# Modeling and Simulation of Permanent Magnet Synchronous Motor

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# Abstract

This paper presents, the mathematical model of the operation of a Permanent Magnet synchronous motor drive system. Today in many industries the use of Permanent Magnet Synchronous Motor (PMSM) is growing due to smaller size, lesser weight & low rotor loss as compared to induction motor of same capacity. One of the important characteristics of Permanent Magnet Synchronous Motor is that they produce constant torque with sinusoidal stator current. The simulation model includes all the required component of the drive system. Due to this the calculation of current and voltages in different parts of the inverter and motor under transient and steady conditions are possible. A closed loop control system in the speed loop has been designed to operate in constant torque and flux weakening regions. The principle of speed control is verified by analyzing the variation in the results of speed & torque.

**Keywords:** PMSM drive, Field Oriented control, constant torque, flux.

# Basic Model of the System.

The motor drive consists of four main components, the PM motor, inverter, control unit and the position sensor. The components are connected as shown in Figure 1.

**Figure 1: Schematic of the Drive System**

The main components of the system are:

* 1. Permanent Magnet Synchronous Motor
	2. Various Position Sensor

# Equivalent Circuit of Permanent Magnet Synchronous Motor

Equivalent circuits of the motors are used for study and simulation of motors. From the d-q modeling of the motor using the stator voltage equations the equivalent circuit of the motor can be derived. Assuming rotor d axis flux from the permanent magnets is represented by a constant current source as described in the following equation *Af* = *Ldmif*, illustrated in the below Figure 2.



**Figure 2:Permanent Magnet Synchronous motor Electric Circuit without Damper Windings**

Detailed modeling of PM motor drive system is required for proper simulation of the system. The d-q model is been developed on rotor reference frame as shown in figure 3

At any time t, the rotating rotor d-axis makes and angle *0r*with the fixed stator phase axis and rotating stator mmf makes an angle α with the rotor d-axis. Stator mmf rotates at the same speed as that of the rotor.



**Figure 3: Motor Axis**

The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions:

1. Saturation is neglected
2. The induced EMF is sinusoidal.
3. Eddy currents and hysteresis losses are negligible.
4. There are no field current dynamics.

Voltage equations are given by

*Vq* = *Rsiq* + *wrAd* + *pAq*..................................... (1)

*Vd* = *Rsid − wrAq* + *pAd*..................................... (2)

Flux Linkages are given by

*Aq* = *Lqiq*............................................................. (3)

*Ad* = *Ldid* + *Af*................................................... (4)

Arranging equations in matrix form

*Vq Rs* + *pLq wrLd iq wrAf*

 *Vd* =  *−wrLq Rs* + *pLd* +  *id* +  *pAf* .... (5)

The developed torque motor is being given by

*Te* = *3* × *P* (*AdAq − AqAd*)...................................... (6)

*2 2*

The mechanical Torque equation is

*Te* = *T* + *Bw* + *]* (*dwm*)………………………………..... (7)

*L m*

*dt*

Solving for the rotor mechanical speed from equation

*wm* = *∫* (*Te − TL − Bwm*)*dt*…………………………..………….. (8)

*dt*

Park Transformation Converting the phase voltages variables *Vabc* to *Vdqo*

Variables in rotor reference frame the following equations are obtained

*Vq* cos *0r* cos( *0r −* 120) cos( *0r* + 120) *Va*

 *Vd* = *2* sin *0r* sin (*0r −* 120) sin (*0r* + 120) *Vb* …… (9)

*3*

*V*

*o* 1/2

1/2 1/2 *Vc*

Convert *Vdqo* to *Vabc*

*Va* cos *0r* sin *0r* 1 *Vq*

 *Vb* = cos( *0r −* 120) sin (*0r −* 120) 1 *Vd* ………...... (10)

*Vc* cos( *0r* + 120) sin (*0r* + 120) 1 *Vo*

Control of PM motors is performed using field-oriented control for the operation of synchronous motor as a dc motor. The stator windings of the motor are fed by an inverter that generates a variable frequency variable voltage. Instead of controlling the inverter frequency independently, the frequency and phase of the output wave are controlled using a position sensor.

Considering the currents as inputs, the three currents are

*ia =* *Im*sin (*wrt* + *a*) ……………………………… (11)

*ib* = *Im*sin (*wrt* + *a − 2n*) ………………………….. (12)

*3*

*ic* = *Im*sin (*wrt* + *a* + *2n*) ………………………….. (13)

*3*

Writing equations in the matrix form

*ia cos* (*wrt* + *a*)

 *i* = *cos* (*wrt* + *a − 2n*) [*I*

] …………………… (14)

*b 3 m*

*ic cos* (*w t* + *a* + *2n*) *3*

*r*

Constant torque control strategy is derived from field oriented control, where the maximum possible torque is desired at all times like the dc motor. This is performed by making the torque producing current *iq* equal to the supply current *Im*. That results in selecting the ‘α’ angle to be 90º degrees according to equation.

Flux weakening is the process of reducing the flux in the d axis direction of the motor which results in an increased speed range. The motor drive is operated with rated flux linkages up to a speed where the ratio between the induced emf and stator frequency (V/f) is maintained constant. After the base frequency, the V/f ratio is reduced due to the limit of the inverter dc voltage source which is fixed. The weakening of the field flux is required for operation above the base frequency. This reduces the V/f ratio. This operation results in a reduction of the torque proportional to a change in the frequency and the motor operates in the constant power region.

The realization process of equivalent flux-weakening control is as follows:

1. Measuring rotor position and speed *wr* from a sensor which is set in motor rotation axis.
2. The motor at the flux weakening region with a speed loop *Te*is obtained from the

PI controller.

1. Calculate *Iq* using equation

*i* = *Te* ………………………….……………… (15)

*q*

*2 2*

1. Calculate *Id* using equation

*i* = ( *d* )....................................................................... (16)

*d*

*Ld*

1. Calculate α using equation

*a* = *Tan 1*( *iq* ) ………………………………………….. (17)

*id*

1. Using α and rotor position the controller will generate the reference currents as per

equation

*ia cos*(*wrt* + *a*)

 *i* = *cos*(*wrt* + *a − 2n*) [*I*

] …………………….….. (18)

*b 3 m*

*ic cos*(*w t* + *a* + *2n*) *3*

*r*

1. Then the current controller makes uses of the reference signals to control the

inverter for the desired output currents.

1. The load torque is adjust to the maximum available torque for the reference speed

*TL* = *Te*(*rated*)

*wrated* …………………………………….. (19)

*wr*

# Drive System in Matlab / Simulink

Figure 4 shown below is a Simulink model of PMSM drive system consisting of PMSM mechanical model



**Figure 4: Permanent Magnet Synchronous Motor Drive System in Simulink**



**Figure 5: d-axis and q-axis circuit**

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