Speed Control of PMSM Drive Based on Vector of PI, PD controllers

K Lavanya[1], P.N.S.Rohit [2], P. Sateesh[3]
[1,2,3] *Department of EEE, ANITS, Sangivalasa, Visakhapatnam, AP, India-531162*

***Abstract*-The present work deals with a simple and robust speed control scheme of permanent magnet synchronous motor (PMSM) drive. Vector control of PMSM drive and a comparison of speed control based on vector pf PI, PD controllers. The main application for the PMSM is that it can be used as low power as well as high power applications. Vector control of PMSM drive is popular kind of its speed control. Different Conventional vector controllers are compared. Vector PI and vector PD. Conventional PI/PD controllers improve the response of the system. Finally these four control techniques are compared. PMSM speed control of conventional PI/PD ,system is modeled in MATLAB/SIMULINK. Simulation circuit is analyzed and results are presented for this system.**

Index Terms: **Permanent magnet synchronous motor (PMSM); Sinusoidal pulse width modulation (SPWM); PI controller, PD controller; Vector Control.**

I. INTRODUCTION

Permanent magnet synchronous motors are widely used in high performance drives such as industrial robots and machine tools. In recent years, the magnetic and thermal capabilities of the Permanent Magnet Synchronous Motors have been considerably increased by employing the high-coercive permanent magnet material. The speed control of synchronous motor depends upon two factors via number of poles, P and supply frequency, f. as in case of shipping propulsion, the speed of the motor can be changed by changing the speed of the alternator – the speed of the motor changes exactly in the same proportion as that of the alternator supplying power to it. It is to be noted here that the voltage and frequency are directly proportional to the speed at which alternator is driven. The effective way of producing the variable speed Permanent Magnet Synchronous Motor drive is to supply the motor with variable voltage and variable frequency or constant v/f supply variable frequency is required because the rotor speed is directly proportional to the stator supply frequency. A variable voltage is required because the motor impedance is reduced at lower frequencies and consequently the current has to be limited by means of reducing the supply voltage. Unlike a DC motors, Permanent magnet synchronous motors (PMSM) are very popular in a wide range of applications. The PMSM does not have a Commutator, which makes it more reliable than a DC motor. The PMSM also has advantages when compared to an AC induction motor. The PMSM generates the rotor magnetic flux with rotor magnets, achieving higher efficiency. Therefore, the PMSM is used in applications that require high reliability and efficiency. Every electric motor has to have some sort of controller. The motor controller will have different features and complexity depending on the task that the motor will be performing. One type of motor speed controlling is an adjustable-speed drive (ASD) or variable-speed drive (VSD) is an interconnected combination of equipment that provides a means of driving and adjusting the operating speed of a mechanical load. An electrical adjustable-speed drive consists of an electric motor and a speed controller or power converter plus auxiliary devices and equipment. In common usage, the term “drive” is often applied to just the controller. PI controllers are quite simple, thought they are the most widely used in practice. But in some applications it may be useful to employ more general controllers, which makes it easier to reach the system specifications and improve their performance, though they can be also more difficult to tune.

II. MATHEMATICAL ANALYSIS OF PMSM

In a motor with more than one pair of magnetic poles the electric angle differ .In a motor with more than one pair of magnetic poles the electric angle differ the mechanical. Their relationship is

$$\theta_r = \frac{p}{2}\theta_m \qquad (2.1)$$

The voltage V, over each stator winding is the sum of the resistive voltage drop and the voltage induced from the time varying flux linkages, $d\psi/dt$.

$V_a = r_a i_a + \frac{d}{dt}\psi_a$ (2.2)

$V_b = r_b i_b + \frac{d}{dt}\psi_b$ (2.3)

$V_c = r_c i_c + \frac{d}{dt}\psi_c$ (2.4)

The stator windings are wound with the same number of turns so the resistance is equal in all three windings,

$r_a = r_b = r_c = r_s$ (2.5)

In matrix form these voltage equations (2.2) to (2.4) becomes

$V_{abc} = r_s i_{abc} + \frac{d}{dt}\psi_{abc}$ (2.6)

$$= \begin{bmatrix} r_s & 0 & 0 \\ 0 & r_s & 0 \\ 0 & 0 & r_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \psi_a \\ \psi_b \\ \psi_c \end{bmatrix} \quad (2.7)$$

Flux linkages in a linear magnetic circuit is the product of inductance and current, the motor model was assumed linear, which is a fairly accurate approximation if saturation does not occur, hence

$\psi_{abc} = L_s i_{abc} + \psi_m$ (2.8)

Where L_s contains self and mutual inductances, Ψ_m is the flux through the stator windings due to the Permanent Magnet.

Using Newton's law

$J\frac{d}{dt}\omega_m = T_e - T_l - B\omega_m$ (2.9)

Where $\omega_m = \frac{d}{dt}\theta_m$ (2.10)

Torque is change in energy per change in angle, thus using co energy

$W_e = \frac{1}{2} i^T{}_{abc} L_s i_{abc} + i^T{}_{abc} \psi_m + W_{PM}$

(2.11)

The torque produced by the machine is

$T_e = \frac{d}{dt} W_e$ (2.12)

$T_e = \frac{3}{2}\frac{P}{2}\left(\psi_d i_q - \psi_q i_d\right)$ (2.13)

Speed can be written as

$\omega_r = \frac{1}{s}\left(\frac{1}{jp}(T_e - T_l)\right)$ (2.14)

III. VECTOR CONTROL OF A PMSM

There are several different ways of creating a two-axis system but generally the method operates with the d- and q- axis current Phasor components, i_d & i_q , which may be defined in a variety of reference frames such as rotor or fixed to the stator. To determine and i from the instantaneous line currents , a reference frame transformation, such as Park's Transformation.

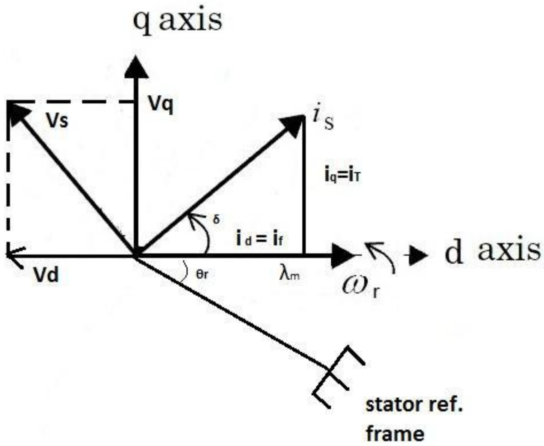

Fig.1.Phasor diagram of PMSM

The PMSMs are designed such that the rotor magnet alone is capable of producing the required air gap flux up to the rated speed. Hence id is normally zero in the constant torque mode of operation. Consider three phase currents are:

$i_a = i_s \sin(\omega_r t + \delta)$ (3.1)

$i_b = i_s \sin\left(\omega_r t + \delta - {2\pi}/{3}\right)$ (3.2)

$i_c = i_s \sin\left(\omega_r t + \delta + {2\pi}/{3}\right)$ (3.3)

Where $\theta_r = \omega_r t$ from phasor diagram we get

$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = i_s \begin{bmatrix} \sin\delta \\ \cos\delta \end{bmatrix}$ (3.4)

i_q = Torque-producing component of stator current $= i_T$

i_d = Flux-producing component of stator current $= i_f$

If we make $i_d = 0$ by $\delta = 90^0$ then the electric torque equation becomes:

$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\lambda_m i_q$ (3.5)

IV.PROPORTIIONAL CONTROLLER

The proportional term makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constantK_p, called the proportional gain. The transfer function of a proportional controller is simply a gain sayK_p. If the input of the controller is $e(t)$ then the output is $u(t) = K_p e(t)$ or in a Laplace transform domain$U(s) = K_P E(s)$. As K_P increases the unit-step response may becomes faster and eventually the feedback system may becomes unstable. For the same unit-step reference input the steady-state plant outputs are different for different K_P.

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the Proportional gain is too low; the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change.

IV.I. INTEGRAL CONTROLLER

In this controller the output u(t) is altered at a rate proportional to the error signal e(t). The output u(t) depends upon the integral of the error signal e(t).

Mathematically,

$\frac{du(t)}{dt} = K.e(t)$ (4.1.1)

(or) $u(t) = K\int_0^1 e(t)dt$ (4.1.2)

(or) U(s) = $\frac{KE(s)}{s}$ (4.1.3)

Integral control action itself is not sufficient, as it introduces hunting in the system. Therefore a combination of Proportional and integral control action is introduced to improve the system performance. In this type of system, the actuating signal consists of proportional error signal added with the integral of the error signal.

Mathematically,

$u(t)$=e(t)=K$\int_0^t e(t)dt$ (4.1.4)

Where e (t) = error signal

$\int_0^t e(t)dt$=integral of error signal (4.1.5)

Or U(S) = E(s) [1+ $\frac{K}{S}$] (4.1.6)

Proportional plus Integral control increases the order and type of the system by one, respectively. Therefore, it improves steady state performance. The effect of proportional and integral control improves system steady state response with in less time and rise time also increases.

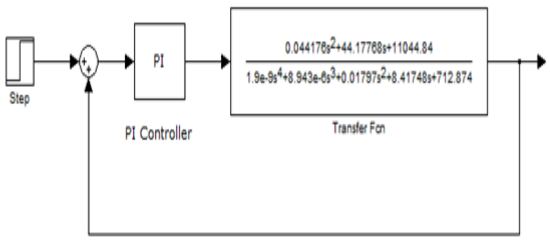

Fig.2. BLOCK DIAGRAM OF PMSM DRIVE USING PI CONTROLLER

IV.II. DERIVATIVE CONTROLLER

If the input of a derivative controller with derivative constant K_d is $e(t)$ then its output is $K_d \frac{de(t)}{dt}$ or in Laplace transform domain $K_d sE(s)$. Therefore the transfer function of the derivative controller is $K_d s$. This is an improper transfer function and is difficult to implement. In practice it is built as $\frac{K_d s}{1+\frac{K_d s}{N}}$ where N ranging from 3 to 10 is determined by the manufacture and is called the 'taming factor'. This taming factor makes the controller easier to build. It also limits high frequency gain therefore high frequency noise will not be unduly amplified. For control signals which are generally of low frequency the transfer function can be approximated as $K_d s$. The derivative control is rarely used by itself in feedback control systems. Suppose the error signal $e(t)$ is very large and changes slowly or in the extreme case it is a constant. In this case a good controller should generate a large actuating signal to force the plant output to catch up with the reference signal so that the error signal will be zero and the error signal will remain large.

Proportional – derivative or PD control combines proportional control and derivative control in parallel.

$C_{pd}(s) = K_p(1 + T_d s)$ (4.2.1)

The proportional plus derivative controller produces an output signal consisting of two terms: One proportional to error signal and the other proportional to the derivative signal.

In PD – controller,

$u(t) \;\alpha\; e(t) + \frac{d}{dt} e(t);$ (4.2.2)

$U(t) = K_p e(t) + K_p T_d \frac{d}{dt} e(t)$ (4.2.3)

Where K_p → proportional gain;

T_d → Derivative time

On taking Laplace transform of equations with zero initial conditions.

We get,

$U(s) = K_P E(s) + K_P T_D \, s \, E(s)$ (4.2.4)

$U(s) = E(s)[(1 + T_D \, s)]$ (4.2.5)

$U(s)/E(s) = K_P \,(1 + T_D \, s)$ (4.2.6)

Where $T_D = K_D/K_P$ is called the derivative time, during which interval the proportional control action takes effect. The anticipatory characteristic of derivative control action is found in PD control action. This means, in transient mode, PD can anticipate the direction of the error in making adjustments before excessive overshoot occurs.

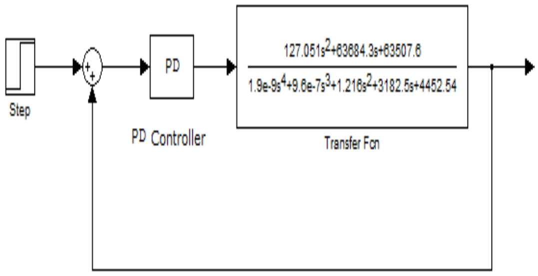

Fig.3. BLOCK DIAGRAM OF PMSM DRIVE USING PD CONTROLLER

V.SIMULATION AND DISCUSSION

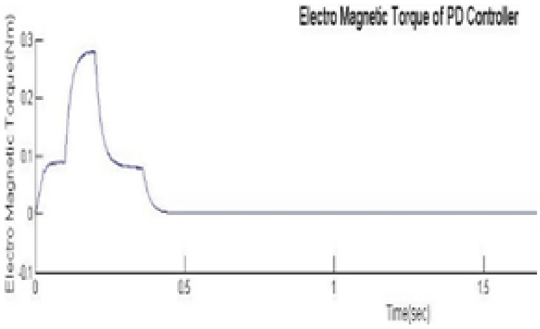

Fig.4.torque of PD Controller

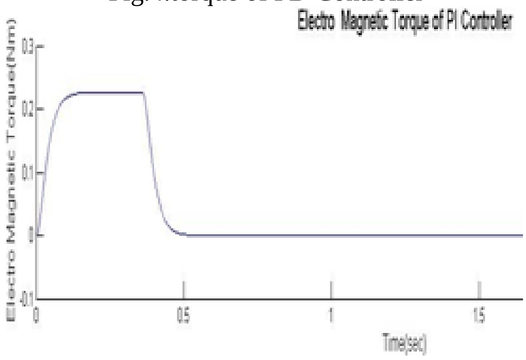

Fig.5. Torque of PI Controller

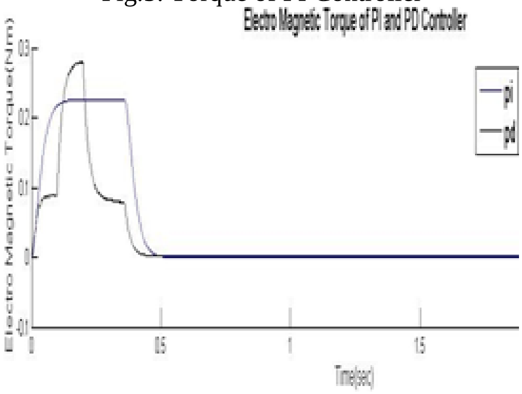

Fig.6.Torque response of PI & PD Controller

The above figures shows that torque response of PI & PD controller. From the above fig the speed response of PD controller is more accurate as the settling time is increased, peak time is increased and the rise time also increased while compared with the PI controller .In the same way the electromagnetic torque of PD controller is accurate as compared with the electromagnetic torque of PI controller as the rise time is increased, peak time is increased and the settling time also increased. As in PI controller the transient response is more which can be rectified by PD controller and it also gives the best performance in damping oscillations and overshoots.

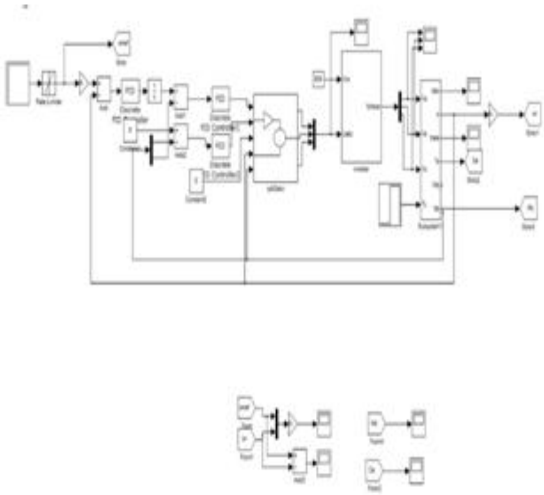

Fig.7. Simulation Block diagram

VI. CONCLUSION

This paper has presented the simulation model of Speed control of PMSM drive based on vector of PI and PD controllers. While comparing the speed response and electromagnetic torque of PI and PD controllers the rise time, settling time of PD reduces while compared with PI. It improves the damping and gain margin, It also keeps system at constant setting time. It is found that the application of PMSM drive in the field of submarine and electric ship.

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AUTHORS

Mrs. K Lavanya is currently working as an assistant Professor in the Department of Electrical and Electronics Engineering at ANITS, Sangivalasa, bheemili mandal, Visakhapatnam, A.P. India. She received BE degree in Electrical and Electronics Engineering from TPIST, bobbili mandal, India and M.Tech in Power Electronics from JNTU Hyderabad, Aurora Engineering College, A.P, India and pursuing Ph.D in JNTUK, Kakinada. She has 15 years of teaching experience. Her research interests include Power Electronics and Machine Drives.

P.N.S. Rohit and P. Sateesh are pursuing B.Tech final year in Electrical and Electronics Engineering at ANITS, Sangivalasa, Bheemili mandal, Visakhapatnam, A.P. India.