ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization *Vol. 5, Special Issue 2, March 2016*

National Conference on Future Technologies in Power, Control and Communication Systems (NFTPCOS-16)

on 10, 11 and 12th March 2016

Organised by

Dept. of EEE, College of Engineering Perumon, Kollam, Kerala – 691601, India

Performance Analysis of a Pi Controller for Closed Loop Speed Controlling Of BLDC Motor

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ABSTRACT: A brushless dc motor is a PMSM that uses position detectors and an inverter to control the armature currents. This paper presents a closed loop speed control of BLDC motor using PI controller. The BLDC motor is sometimes referred to as an inside-out dc motor because its magnets are on the rotor and armature is in the stator and its operating characteristics those of a dc motor. The closed loop speed control is most widely used in industries. In this paper the derivative part gain is taken as zero, and a PI controller is used[3]. The use of derivative part increases the effect of noise in motor speed control, so the most industrial applications didn't use any derivative parts in the controllers. The PI controller calculation involves two separate modes the integral mode and proportional mode. PI controller overcomes the noise issue & increase the system stability. Simulation of closed loop speed control with PI controller is carried out for a BLDC [3, 4].

KEYWORDS: BLDC, Three phase inverter, PI Controller, Simulation.

I.INTRODUCTION

The BLDC motor is an AC synchronous motor with permanent magnets on the rotor (moving part) and windings on the stator (fix part). Permanent magnets create the rotor flux and the energized stator windings create electromagnet poles. The rotor (equivalent to a bar magnet) is attracted by the energized stator phase. By using the appropriate sequence to supply the stator phases, a rotating field on the stator is created and maintained. This action of the rotor - chasing after the electromagnet poles on the stator - is the fundamental action used in synchronous permanent magnet motors[6]. To accurately control the speed of drive without extensive operator involvement, a speed control system that relies upon a controller is essential. Proportional Integral controller is most preferable controller in industries for servo drives for closed loop control. It compares the actual speed to the desired control speed otherwise called set point, and provides an output, which adjusts the duty cycle of PWM pulses applied to the MOSFET based three phase inverter fed BLDC drive. BLDC motors have many advantages over disadvantages. Brushless DC motors require less maintenance and therefore have a longer life span as compared to brushed DC motors. BLDC motors produce more output power per frame size than brushed DC motors and induction motors. PI controller implementation is done in varies digital controllers. PI controller is widely used in industry due to its ease in design and simple structure.

II. HISTORY OF BLDC

Brushless DC motors first made the scene in 1962. The main feature of brushless DC motors is that it requires no physical commutator. When the motors developed, it became a suitable device for special applications such as computer disk drives, in aircrafts, robotics and so on. In fact, brushless DC motors are used in these devices today, fifty four years later, because of its reliability. The reason for these motors were such a great selection for these devices is that in these devices brush wear was a major problem, either because of the intense demands of the application or, in the case of aircraft because of its light weight. Because brushless DC motors had no brushes that could wear out and use electronic commutation, they represented a great step forward in technology for these types of devices.

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Earlier times, the problem was that as reliable as they are, these early brushless DC motors were not able to generate a great deal of power. With the development of permanent powerful magnets and high voltage transistors in the middle of 1980's motors with 50 hp or more become reality. The first largest BLDC motor was designed by Robert E. Lordo of POWERTEC Industrial Corporation in late 80's.Now Brushless motor with large horsepower rating are available.

III. SIMULATION OF MOTOR USING THREE PHASE INVERTER

A. MODELING OF MOTOR

1. PERMANENT MAGNET SYNCHRONOUS MACHINE

Model the dynamics of a three-phase permanent magnet synchronous machine with sinusoidal or trapezoidal back electromotive force. The key to effective torque and speed control of a BLDC motor is based on relatively simple torque and Back EMF equations, which are similar to those of the DC motor. The Back EMF magnitude can be written as[7]:

$$E = 2NlrBw$$

and the torque term as:

$$T = \left(\frac{1}{2} i^2 \frac{dL}{d\theta}\right) - \left(\frac{1}{2} B^2 \frac{dR}{d\theta}\right) + \left(\frac{4N}{\pi} Brl\pi i\right)$$

where N is the number of winding turns per phase, l is the length of the rotor, r is the internal radius of the rotor, B is the rotor magnet flux density, w is the motor's angular velocity, i is the phase current, L is the phase inductance, θ is the rotor position, R is the phase resistance.

The first two terms in the torque expression are parasitic reluctance torque components. The third term produces mutual torque, which is the torque production mechanism used in the case of BLDC motors. To sum up, the Back EMF is directly proportional to the motor speed and the torque production is almost directly proportional to the phase current. These factors lead to the following BLDC motor speed control scheme.

The dynamic equations of BLDC [7] are as follows:

$$V_{an}(t) = i_a(t)R_a + L_a \frac{di_a(t)}{dt} + e_a(t) \ldots\ldots(1)$$

$$V_{bn}(t) = i_b(t)R_b + L_b \frac{di_b(t)}{dt} + e_b(t) \ldots\ldots(2)$$

$$V_{cn}(t) = i_c(t)R_c + L_c \frac{di_c(t)}{dt} + e_c(t) \ldots\ldots(3)$$

$$T = K_\phi I \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$E = K_\phi W \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

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B. SIMULINK MODEL OF INVERTER

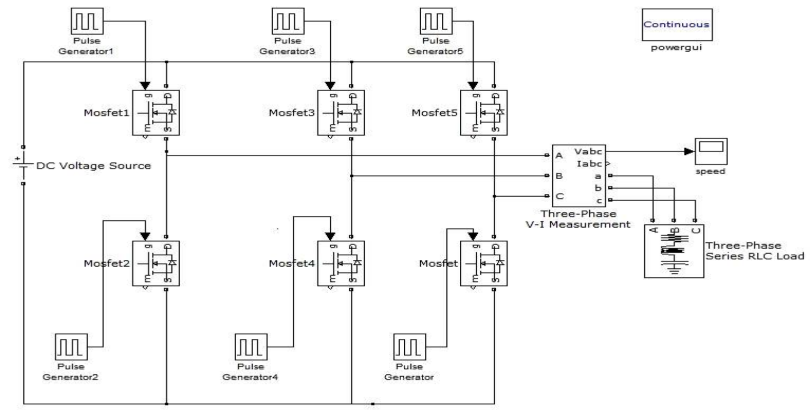

Fig 1 Simulink model of three phase inverter

Fig 1 shows the simulink model of three phase inverter. The whole system is comprised of DC Voltage source, MOSFET, Pulse generator and three phase measurement block. The DC Voltage source is an ideal voltage source fed to inverter. MOSFETs are voltage controlled devices, used as the switching elements. Pulse generator is used for gate triggering of MOSFET switches. Three phase V-I measurement block can output the voltages and currents in per unit values or in volts and amperes.

C.SIMULINK MODEL FOR CLOSED LOOP SPEED CONTROL WITH PI CONTROLLER

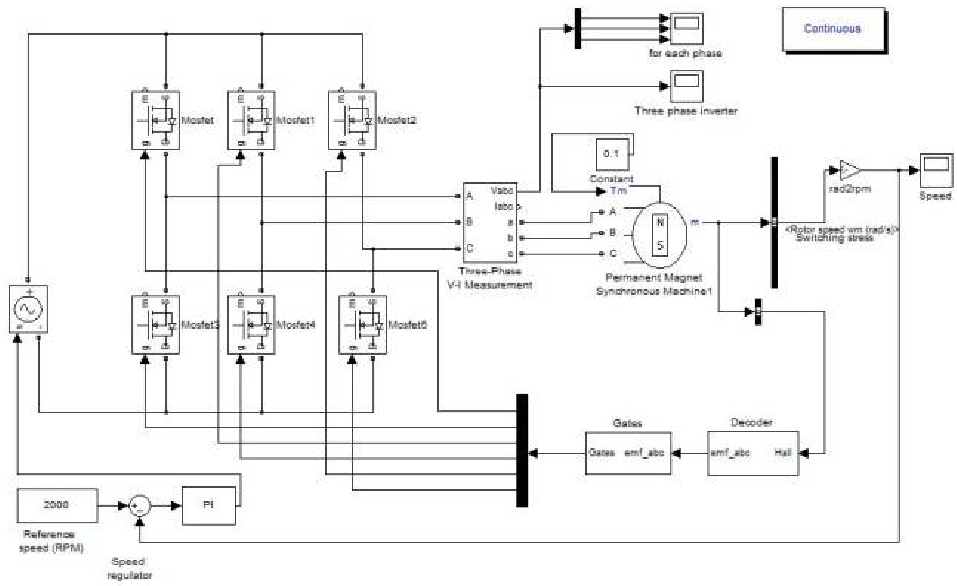

Fig 2 Simulink Model of Speed Control of BLDC Motor

Fig 2 shows the simulink model of closed loop speed control of BLDC Motor. The whole system is comprised of a controller circuit, motor module, measurement unit and logic unit. Main power circuit consists of controlled voltage source which provide required voltage to driver circuit. The motor module “Permanent magnet synchronous motor” is selected with the waveform of air gap magnetic flux density being trapezoidal and the width of its flux part is 120 degree electrical. Measurement unit consists of bus selecting module “Bus selector,” which is used to measure the variables of the motor when it operating such as back EMF, current, rotor speed, torque etc. Logic unit consists of logical operator AND/NOT which are used for generating gate pulse signals for driving circuit.

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D. PI CONTROLLER

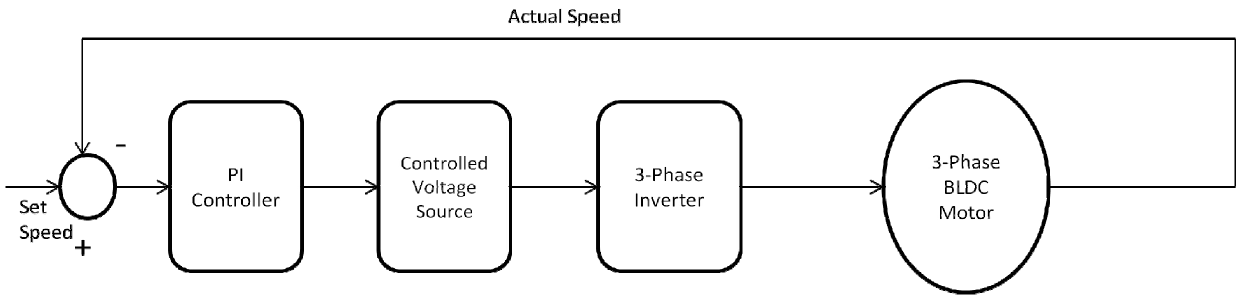

Fig 3:-Block diagram representing 3-Phase BLDC Motor with PI Controller

Fig 3 shows the block diagram representing 3-phase BLDC Motor with the PI Controller. The PI Controller is the heart of the system. The controller controls the speed of the BLDC Motor at the desired speed. The controller which minimizes the error between the actual speed of motor which needed to be controlled and the desired speed called set speed. This error output is given to a controlled voltage source which controls the gate pulse given to the MOSFET switches and maintained the motor at the desired speed.

IV. SIMULATION RESULTS

A.RELATION BETWEEN Kp AND SPEED

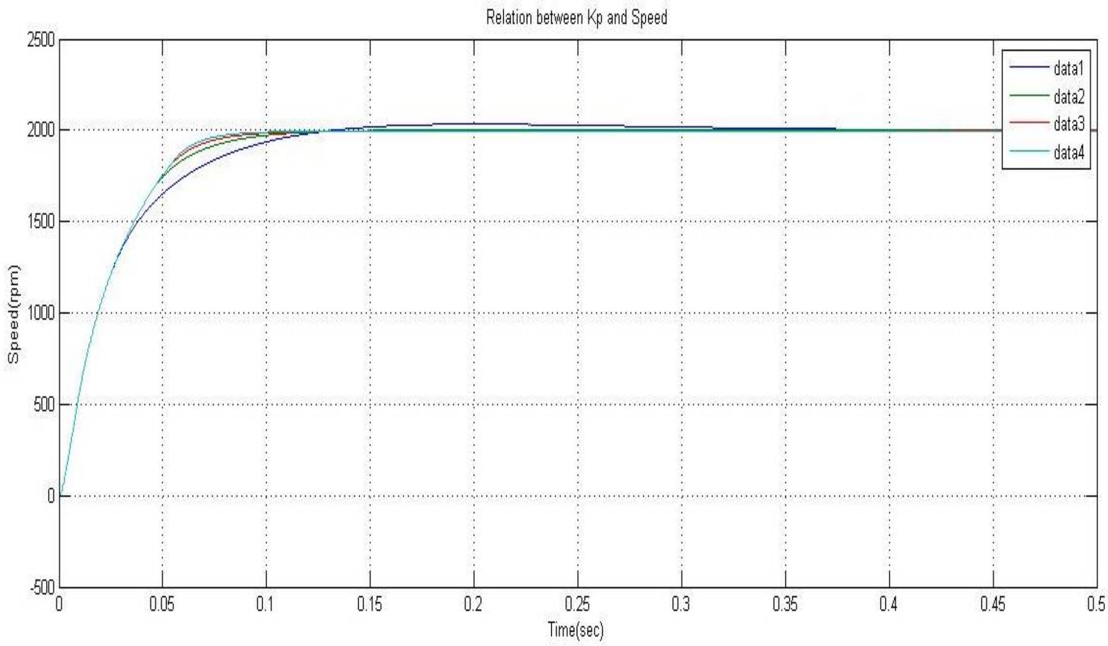

Fig 4:-Speed in RPM for different Kp

Fig 4 shows the variation of speed with the changes in Kp. While taking Kp=10, Ki=60, at time t=0.1sec, the actual speed can be observed as 1990 rpm. The set speed is 2000rpm.So the error in speed can be reduced.

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Table 1:-Variation of speed with the variation of Kp

Kp	Ki	Actual speed	Set speed	Error
5	60	1937	2000	63
10	60	1985	2000	15
15	60	1990	2000	10
20	60	1990	2000	10

The variation of Kp and variations in speed are tabulated and error calculated.

B. RELATION BETWEEN Ki AND SPEED

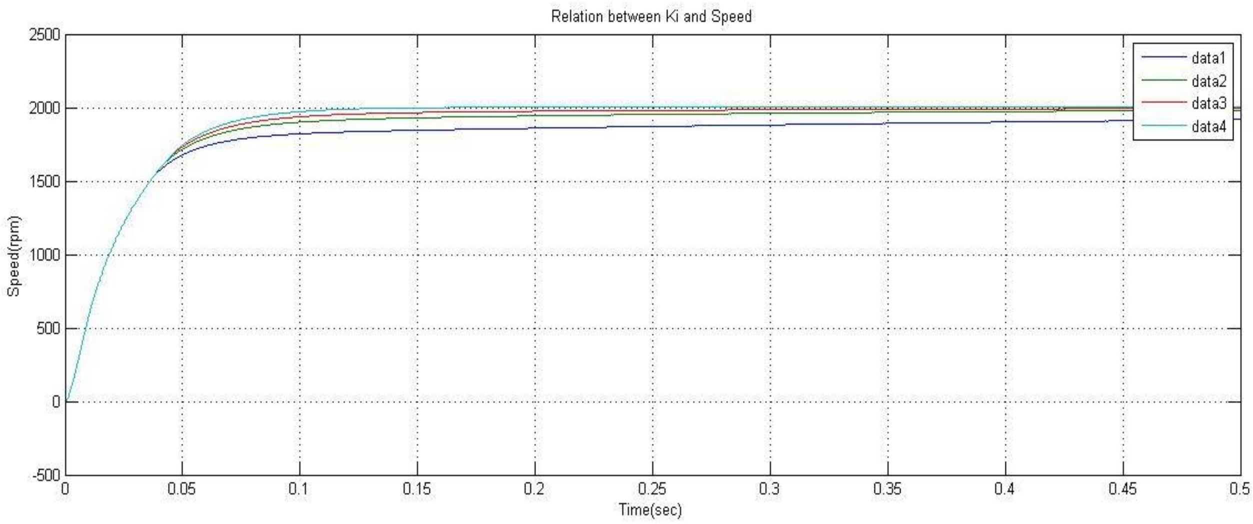

Fig 5:-Speed in RPM for different Ki

Fig 5 shows the variation of speed with the changes in Ki. While taking Ki=60, Kp=10, at time t=0.15sec the actual speed can be observed as 1973 rpm. The set speed is 2000rpm.So the error in speed can be reduced.

Table 2:-Variation of speed with the variation of Ki

Kp	Ki	Actual speed	Set speed	Error
10	20	1845	2000	155
10	40	1930	2000	70
10	50	1966	2000	109
10	60	1998	2000	2

The variation of Ki and variations in speed are tabulated and error calculated.

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C. RELATION BETWEEN Kp, Ki AND SPEED

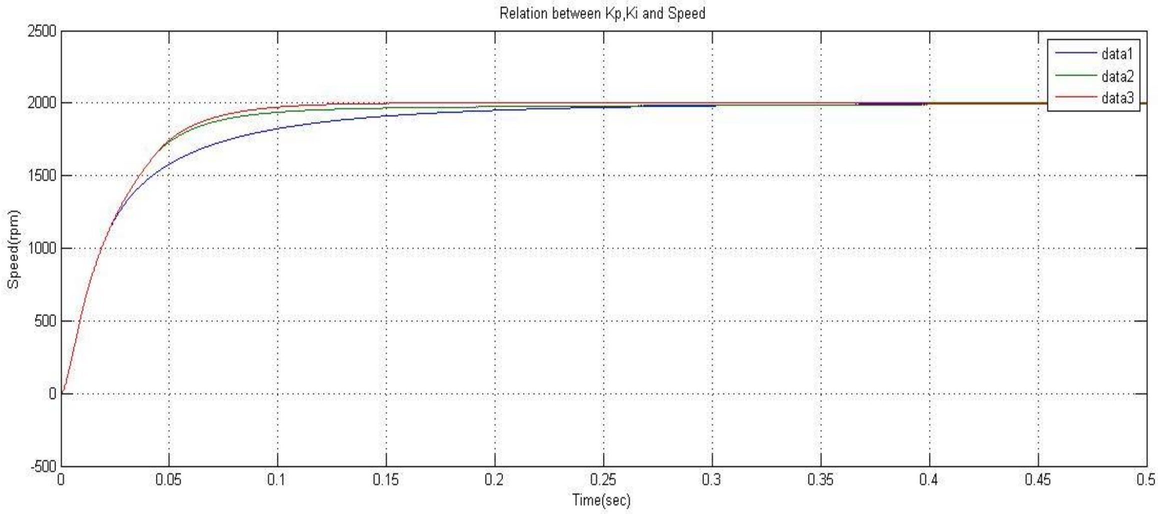

Fig 6:-Speed in RPM for varying Kp and Ki

Fig 6 shows the variation of speed with the changes in both Kp and Ki. While taking Ki=60,Kp=10,at time t=0.15 sec, the actual speed become1999rpm.The set speed is 2000rpm. The change in speed is so small and error can be negligible. Then the speed is controlled at the desired speed using PI controller.

Table 3:-Variation of speed with the variation of Kp and Ki

Kp	Ki	Actual speed	Set speed	Error
5	40	1911	2000	89
10	50	1966	2000	34
10	60	1999	2000	1

The variation of both Kp and Ki are tabulated and error is calculated. From these tabular analysis, for better performance of BLDC motor at the desired speed the values of Kp and Ki are chosen as 10,60.

D.SIMULATION OF MOTOR

The BLDC motor speed can be controlled at desired rate with PI controller choosing Kp=10,Ki=60.For a given reference speed 2000RPM,the simulation graph for speed, stator current, back emf can be given below:-

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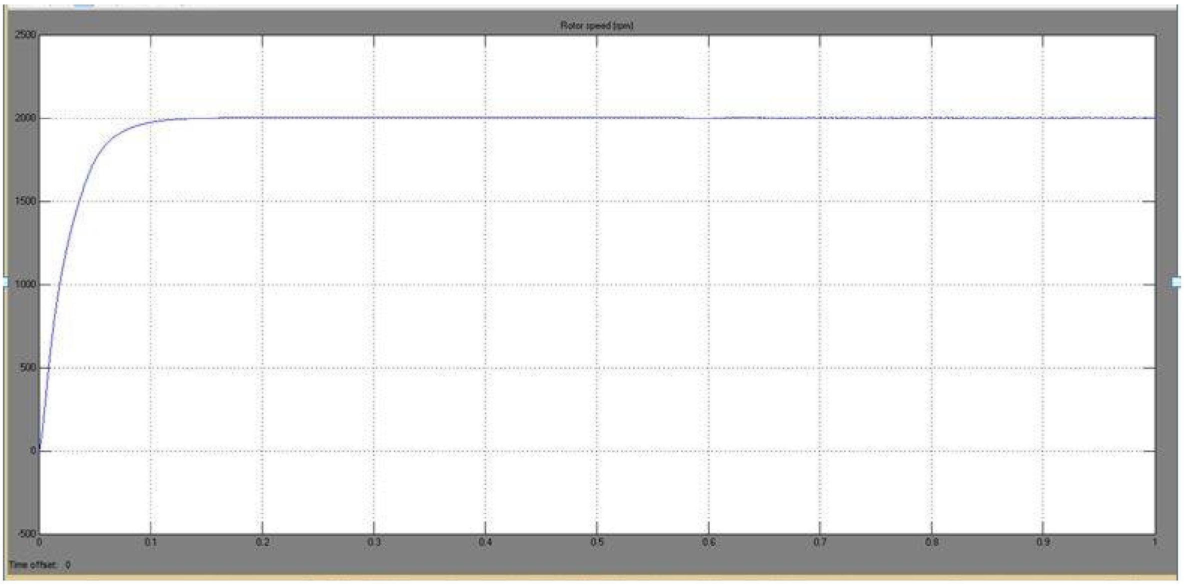

Fig 7:- Simulation result for speed

From the simulation graph it is clear that the speed is maintained at 2000RPM.

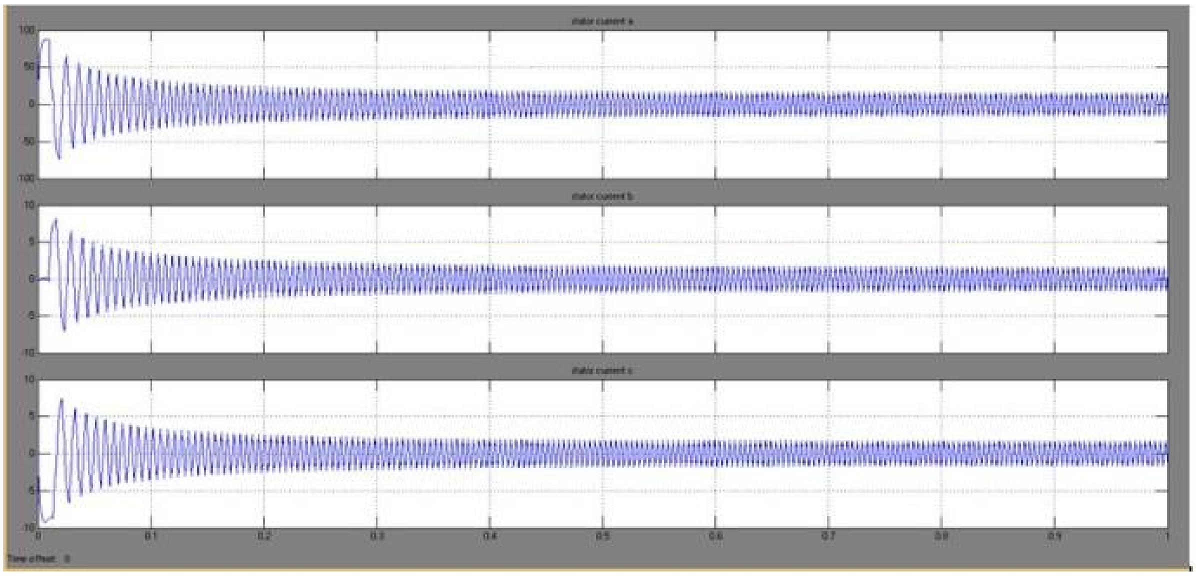

Fig 8:- Simulation result for stator current

This figure shows the stator current through each phase a, b and c respectively.

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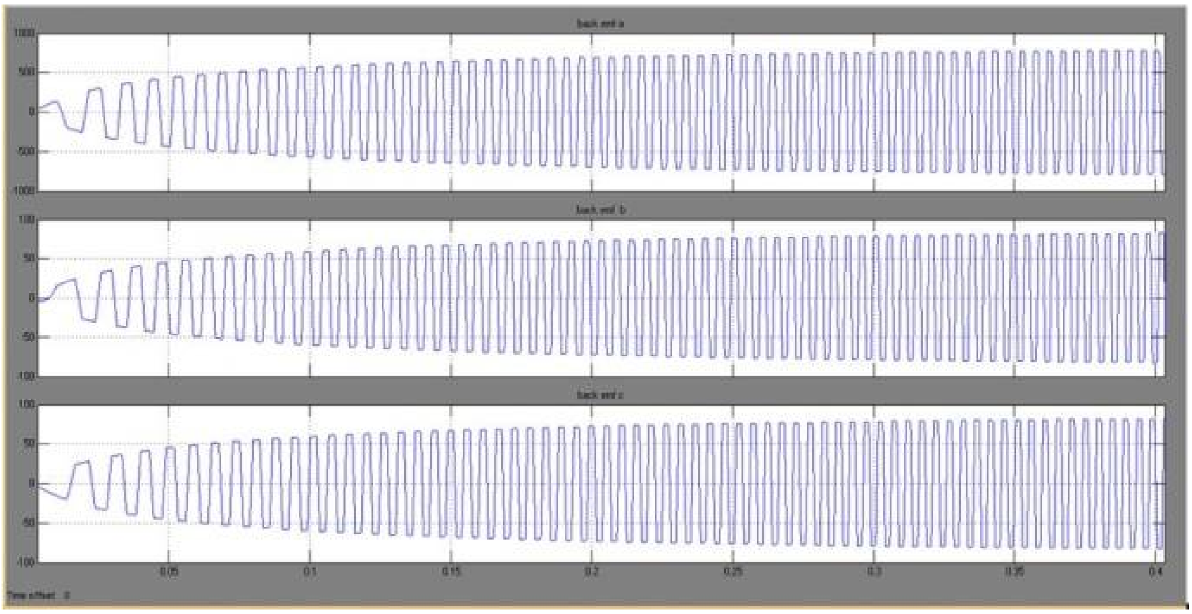

Fig 9:- Simulation result for back emf

The fig shows the back emf generated in each phase a, b and c respectively.

V. DISCUSSIONS AND CONCLUSIONS

The closed loop speed control of three phase BLDC motor using PI controller is successfully simulated. The better value of proportional gain and integral gain are chosen by verifying the speed response curve for different values of Kp and Ki and by calculating error. The minimum error was found for the proportional gain Kp of value 10 and integral gain Ki of value 60 and the value is used for the simulation of closed loop speed control of BLDC Motor.

ACKNOWLEDGEMENT

We have much pleasure in thanking TEQIP PHASE II, College Of Engineering, Kidangoor for funding our project work.

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