Modelling of Closed Loop Speed Control for Pmsm Drive

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Abstract- Permanent magnet synchronous motors (PMSM) are widely used in high performance drive such as ratio, high power density, high reliability, and easy to control. High power density and high efficiency industrial robot, machine tool. PMSM has characteristics like high efficiency, simple structure, high torque/inertia make PMSM as better option as compared to induction motor. The electromagnetic torque in PMSM is usually controlled by controlling the armature current due to fact that the electromagnetic torque is proportional to the armature current. Direct Torque Control (DTC) technique for a PMSM motor is receives increasing attention because it eliminate current controller & low dependence on motor parameters as compared with other motor control techniques. The basic principle of DTC is to directly select stator voltage space vectors according to the differences between reference and actual values of torque and stator flux linkages. A mathematical model for the proposed DTC of the PMSM topology is developed. A simulation model is developed using MATLAB/SIMULINK software used to verify the performance of the PMSM drive using two level inverter.

Keywords- *Permanent Magnet Synchronous Motor (PMSM), DTC, Voltage Space Vectors, Sector*

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I. INTRODUCTION

The Permanent Magnet Synchronous Motors (PMSM) has found wide applications due to its high power density (compactness), high torque/inertia ratio, high efficiency and high reliability. Motor control techniques can be divided as scalar and vector control. Scalar control is based on relationship valid in steady state. Amplitude and frequency of controlled variables are consider. Scalar control is used e.g. where several motors are driven are driven in parallel by same inverter. In vector control amplitude and position of controlled space vector is consider. The problem in scalar control technique is that motor flux and torque in generally are coupled. This inherent coupling affects the response and makes the system prone to instability if it is not consider. The basic idea of DTC for induction motor is to control the torque and flux linkages by selecting the voltage space vectors properly, which is based on the relationship between the slip frequency and torque. Direct Torque Control (DTC) directly controls the inverter states based on errors between reference and estimated values of torque and flux. It select one of six voltage space vectors generated by a Voltage Source Inverter to keep torque and flux within the limit of two hysteresis band [1].

It has been proven that the DTC scheme for induction motors could be modified for PMSM drive. As DTC does not require any current regulator, co-ordinate transformation and PWM signal generator. The Direct Torque Control scheme has the advantages as simplicity, good dynamic performance and insensitive to motor parameters except stator winding resistance [7].

Scalar control is used e.g. where several motors are driven are driven in parallel by same inverter. Volts/Hertz control is among the simplest control scheme for motor control. The control is an open loop scheme and does not use any feedback loop. The basic idea is to keep stator flux at constant rated value so that motor develops rated torque/ampere ratio over its entire speed range. In vector control amplitude and position of controlled space vector is consider. The problem with scalar control is that motor flux and torque are generally coupled. This inherent coupling affects the response and makes the system instable if it is not considered. In vector control not only magnitude of stator and rotor flux is consider but also their mutual angle.The vector control of currents and voltages result in control of spatial orientation of electromagnetic fields in machine and hence name Field Oriented Control (FOC) [2]. Field Oriented Control usually refers to controllers which maintain 90^0 electrical angle between rotor and stator field components. Field Oriented Control (FOC) scheme is quite complex due to reference frame transformation and its high dependence upon motor parameters and speed.

The main objective of the project is speed control of permanent magnet synchronous motor through direct torque control technique. Direct torque control means direct control of torque and stator flux of drive by inverter voltage space vector selection through look up table. Actual and reference values of Torque and Flux are compared through the Hysteresis Comparator [1].

This paper proposes a system simulation model of a complete PMSM drive based on the mathematical model of an inverter fed Permanent Magnet Synchronous Motor (PMSM) implemented using MATLAB\Simulink, which could be used for simulating various control techniques. In the developed model, speed and torque as well as the voltages and currents of voltage source inverter components can be effectively monitored and analyse.

II. MATHEMATICAL MODEL OF PMSM

As to the widely known three-phase PMSM, the voltage equations for the stator windings in the stationary reference frame (a, b, c) can be written in the matrix form as

$$V_{abcs} = r_s I_{abcs} + \frac{d}{dt}\lambda_{abcs} \qquad (1)$$

where V_{abc} the stator phase voltage,
r_s the phase winding resistance,
I_{abc} the phase current, and
Λ_{abc} the flux linkage of phase winding.

Transformed to the *d-q* reference frame, which rotates with the rotor, the inductances no longerdepend on the rotor position, and the voltage and

$$\begin{cases} V_q = r_s i_q + \omega_r \lambda_d + \frac{d\lambda_q}{dt} \\ V_d = r_s i_d - \omega_r \lambda_q + \frac{d\lambda_d}{dt} \end{cases} \quad (2)$$

$$\begin{cases} \lambda_d = L_d i_d + \lambda_M \\ \lambda_q = L_q i_q \end{cases} \quad (3)$$

$$T_e = \frac{3P}{4} \lambda_M i_q \quad (4)$$

$$J \frac{d\omega_r}{dt} = \frac{p}{2}(T_e - T_L) \quad (5)$$

In the stationary stator reference frame, the model of PMSM in the rotor reference frame can be expressed as

$$\begin{cases} \lambda_q = \int (V_q - R_s i_q) dt \\ \lambda_d = \int (V_d - R_s i_d) dt \end{cases} \quad (6)$$

where,

V_q the *q*-axis voltage,
V_d the *d*-axis voltage,
i_q the *q*-axis current,
i_d the *d*-axis current,
r_s the stator resistance,
L_d, L_q the inductance,
w_r the electrical angular velocity,
λ_d, λ_q the *d-q* components of the stator flux linkage,
λ_M the permanent magnet rotor flux linkage,
P the number of poles,
J the mechanical inertia of motor, and
T_L the load torque

III. PROPOSED WORK

The principle of Direct Torque Control (DTC) techniqueis directly select voltage vectors according to the difference between actual and reference value of torque and flux linkages. Torque and flux errors are compared in hysteresis comparators. Depending on the comparison voltage space vector is selected from table. Advantages of the DTC are low complexity and that it only need to use of one motor parameter, stator resistance. No pulse width modulation is needed, instead one of the six VSI voltage space vector is applied during the whole sample period. All calculations are done in stationary reference frame which does not involve explicit knowledge of rotor position. Still for synchronous motor,at start up rotor position must be known. The DTC hence require low computational power when implemented digitally. The system possess good dynamic performance. Its simplicity makes it possible to execute every computational cycle in short time period and uses high sample frequency. For every doubling in a sample frequency, the ripple will approximately halve [4].

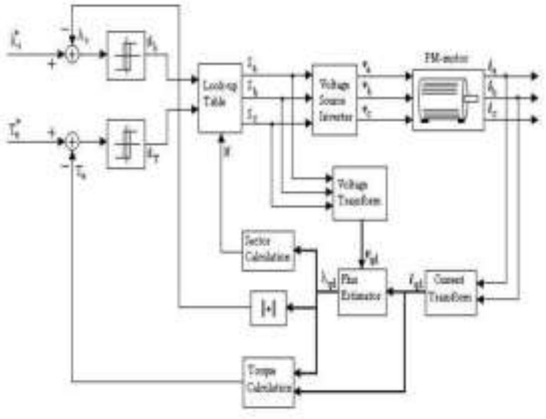

Fig. 1. Block Diagram

There are three signals which affect the control action in a DTC system i.e. torque, flux linkage and the angle of the resultant flux linkage vector. The goal of controlling the flux in DTC is to keep its amplitude within a predefined hysteresis band. Amplitude of stator flux linkage can be controlled by application of required voltage space vector. The voltage and current are sensed from the motor terminals and for calculation of flux it is converted from 3phase to 2phase. One revolution is divided into six sectors, each sector is 60^0 apart from each other. In each sector the DTC chose between 4 voltage vectors. Both flux and torque errors are compared in 2-level hysteresis comparators. Two of the vectors increase and the other two decrease torque [3]. Another pair of vectors increase and decrease flux. For each combination of the torque and flux hysteresis comparators states there is only one of the four voltage vectors which at the same time compensate torque and flux as desired.

For calculation of flux voltage V_{abc} is transformed to its quadrature and direct axes according to the Park's Transformation. As seen in figure 1 only two of the input currents are sensed. The motor in a drive system is normally operated with its neutral point floating, in this case $i_a + i_b + i_c = 0$, so the current not sensed is given of them other two. The i_{abc} current is transformed to its quadrature and direct axes components according to the Park's Transformation [3].

Park's transformation is given by,

$$\begin{bmatrix} Vq \\ Vd \\ Vo \end{bmatrix} = Ks \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (7)$$

Where,

$$Ks = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{\pi}{3}\right) & \cos\left(\theta + \frac{\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{\pi}{3}\right) & \sin\left(\theta + \frac{\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (8)$$

Similar transformation is applied for current transformation. The zero component is left out since, when the neutral floats there is no need to consider it. After this transformation we get quadrature and direct axes components of voltage and current [5].

.The control action taken by the DTC control technique is based on the states of the flux and torque hysteresis comparators. Flux is increased by applying a vector pointing in the flux λ_{qd} direction and torque is increased by applying vector pointing in the rotational direction. In order to do this, the angular position of the stator flux vector must be known so that DTC technique can choose between an appropriate set of vectors depending on the flux position. There are 6sectors and each sector spans 60^0 as shown in fig 3. During sampling interval time or switching interval, one of the six voltage vectors is applied as shown in fig 2[1].

The goal of controlling flux in DTC technique is to keep its amplitude within the predefined hysteresis band. Amplitude of stator flux linkage can be controlled by application of required voltage space vector. To select the voltage space vectors for controlling amplitude of the stator flux linkages, voltage plane is divided into six regions.

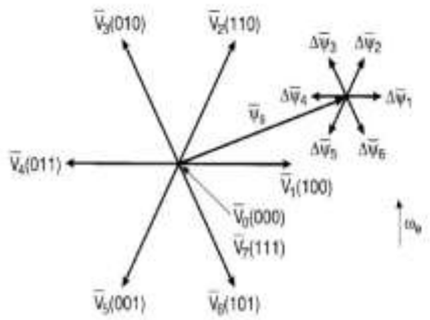

Fig. 2. Voltage Space Vector

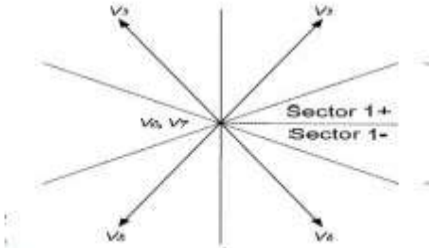

Fig. 3. Sector

Now we know in which sector is the flux and its norm, and we also know how much torque motor develops. Estimated torque and flux values are compared with reference values. The difference between actual and reference value is compared the in hysteresis comparator as shown in Fig 4.

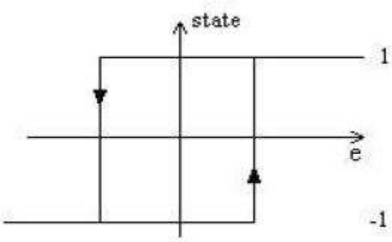

Fig. 4. Hysteresis Controller

The hysteresis comparator states H_ψ & H_{Te}, together with sectors are now used by the look up table to choose an appropriate voltage vector as shown in Table 1.

H_ψ	H_{Te}	S(1)	S(2)	S(3)	S(4)	S(5)	S(6)
1	1	V_2 (110)	V_3 (010)	V_4 (011)	V_5 (001)	V_6 (101)	V_1 (100)
	0	V_0 (000)	V_7 (111)	V_0 (000)	V_7 (111)	V_0 (000)	V_7 (111)
	−1	V_6 (101)	V_1 (100)	V_2 (110)	V_3 (010)	V_4 (011)	V_5 (001)
−1	1	V_3 (010)	V_4 (011)	V_5 (001)	V_6 (101)	V_1 (100)	V_2 (110)
	0	V_7 (111)	V_0 (000)	V_7 (111)	V_0 (000)	V_7 (111)	V_0 (000)
	−1	V_5 (001)	V_6 (101)	V_1 (100)	V_2 (110)	V_3 (010)	V_4 (011)

Table 1. Switching table

A high hysteresis state increases the corresponding quantity and vice versa. The selected voltage space vector is sent to Voltage Source Inverter in suitable format and then synthesized.

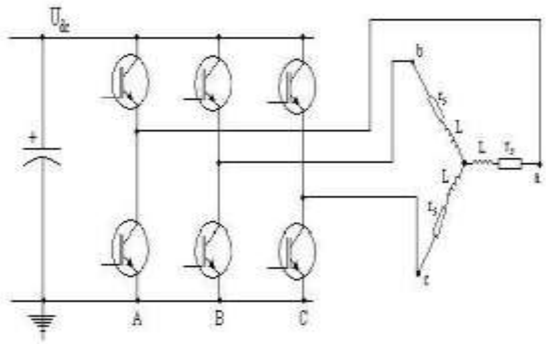

Fig 5. Voltage source inverter

The Voltage Source Inverter synthesizes the voltage vector commanded by the look up table block. In case of DTC this task is quite simple since no pulse width modulation is used. The output devices stay in the same state during the entire sampling period. Fig. 5 shows a simplified sketch of VSI output stage and how motor winding is connected [6]. The output signals from lookup table block in fig 1. are named as $S_a, S_b \& S_c$. These are the boolean variables indicating the switch state in the inverter output branch. Let $S_i = 1$ when the high or upper switch is on and lower is off, and $S_i = 0$ when the lower is on and upper is off. The voltage vector obtained in this way is shown in fig 5. There are six non-zero voltage vectors i.e. V_1(100), V_2(110), V_3(010), V_4(011), V_5(001), V_6(101) and two zero voltage vectors V_0(000), V_7(111).

IV. SIMULATION RESULT

In order to verify the performance of PMSM DTC system, simulation model was built usingMATLAB/Simulink software.The motor parameters used are: Rs=0.2; Ld & Lq= 0.0085H; J=0.089; B=0.005; P=4.The reference speed is 200rpm set as shown in fig 6. Simulation results of the developed model is shows in fig 7.i.e. actual speed of PMSM. Fig 8 shows comparison between actual and reference speed of PMSM. The flux linkage wave of the developed simulation is shown in fig9.Now we set reference speed at two different values i.e. 150rpm and 200rpm respectively as shown in fig10. Actual speed of permanent magnet synchronous motor is shown in fig11. Comparison between actual & reference speed in shown in Fig 12.

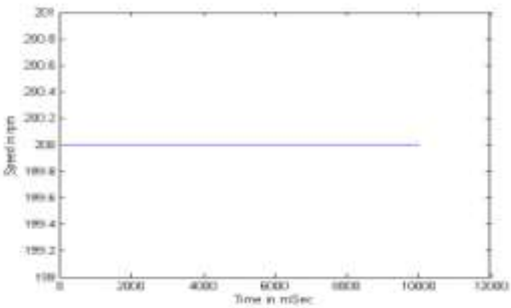

Fig. 6. Reference Speed at 200rpm

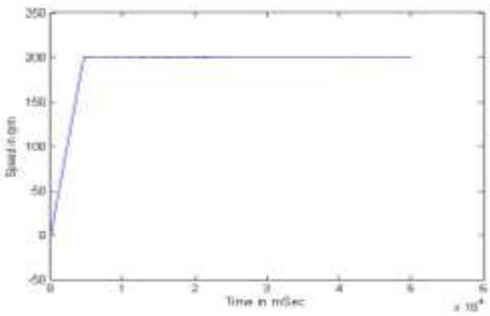

Fig. 7. Actual Speed of PMSM

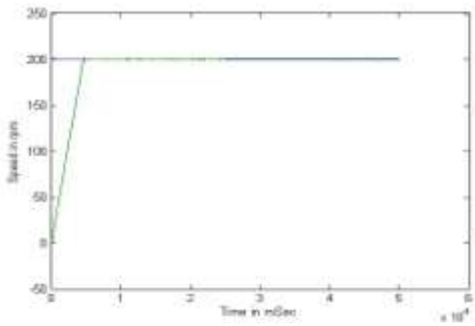

Fig. 8. Comparison of Actual & Reference Speed

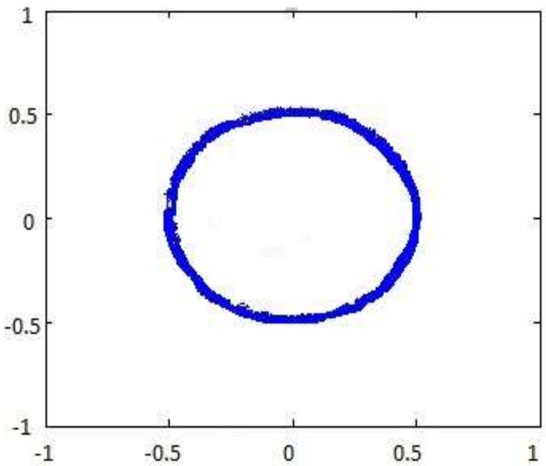

Fig. 9. Flux linkage wave

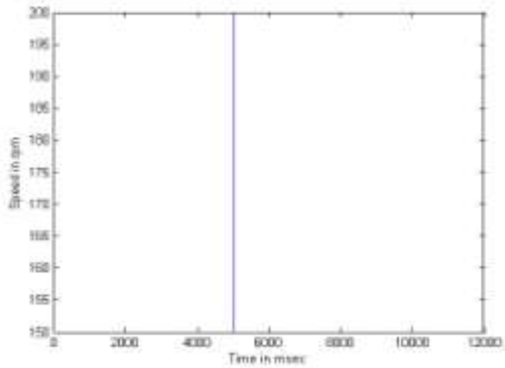

Fig. 10. Reference Speed at 150rpm & 200rpm

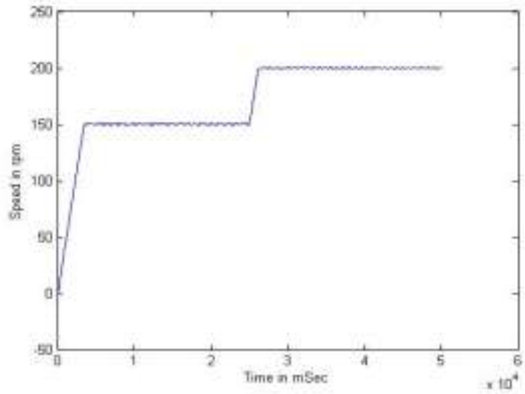

Fig. 11. Actual Speed of PMSM

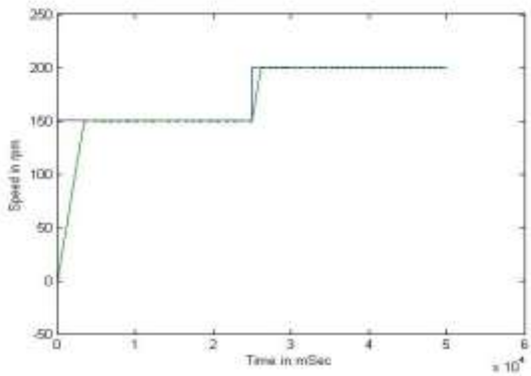

Fig. 12. Comparison of Actual & Reference Speed

V. CONCLUSION

A simulation model of closed loop PMSM drive system has been developed by utilizing the mathematical model of PMSM and hysteresis controlled three phase VSI inverter. Simulation results have shown that steady-state performance of the system has been significantly improved. System robustness has been enhanced, and the electromagnetic torque and flux linkage ripples are reduced significantly. This developed model can be well utilized in the design and development of closed loop PMSM drives system for experimenting with different control algorithms and topological variations but with a much reduced computational time and memory size.

VI. REFERENCES

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