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Field Oriented Control of Permanent Magnet Synchronous Motor Using PID Controller

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ABSTRACT: This project presents the comprehensive performance analysis on the principle of operation, design considerations and control algorithms of the field oriented control (FOC) for a permanent magnet synchronous motor (PMSM) drive system and proportional-integral-derivative PID for speed control in closed loop operation. To perform speed control of typical PMSM drives, PID controllers and FOC method are classically used. The Space Vector Pulse Width Modulation is a standard model that provides pulse to the inverter. The orientation of pulse from FOC to PMSM is subjected to monitoring and control, made feasible by PID controllers. It is popularized that control properties of PID controller is far superior in consideration with PI controller. In this paper, the FOC system is enabled with PID replacing PI from standard model. The system was experimented on MATLAB/SIMULINK 2010a and the results with proposed structure outperformed the standard model.

KEYWORDS: FOC, PMSM, MATLAB, Simulink, PID and for Speed Control.

I. INTRODUCTION

Permanent Magnet Synchronous Machine is the brushless motor designed for low voltage electronic equipment. In their initial stage the operations of PMSM were limited to simple DC motor circuits with low power input and high performance index. However, with later improvement in machines introduced the applications of PMSM in heavy industrial equipment considering the benefits over conventional motors. The panorama of PMSM has covered areas of automobiles, military, precision tools, Medical instruments etc. However PMSM motors perform poorly with open-loop scalar V/Hz control, since there is no rotor coil to provide mechanical damping in transient conditions.

Field Oriented Control is the most popular control technique used with PMSMs. FOC technique operates smoothly and provides maximum torque, full speed range and instantaneous acceleration and deceleration by controlling the iq and dq currents for three phase voltage supply in lower performance applications. To convert the low voltage input in high voltage for motor coordination, the FOC is implemented with a voltage inverter. The capability of inverter to modulate the voltage signifies the operating range of PMSM. The difference in the input voltage pulse and the required modulation voltage are subject of PID controllers installed in FOC controllers. However, to generate maximum torque at zero speed and maximize the overall performance of PMSM the inverters are generally operated in over modulation range. The difference in actual flux and torque compared with estimated values are basis for switching of inverters. The gate (electric) pulses for control of inverter are derived from a standard unit known as Space Vector Pulse Width Modulation.

II. LITARATURE REVIEW

PM motor drives have been an area of interest for the past thirty years. Different researchers have carried out modeling, analysis and simulation of PMSM drives. This content offers a brief review of some of the published work on the PMSM drive system.

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In the year 1986 Jahns, T.M., Kliman, G.B. and Neumann, T.W. [1] proposed that in IPMSM had special features for adjustable speed operation. The control principle of the sinusoidal currents in magnitude along with phase angle wrt the rotor direction was a path for achieving smooth response of torque control.

Extr-high energy magnets are used in IPM motor to improve the performance characteristics of the rotor. In this method Sebastian, T. Slemon, G. R. and Rahman, M. A. [2] in 1986, presented equivalent electric circuit models for these motors and compared estimated parameters with measured parameters.

Pillay and Krishnan, R. [3] in 1988, presented views on PM motor drives and classified them into two types. These are permanent magnet synchronous motor drives and brushless dc motor (BDCM) drives. The PMSM had a sinusoidal back emf and required sinusoidal stator currents which produced constant torque while the BDCM had a trapezoidal back emf, required rectangular stator currents for producing constant torque.

III. BASIC PRINCIPLES OF FOC AND TRANSFORMATION

Vector Control of currents & voltages which result in control of the space alignments of the electromagnetic fields.
a) Rotor flux oriented control
b) Stator flux oriented control

To perform vector control
1. Measure the motor phase currents
2. Transform them into the two phase system (a, b) using Clarke transformation.
3. Calculate the rotor position angle
4. Transform stator currents into the d,q-coordinate system using Park transformation
5. The stator current torque (isq) and flux (isd) producing components are controlled separately by the controllers
6. The output stator voltage space vector is transformed back from the d,q-coordinate system into the two phase system fixed with the stator by inverse Park transformation.
7. Using the space vector modulation, the output three-phase voltage is generated.

Clarke's Transformation:
The Clarke transformation changes a three phase system into at two phase system with orthogonal axes in the same stationary reference frame. The new two phase variables are denoted α and β the original and transformed system. The ABC parameters are transformed into αβ0 parameters by equation

$$f_{\alpha\beta 0} = T f_{ABC}$$

$$f_{ABC} = T^{-1} f_{\alpha\beta 0}$$

Where f can be any one of the motors armature parameters.

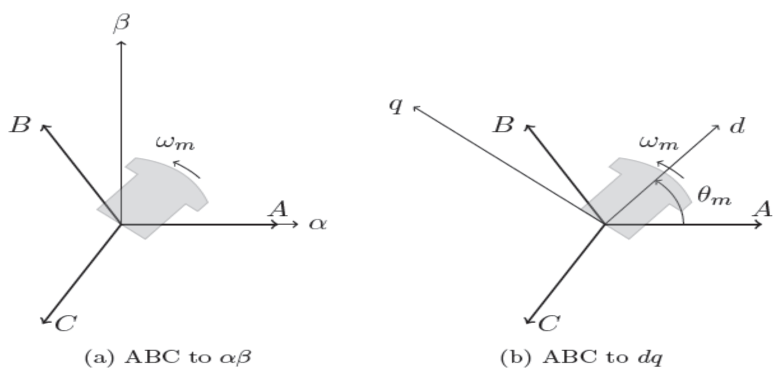

Figure1. Clark Transformation

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Park's Transformation: The Park transformation changes a three phase system in one stationary reference frame into a two phase system with orthogonal axes in a different rotating reference frame. The two new phase variables are denoted d and q, and are referred to as the motors direct- and quadrature axis. The ABC parameters are transformed into dq0 parameters and in reverse by equation

$$f_{dq0} = T(\theta) f_{ABC}$$

$$f_{ABC} = T(\theta)^{-1} f_{dq0}$$

By using the Park's transform, the stator parameters such as voltages, currents, and flux linkages, are associated with fictitious stator windings that rotate with the rotor. The time varying parameters between stator and rotor are thus eliminated and all variables are expressed in the same orthogonal or mutually decoupled direct- and quadrature axes.

Inverse Park transformation: Equation of inverse park transformation

$$I_q = \mathrm{ID}\sin\theta + \mathrm{IQ}\cos\theta$$

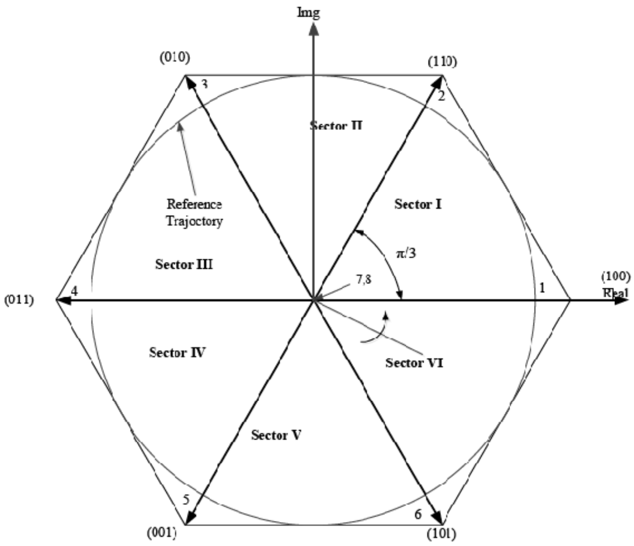
$$I_d = \mathrm{ID}\cos\theta - \mathrm{IQ}\sin\theta$$

Space vector pulse width modulation :

The space vector pulse width modulation (SVPWM) technique of the most popular technique due to a higher DC bus voltage and offered easy digital realization. The concept of SVPWM relies on the representation of the output voltage the inverter output as space vector or space phasors. Space vector representation of the output voltages of the inverter is realized of the implementation of SVPWM. The maximum output voltage based on the space vector theory is ${}^{2}/_{\sqrt{3}} =$ 1.55 times as large as the conventional sinusoidal modulation. It enables to feed the motor with a higher voltage than the easier sub-oscillation modulation method. This modulator allows to have a higher torque at high speeds, and a higher efficiency. The space vector is defined as

$$f_s = \frac{2}{3}[f_a + e^{j2\frac{2}{3}} f_b + e^{j4\frac{\pi}{3}} f_c]$$

Where f_a, f_b and f_c are three phase quantities of voltages, current and fluxes. In the inverter PWM, the voltage space vectors considered. The hexagon consists of six distinct sector spanning over 360 degrees with each sector of 60 degrees.



Space vector 1, 2…6 called the active states and 7, 8 called zero states vectors. Are redundant vector but they are used to minimize the switching frequency. The inverter is operating in the six-step mode.

IV. IMPLEMENTATION OF CONTROLLED METHOD FOR PMSM

The P stands for proportional control, I for integral control and D for derivative control. This is also called a three term controller. The basic function of a controller is to execute an algorithm based on the control engineer's input

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(tuning constants), the operator's desired operating value (set point) and the current plant process value. In most cases, the requirement is for the controller to act so that the process value is as close to the set point as possible. In a basic process control loop, the control engineer utilizes the PID algorithms to achieve this.

With its three-term functionality covering treatment to both transient and steady-state responses, proportional-integral-derivative(PID) control offers the simplest and most efficient solution to many real-world control problems. The PID controllers are usually standard building blocks for industrial automation. The most basic PID controller has the form:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt}(e(t))$$

Where, $u(t)$ is the control output and the error
$e(t)$ is defined as $e(t)$ = desired value – measured value of quantity being controlled.
K_p , K_i , and K_d are the control gains.
Diagrammatically, the PID controller can be represented as Figure

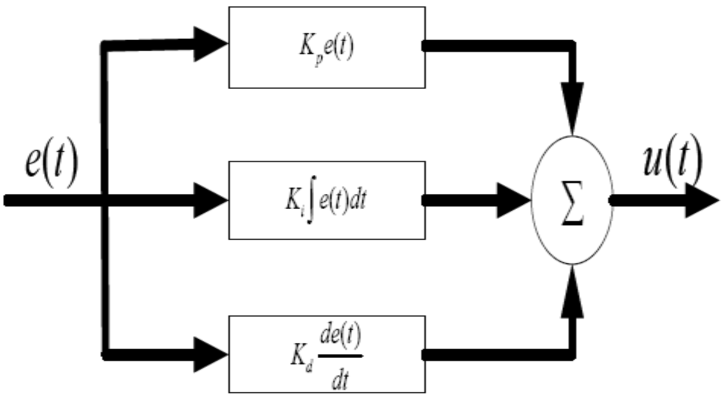

Figure 2. Structure of PID Controller

A control method which is popular because of its robustness, its simplicity, and its reusability is PID control. A PID controller contains a proportional gain, an integrator, and a differentiator (hence its name), all of which are summed together to produce the output of the controller. The transfer function of a PID controller has the form

$$PID = K_p + \frac{K_i}{s} + K_d.s = \frac{K_d.s^2 + K_p.s + K_i}{s}$$

Where K_P is the proportional gain coefficient, K_I is the integrator coefficient, and K_D is the differentiator coefficient. The proportional gain is used to amplify the input signal. The integrator is used to improve the accuracy of the control system, that is, to minimize the steady-state error as much as possible. The differentiator is used to increase the damping in the system, which will decrease both the peak time and the settling time of the system.

Field oriented control of PMSM :

Field oriented control of PMSM is one important variation of vector control methods. The aim of the FOC method is to control the magnetic field and torque by controlling the d and q components of the stator currents or relatively fluxes. With the information of the stator currents and the rotor angle a FOC technique can control the motor torque and the flux in a very effective way. The main advantages of this technique are the fast response and the little torque ripple. The implementation of this technique will be carried out using two current regulators, one for the direct-axis component and another for the quadrature-axis component, and one speed regulator.

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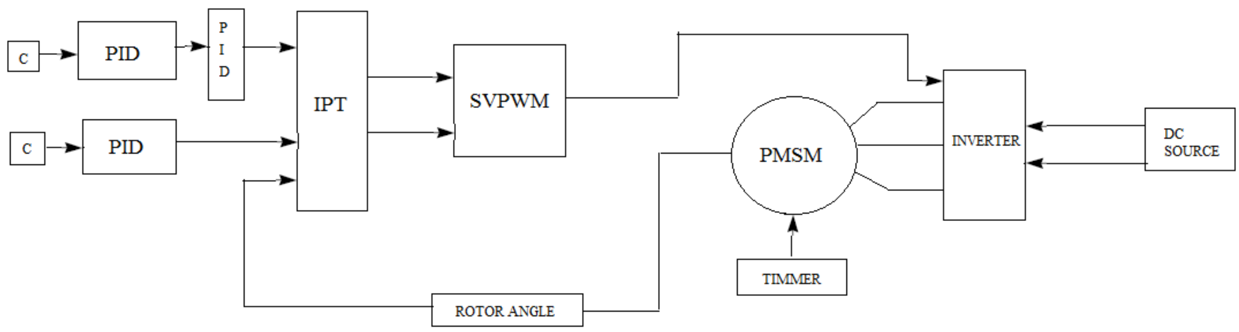

Figure 3. Block diagram of FOC control of PMSM

As shown in the figure, there are three PID regulators in the control system. One is for the mechanical system (speed) and two are for the electrical system (d and q currents).

At first, the reference speed, ω_{ref}, is compared with the measured speed, ω_r, and the error signal, ε_ω, is fed to the speed PID controller. This regulator compares the actual and reference speed and outputs a torque command. The torque is related to the speed by the mechanical equation of the motor:

$$\frac{d\omega_r}{dt} = \frac{1}{J}(T_e - T_m - B\omega_r)$$

Where J is the inertia of the motor, B is the viscous coefficient, T_m is the mechanical torque applied in the shaft (load) and Te is the electrical torque developed by the motor.

The PID outputs, $V_{d,ref}$ and $V_{q,ref}$, are first transformed to *abc* domain by the use of inverse Park. Then, those reference voltages are used by the PWM unit to generate the inverter's command signals. A saturation block has been included to avoid exceeding the maximum torque and voltages allowed in the machine. When these limits are reached, the regulators control that the torque or voltage values do not overpass their maximum values. This causes a problem, a large overshoot of the current values caused by the integrator windup. The integral term of the regulator keeps accumulating the error during the time of maximum voltage output, and when the value of the current reaches its maximum, the integrator has wound up so that the voltage remains large.

V. SIMULATION AND RESULT

Simulations: The value of DC voltage source in the circuit is 400 volt.
Data of Permanent Magnet Synchronous Motor's Parameters

1.	R_s	Stator Resistance	18.7Ω
2.	L_d	d-axis inductance	0.02682mH
3.	L_q	q-axis inductance	0.02682mH
4.	ψ_f	Rotor flux linkage	0.18Wb
5.	J	Inertia	0.0008 kg.m^2
6.	n_p	Pair of poles	2

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Simulink Model:

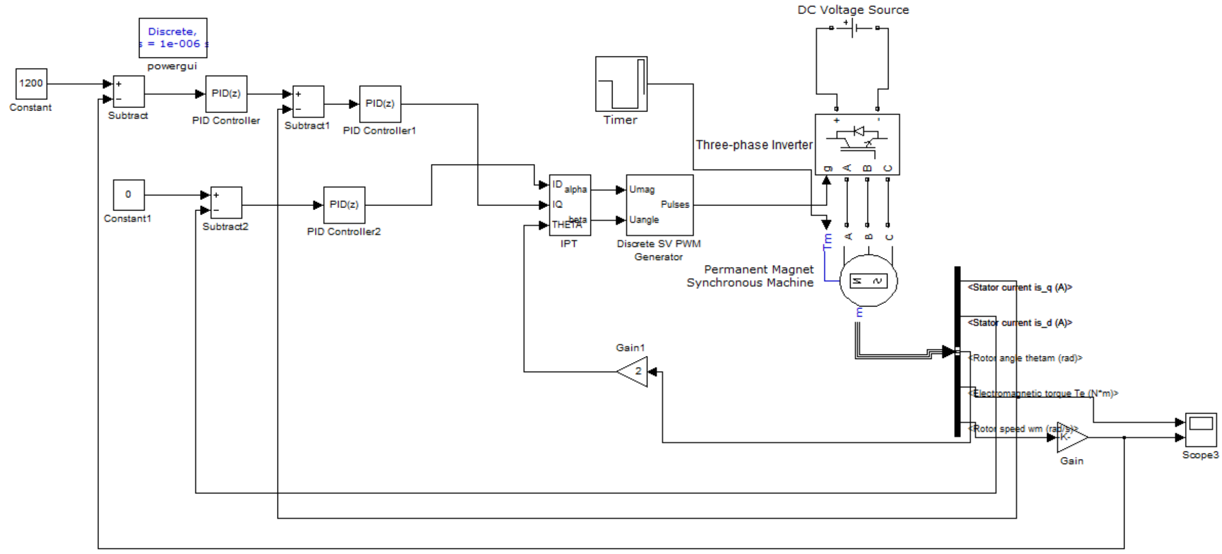

Figure 4. PMSM FOC model Using MATLAB/Simulink

Sub system:

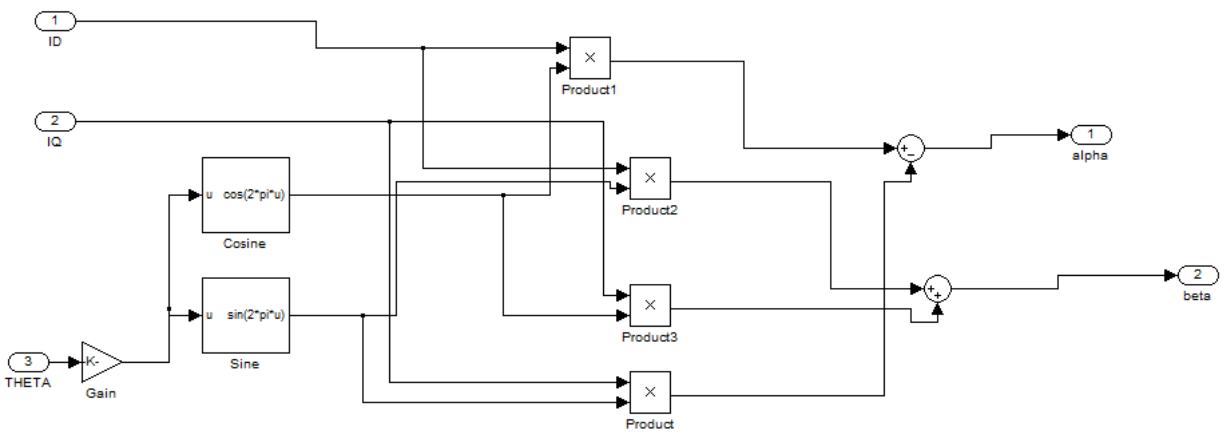

Figure 5. Subsystem of Inverse Park Transform

Table for different value of K_p, K_d and K_i of PID controller

Gain	PID controller 1	PID controller 2	PID controller 3
K_p	400	2	400
K_d	1	0.1	1
K_i	0.001	0.001	0.001

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Output Results:

Result for Electromagnetic torque:

Here, figure 6 shows the electromagnetic torque for detailed value of torque at a particular time.

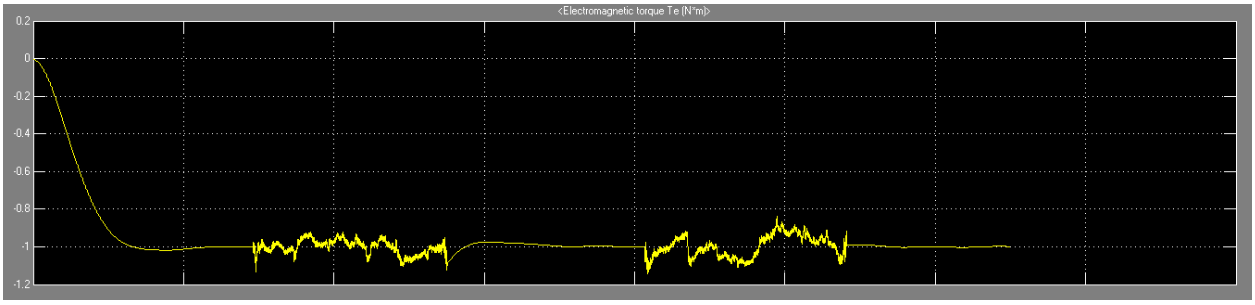

Figure 6. Electromagnetic torque

Here Figure 7(a) Rotor speed for PMSM motor shows the rotor speed for PMSM motor and Figure 7(b) shows the actual speed and the desired speed graph.

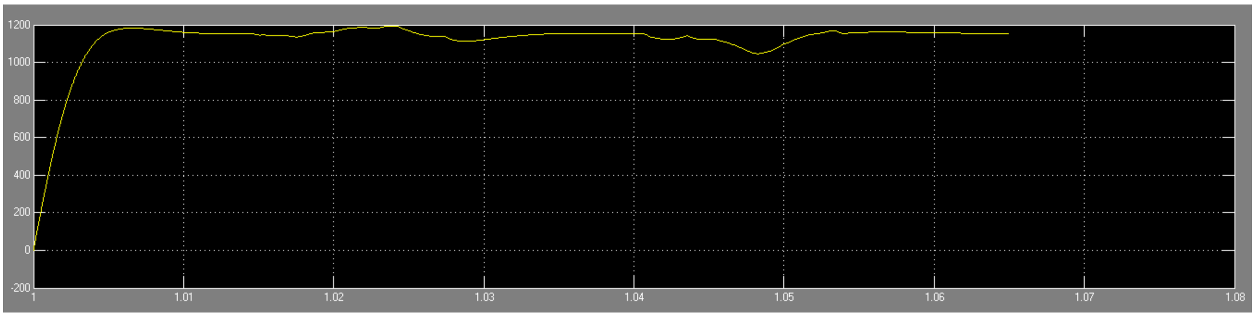

Figure 7(a). Rotor speed for PMSM motor

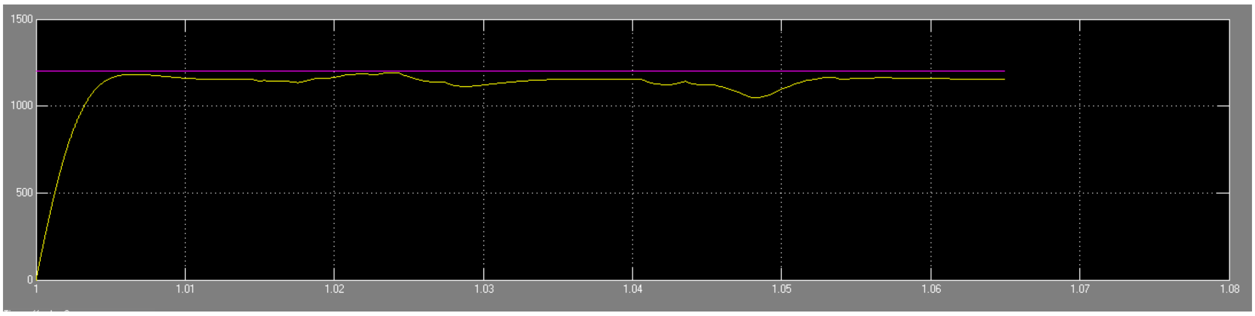

Figure 7(b). Actual speed/desired speed graph

From the simulation diagram, we see that the the dc input is given to a three phase inverter, which has its pulse controlled by inverse park's transformation block and space vector pulse width modulation block. And the PMSM motor output is fed to the PID controller which acts as a feedback controller to the IPT block. Where the gain value for rotor speed is $30/\pi$.

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Here, from the above figures and table we can see that the rise time , overshoot and settling time is less when the values of PID controller block 1 is is K_p=400, K_i=1 and K_d=0.001,which is same as PID block 3 and the value of PID block 2 is K_p=2, K_i=0.1 and K_d=0.001. Here we get the value of K_p, K_d, and K_i using hit and trial method. And at no load electromagnetic torque remains constant but when we increase the load, torque increases. We know that in case of synchronous motor speed remains constant even if load is increased.

VI. CONCLUSION

FOC is the standard regulator for Permanent Magnet Synchronous Motors. The chief constituents of this algorithm for example SVPWM and PID controllers are error less models with constant performance defined over a set of parameters. With desired simulation parameters and experiments performed on MATLAB 2010a model, the system proposed validated the better expectations from against the standard architecture. And for the given input parameters and control variables, the output value was found as desired.

REFERENCES

[1] Jahns Thomas M., Kliman Gerald B. and Neumann Thomas W., ***"Interior Permanent-Magnet Synchronous Motors for Adjustable-Speed Drives,"*** IEEE Transactions on Industry Applications, vol.IA-22, no.4 (1986): pp.738-747.

[2] Sebastian T. Slemon G. and Rahman M., ***"Modelling of Permanent Magnet Synchronous Motors,"*** IEEE Transactions on Magnetics, vol. 22 (1986): pp. 1069- 1071.

[3] Pillay P. and Krishnan R., ***"Modelling of Permanent Magnet Motor Drives,"*** IEEE Transactions on Industrial Electronics, vol.35, no.4 (1988): pp.537-541.

[4] Hoang Le-Huy.**,*"Modeling and Simulation of Electrical Drives using MATLAB/Simulink and Power System Block set"***, The 27th Annual Conference of the IEEE on Industrial Electronics Society, IECON '01. Vol. 3 (2001): Page(s): 1603- 1611.

[5] Chen ming, Gao Ranying, Song Rongming,***"Simulation Study on a DTC System of PMSM"*** 2011 The 6th International Forum on Strategic Technology978-1-4577- 0399-7111/$26.00 ©2011IEEE

[6] ***"Permanent Magnet Synchronous and Brushless DC Motor Drives"*** by R. Krishna Electrical and Computer Engineering Department Virginia Tech Blacksburg, Virginia, U.S.A.(Textbook)

BIOGRAPHY

Puspendu Maji was born in West Bengal, India on March 28, 1992. He has received his B.Tech degree in Electrical Engineering from Bankura Unnayani Institute Of Engineering, Bankura, West Bengal in 2013. Currently he is persuing his M.Tech degree in Power Electronics and Drives from Jalpaiguri Govt. Engineering College, Jalpaiguri, West Bengal.

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