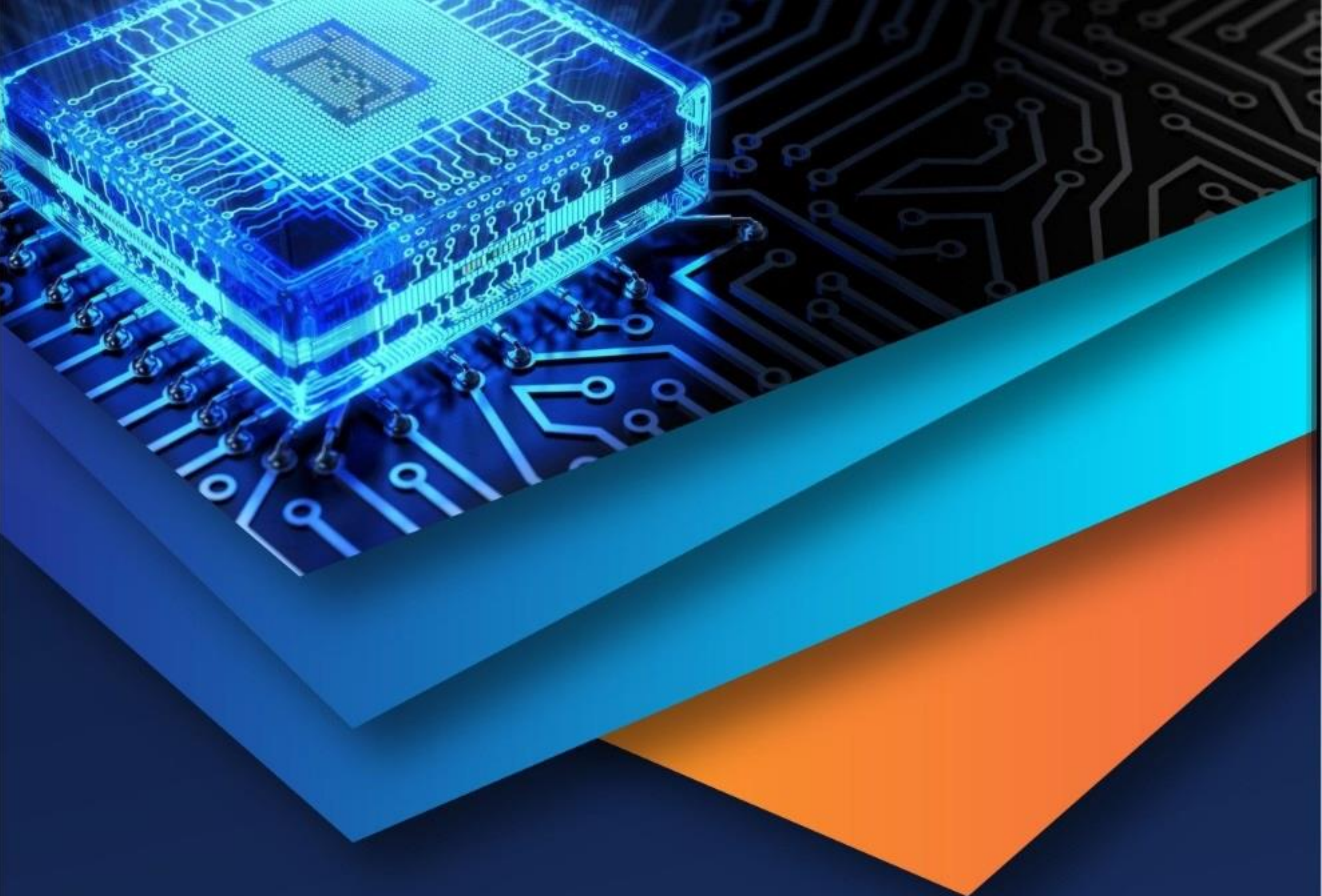
BIOGRAPHY

Mr.J.Vikramarajan received his Master degree in Power Electronics and Drives and Bachelor degree in Electrical and Electronics Engineering from VIT University, India. He has published several international research books and journals. His research interests are electrical machines, power electronic applications, power quality, power electronic converters and power electronic controllers for renewable energy systems.



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