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# PERFORMANCE OF SIX PHASE PMSM DRIVE AT DIFFERENT SPEED LEVELS

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## ABSTRACT

This paper gives a detail modelling of six phase Permanent magnet synchronous machine (PMSM) and complete simulation of it's drive system and performance analysis in different speed with PI controller. proposed method can be used easily in many applications like ship propulsion, Hybrid electric vehicle, Washing machine, Ship propulsion, Traction, Spinning mills, Aerospace etc. Proportional-Integral controller is mostly used in drives system. The combination of proportional and integral is important to increase the speed of response and also to eliminate the steady state error. Performance analysis with proportional (Kp) and integral (Ki) constant with different speeds and constant torque is studied in the drive system.

**KEYWORDS**: **Multiphase, Permanent magnet synchronous motor (PMSM), PI controller, PWM Inverter .**

## INTRODUCTION

Multiphase variable speed drive has received growing interest since the second half of the 1990s because of several advantages of multiphase and superiority of PMSM drive system over other drive system. This growing interest is cause by the fact that this machine can provide notable improvements in various aspects of performance as compared to conventional three phase motor and six phase induction Motors.The main application areas of multiphase machines specially motor drives are ship propulsion, traction (including Electric and hybrid electric vehicles) and the concept of More-electric "aircraft. Other suitable applications are Locomotive traction, aerospace and high power Applications.

## THREE PHASE DRIVES VS. SIX PHASE DRIVES

Historical technical reasons that required adopting the multiphase drive solution instead of three-phase are listed below [1,2,3,4,5,6 ]:-

1) Multiphase variable speed drive reduces the stator current per phase, for a given motor output power.

2) The use of more than three phases offers an improved reliability.

3) Multiphase machines present reduced pulsating toques produced by time harmonic components in the excitation waveform.

4) Fault tolerant drives

5) Higher degree of freedom

## SUPERIORITY OF PMSM MOTOR

PMSM have the following advantages over DC Motors:-

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Less audible noise, longer life, Spark less (no fire hazard), Higher speed, higher power density and smaller size, Better heat transfer [3,7,8,9,10,11].

PMSM have the following advantages over Induction Motors:-

Higher efficiency, Higher power factor, Higher power density for lower than 10 KW applications, resulting in smaller size Better heat transfer [4-11]

The above comparison shows that the PMSM are superior to the induction motor /DC motor.

## MODELLING OF SIX PHASE PMSM

In this study, a six-phase PMSM with two three-phase Windings is adopted where *ABC* winding is spatially 30 electrical degrees phase led to *XYZ* winding[12,13].

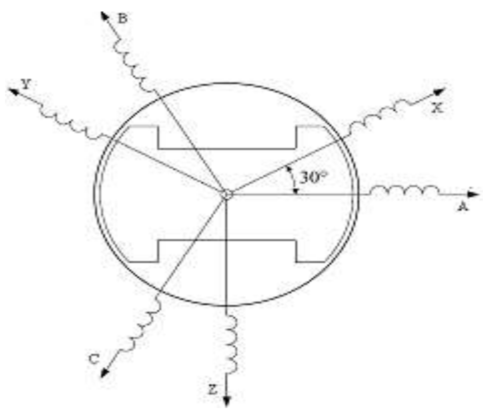


Fig:1 Six- Phase PMSM Motor (Stator winding)

The phase voltage and flux linkage equations in the stationary reference frame for *ABC* winding and *XYZ*winding of six-phase PMSM are shown as:

$$V_{ABC} = R_S I_{ABC} + \frac{d\phi_{ABC}}{dt} \tag{1}$$

$$\phi_{ABC} = L_{11} I_{ABC} + L_{12} I_{XYZ} + \phi'_{MABC} \tag{2}$$

$$V_{XYZ} = R_S I_{XYZ} + \frac{d\phi_{XYZ}}{dt} \tag{3}$$

$$\phi_{XYZ} = L_{22} I_{XYZ} + L_{21} I_{ABC} + \phi'_{MXYZ} \tag{4}$$

Where Rs = diag [Rs, Rs, Rs]$^T$ is the stator resistance vector; $V_{ABC}=[V_A\ V_B\ V_C]^T$ is the phase voltage vector of abc winding; $I_{ABC}=[i_A\ i_B\ i_C]^T$ is the current vector of ABC winding; $Vxyz=[Vx\ Vy\ Vz]^T$ is the phase voltage vector of winding; $i_{XYZ}=[i_x\ i_y\ i_z]^T$ is the current vector of XYZ winding;$Ø_{ABC}=[Ø_A\ Ø_B\ Ø_C]^T$ is the stator flux linkage vector of win ABC ding; $Ø_{XYZ}=[Ø_X\ Ø_Y\ Ø_Z]^T$ is the stator flux linkage vector of *xyz* winding; $\mathbf{L_{11}}$ is the stator inductance vector of win ABC winding;$L_{22}$ is the stator inductance vector of *XYZ* winding; $\mathbf{L_{11}}$ and $\mathbf{L_{22}}$ are the mutual inductance vectors; Ø'$_{MABC}$' is the permanent-magnet flux linkage vector of ABC winding; Ø'$_{MXYZ}$ is the permanent-magnet flux linkage vector of *XYZ* winding[14,15,16].

In order to control the six-phase PMSM, the followingTransformation matrixes have been used to transfer the above equations into the synchronous rotating reference frame:

$$Tqd1 = \frac{2}{3}\begin{bmatrix} \cos\theta_e & \cos(\theta_e - 120^0) & \cos(\theta_e + 120^0) \\ \sin\theta_e & \sin(\theta_e - 120^0) & \sin(\theta_e + 120^0) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (5)$$

$$Tqd2 = \frac{2}{3}\begin{bmatrix} \cos(\theta_e - 30^0) & \cos(\theta_e - 150^0) & \cos(\theta_e + 90^0) \\ \sin(\theta_e - 30^0) & \sin(\theta_e - 150^0) & \sin(\theta_e + 90^0) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (6)$$

where $T_{qd1}$ is the transformation matrix for *ABC* winding; $T_{qd\,2}$ is the transformation matrix for *XYZ* winding; $\theta e$ is the rotor flux angle[15]. Moreover, the machine model of a six-phase PMSM can be described in synchronous rotating reference frame as follows:

$$v_{q1} = R_s I_{q1} + L_{q11}\frac{dI_{q1}}{dt} + \omega_e(L_{d11}I_{d1} + \phi_{PM}) \quad (7)$$

$$v_{d1} = R_s I_{d1} + L_{d11}\frac{dI_{d1}}{dt} - \omega_e L_{q11} I_{q1} \quad (8)$$

$$v_{q2} = R_s I_{q2} + L_{q22}\frac{dI_{q2}}{dt} + \omega_e(L_{d22}I_{d2} + \phi_{PM}) \quad (9)$$

$$v_{d2} = R_s I_{d2} + L_{d22}\frac{dI_{d2}}{dt} - \omega_e L_{q22} I_{q2} \quad (10)$$

$$\omega_e = \frac{P}{2}\omega_r \quad (11)$$

where $v_{d1}$ and $v_{q1}$ are the *d-q* axis voltages of *ABC* winding; $v_{d2}$ and $v_{q2}$ are the *d-q* axis voltages of *XYZ* winding; $i_{d1}$ and $i_{q1}$ are the *d-q* axis currents of *ABC* winding; $i_{d2}$ and $i_{q2}$ are the *d-q* axis currents of *XYZ* winding; $L_{d11}$ and $L_{q11}$ are the *d-q* axis inductances of *ABC* winding; $L_{d22}$ and $L_{q22}$ are the *d-q* axis inductances of *XYZ* winding; $\omega_r$ is the rotor angular velocity; $\omega_e$ is the electrical angular velocity;$Ø_{PM}$ is the permanent magnet flux linkage; p is the no.of pole pairs of six phase PMSM. As assumed that winding sets are identical ($L_{q11}$=$L_{q22}$= $L_q$ and $L_{d11}$=$L_{d22}$= $L_d$). Furthermore, the developed electric torque *e Te* can be represented by the following equation:

$$T_e = \frac{3}{2}\frac{P}{2}\left[\phi_{PM}(I_{q1} + I_{q2}) + (L_d - L_q)(I_{d1}I_{q1} + I_{d2}I_{q2})\right] \quad (12)$$

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However, the electromagnetic torque cannot be estimated accurately in a general case without knowledge of the currents of both winding sets and the inductance parameters that describe the magnetic coupling between them.

In addition, the mechanical dynamic equation of the six-phase PMSM is:

$$T_e = J\frac{d\omega_r}{dt} + B\omega_r + T_L \tag{13}$$

Where *J* is the inertia of six-phase PMSM; *B* is the damping Coefficient; *L T* is the load torque.[14,15,16].

## MACHINE PARAMETER AND MODEL

The Six phase PMSM parameter and model is given in following table and diagram for simulation purpose [14,15,17].

**Table**

| S.No. | Name | Rating |
|---|---|---|
| 1. | Nominal voltage *V*n | 380 volts |
| 2. | Nominal speed *n*n | 350RPM(36.5rad/s) |
| 3. | No.of Poles | 8 |
| 4. | Stator Resistance Rs | 0.64 ohm |
| 5. | PM flux Linkage $Ø_{PM}$ | 2.04 wb |
| 6. | Ld,Lq | 24mH,31.4mH |
| 7. | Inertia J | .014Nm/(rad/sec$^2$) |
| 8. | Damping coefficient B | .0124Nm/(rad/sec) |

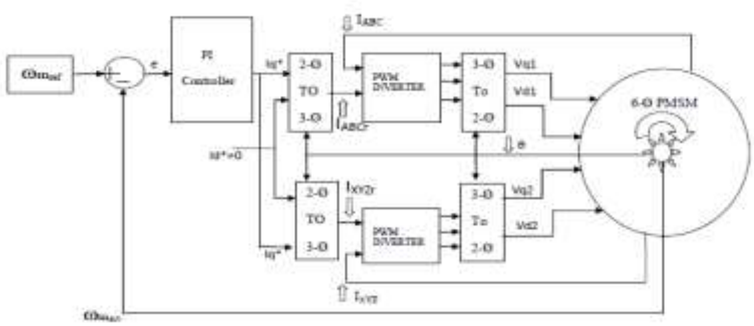

Figure-2 Six-Phase PMSM model

## RESULTS AND DISCUSSION

The above model of six phase PMSM drive system has been simulated for 0.2s ,the load Torque is set fix at 50N-M

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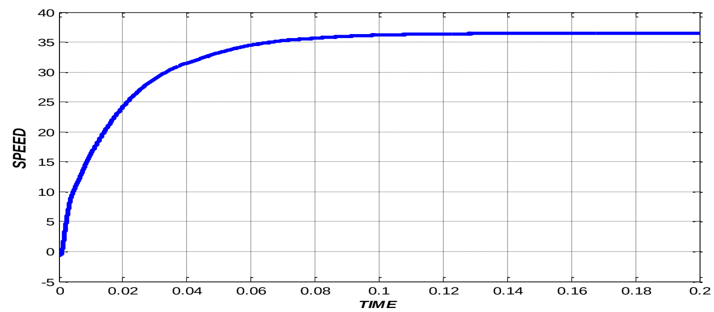
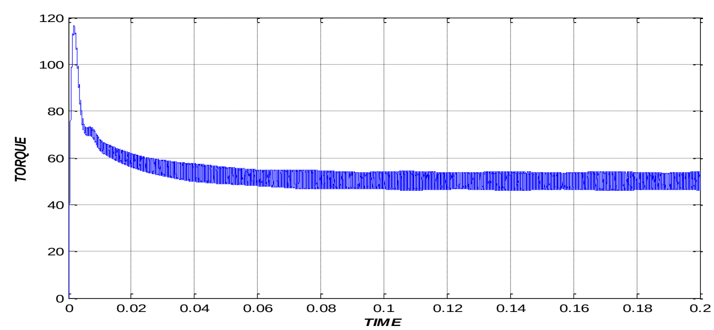
1.At Reference speed =36.5 rps:-

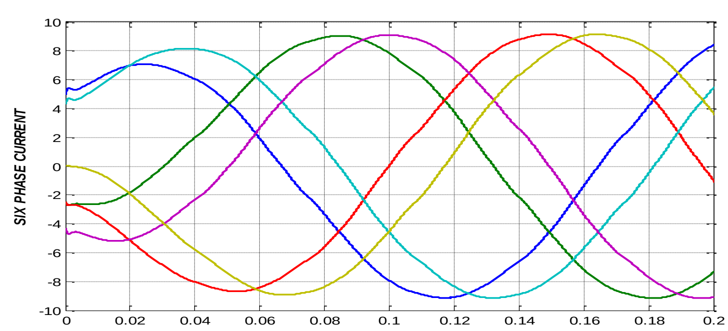
In this Case desired speed is set to 36.5 r.p.s. it is found that the after 0.125 sec the system reaches it's stable state i.e. at the desired value of speed..and the steady state current value is around 9A.




(a)




(b)

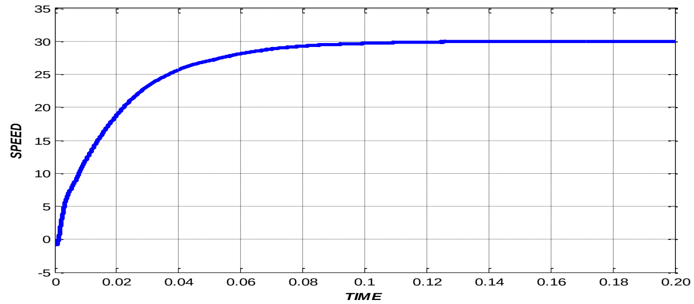



(c)

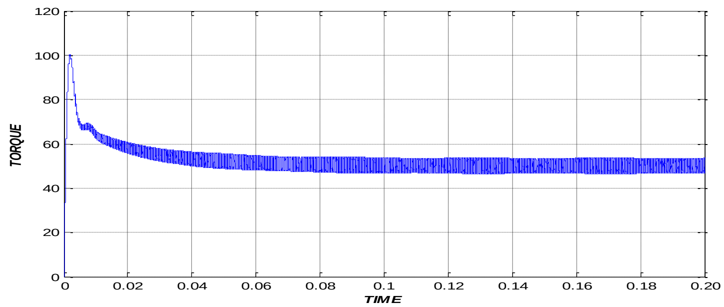
Fig:3 (a) Speed, (b) Torque,(c) Currents

2.At speed =30rps:-

Now in second case desired speed is set to 30 r.p.s. It is found that after 0.11 sec the proposed system reaches it's stable state i.e. at the desired value or set value. And this time steadt state current value is around 8 A.




(a)

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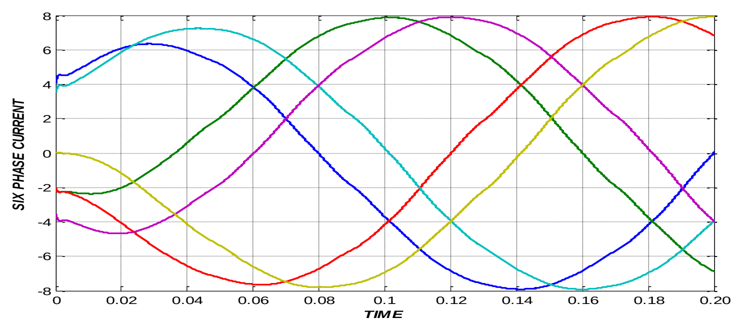
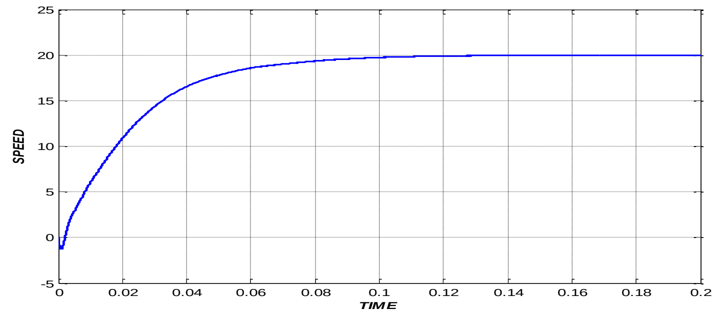



(c)

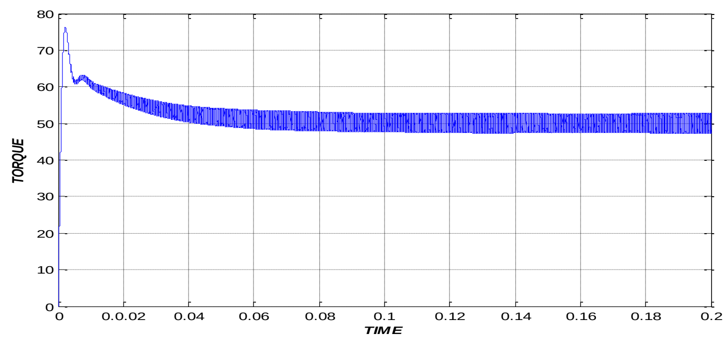
Fig:4 (a) Speed, (b) Torque,(c) Currents

3. At speed = 20rps:-

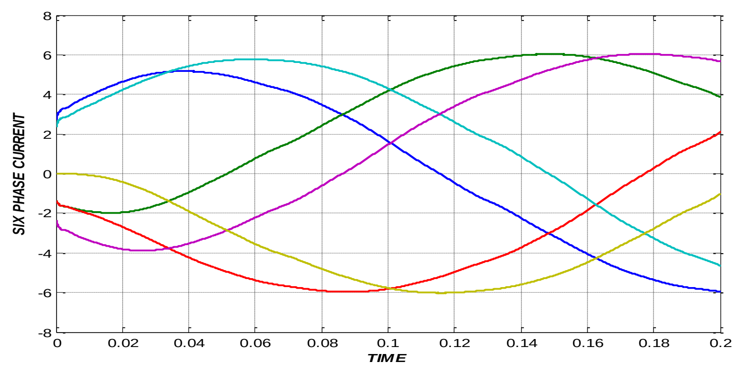
Now in third case desired speed is set to 20 r.p.s. It is found that after 0.125 sec. the proposed system reaches it's stable state i.e. at the desired value or set value. And this time steady state current value is around 6 A.




(a)




(b)




(c)

Fig:5 (a) Speed (b) Torque (c) Currents

## CONCLUSION

Mathematical and computer model of multiphase motor with six-phase stator winding and Permanent magnet rotor is presented. Starting transients of torque, speed and current obtained by solving of differential equations of the motor.The simulation results are obtained under various speed conditions and result demonstrate that the proposed model is able to operate at different speed. Overall it can be said that the performance of the proposed scheme is satisfactory.

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