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Direct Torque Control (DTC) of PMSM Using Space Vector Modulated Inverter: A Simulink Approach

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***Abstract*— In order to improve the dynamic performance of PMSM, a Direct Torque Control (DTC) scheme of Permanent Magnet Synchronous Motor (PMSM) is presented. Based on in depth analysis of PMSM, mathematical model and the operation principle of DTC system, Matlab /Simulink is used to establish a simulation model of this system, and extensive research of simulation is conducted. Simulation results show that the DTC System of PMSM has fast response and good dynamic performance, which verify correctness and feasibility of this system. In this paper, for a torque drive with hysteresis controller in the current control loop will be implemented in MATLAB.**

***Index Terms*— PMSM, Flux Linkage Estimation, DTC.**

I. INTRODUCTION

The PMSM has numerous advantages over other machines that are conventionally used for ac servo drives. The stator current of an induction motor contains magnetizing as well as torque producing components. The use of the permanent magnet in the rotor of the PMSM makes it unnecessary to supply magnetizing current through the stator for constant air gap flux; the stator current need only be torque – producing. Hence for the same output, the PMSM will operate at higher power factor and will be more efficient than the IM. The conventional wound rotor synchronous machine, which is often supplied by brushes and slip rings. The reason for development of the PMSM was to remove the foregoing disadvantages of the SM by replacing its field coil, dc power supply, and slip rings with a permanent magnet. The PMSM, therefore, has a sinusoidal induced EMF and requires sinusoidal currents to produce constant torque.

PMSM drive has gained an increasing popularity in low and medium poor applications such as computer peripheral equipments, robotics, adjustable speed drives and electric vehicles are due to its following merits: high torque/inertia ratio, high power density and high efficiency etc. however the dynamic performance of VSI fed PMSM drive system largely depends on the applied current control strategy. The main function of current controller is to force the load current to follow the reference current trajectory in order to minimize the current error. In this paper, hysteresis controller is proposed in the inner loop of vector control of PMSM drive system.

II. MATHEMATICAL MODEL OF PMSM

The vector relationships of stator flux linkage, voltage and current are shown in fig 1. The dq coordinate and is fixed on the rotor rotational coordinate is fixed on the rotor rotational coordinate and the positive direction of d is the direction of rotor flux.

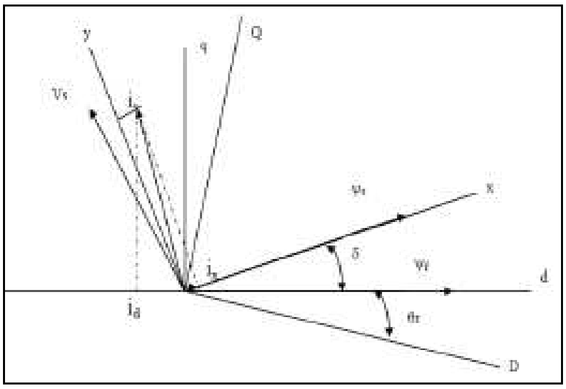

Fig. 1: Vector diagram of PMSM

The xy coordinate is fixed on the stator rotational coordinate and the positive direction of x is direction of stator flux linkage .The angle between stator flux and rotor flux is defined as load angle when the stator resistance is neglected. So the relations of flux linkage, voltage and electromagnetic torque of PMSM are described as follows.

$$V_d = R_d\, i_d + d/dt\,(\Psi_d) - \omega_r\, \Psi_q$$

$$V_q = R_q\, i_q + d/dt\,(\Psi_q) + \omega_r\, \Psi_d$$

$$\Psi_d = L_d\, i_d + L_m\, i_f$$

$$\Psi_q = L_q\, i_q$$

$$T_e = (3/2)\, N_p\, [\Psi_q\, i_q - (L_q - L_d)\, i_d * i_q]$$

Where φd and φq are the stator flux linkages, ud and uq are phase voltages, id and iq are currents, Ld and Lq are inductances in the rotational d-q coordinate respectively. and Rs, ω,φf, Te, Np,δ,θ and p are stator resistance, angular velocity, permanent rotor flux linkage, electromagnetic torque, pairs of poles, load angle, rotor position and differential operator respectively.

According to the classical theory of electrical machines, the PMSM drive system is equivalent to that of the dc motor when a decopling control is possible known as vector control. The vector control decouples the torque component and flux producing current in the motor through its stator excitation by applying instantaneous space vector theory. The vector control of the PMSM is derived from its dynamic dq model considering the currents as inputs the phase currents are given by

$$I_a = I_m \sin(\omega r t + \delta)$$

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$I_b = I_m \sin(\omega rt + \delta - 2\pi/3)$

$I_c = I_m \sin(\omega rt + \delta + 2\pi/3)$

Where δ is the angle between the rotor field and stator.

The currents assigned above are the stator currents that must be transformed to the rotor reference frame with the rotor speed ωr. Using park's transformation the q and d axis currents are constants in the rotor reference frame .since δ is a constant for a given load torque. Solving by using park's transformation,

$I_q = Im \sin \delta$

$I_d = Im \cos \delta$

From the above equations electromagnetic torque is obtained by

$Te = (3/2)(p/2)[1/2(L_d - L_q) I_m * I_m \sin 2\delta + \varphi f Im]$.

III. Hysteresis Current Controller Design

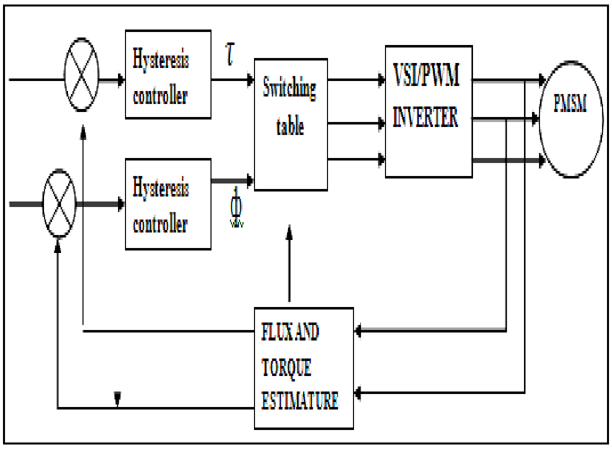

Fig. 2: Hysteresis Current Controller Schematic

In the vector control scheme, the current controller has direct influence on the device performance and its design requires special considerations. The basic requirements from the current controllers are low harmonics to reduce losses, low noise in the motor and fast response in order to provide high dynamic performance.

In the hystresis current controller, load current ia, ib and ic are forced to follow the reference currents ia*,ib* and ic* respectively, within a hysteresis band by the switching action of the inverter. The upper and lower bounds of the hysteresis band are set for the motor current, and the hysteresis controller logic control can be described according to the following rules.

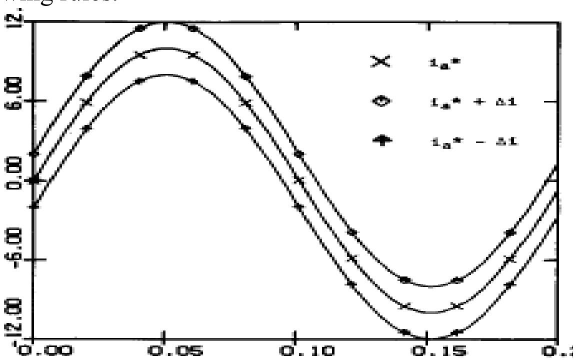

Fig. 3: Current Bands for Hysteresis Controller

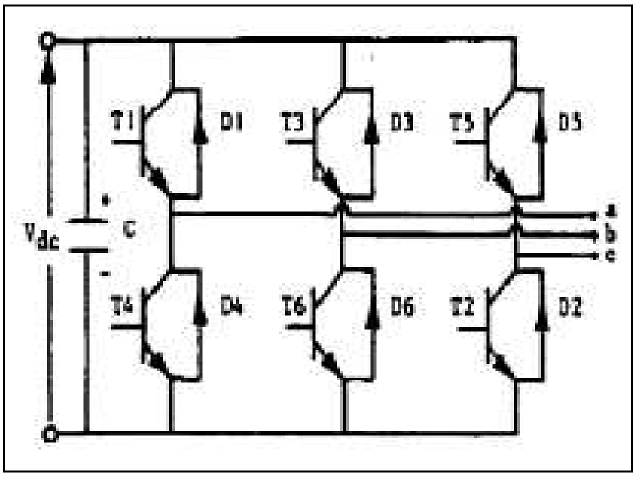

Fig. 4: Inverter Power Circuit

The power circuit that drives the PMSM is shown in fig. The six switches T1-T6 are used to control the three stator phase currents. The control strategy is as follows.

The actual values of ia and ib that are flowing into the motor are measured. From this ic can be constructed; this removes the need for an additional current sensor. The actual and reference values are compared and error signals generated. The hysteresis property allows the actual value of ia to exceed or be less than the reference value by delta i. Similar logic applies to the other two phases.

IV. Space Vector Approach

For a particular time period, the stator space voltage vector may be in one of the six areas which are divided by the six basic space voltage vectors. Supposing that the stator space voltage vector is in the first sector, As shows that the stator space voltage vector can be synthesized by two adjacent basic nonzero space voltage vectors U1, U2 and two zero vectors U0, U7. One of the six VSI voltage vectors is applied during the whole sample period No pulse width modulation is needed The Input To The Stator Winding Of PMSM And Switching Status Of The VSI Obtained By Optimum Voltage Vector Selection Table .The Phase Voltage Of The PMSM Are Obtained From The Switching Status Of VSI And Dc Link Voltage. The Optimum Voltage Vector Selection Is Shown In Table-I

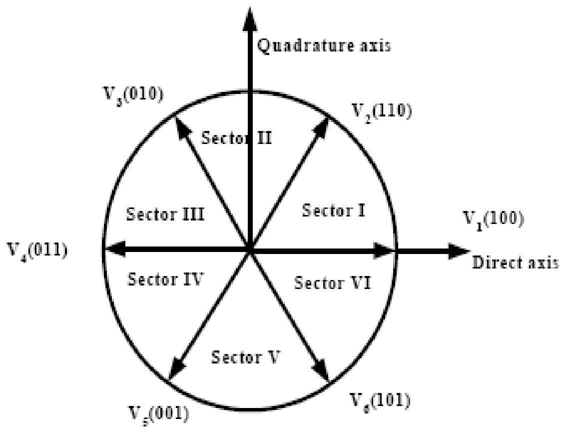

Fig. 5: Sectors of Stator Flux Linkage Space Vector

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TABLE I: Switching table for selection of inverter optimum voltage.

FLUX ERROR $d\phi_s$	TORQUE ERROR dTe	SECTOR I	II	III	IV	V	VI
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_8	V_7	V_8	V_7	V_8	V_7
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_7	V_8	V_7	V_8	V_7	V_8
	-1	V_5	V_6	V_1	V_2	V_3	V_4

V. SIMULATION RESULTS

The dynamic performance of a torque controlled drive with hysteresis current controller, simulation results is shown below.

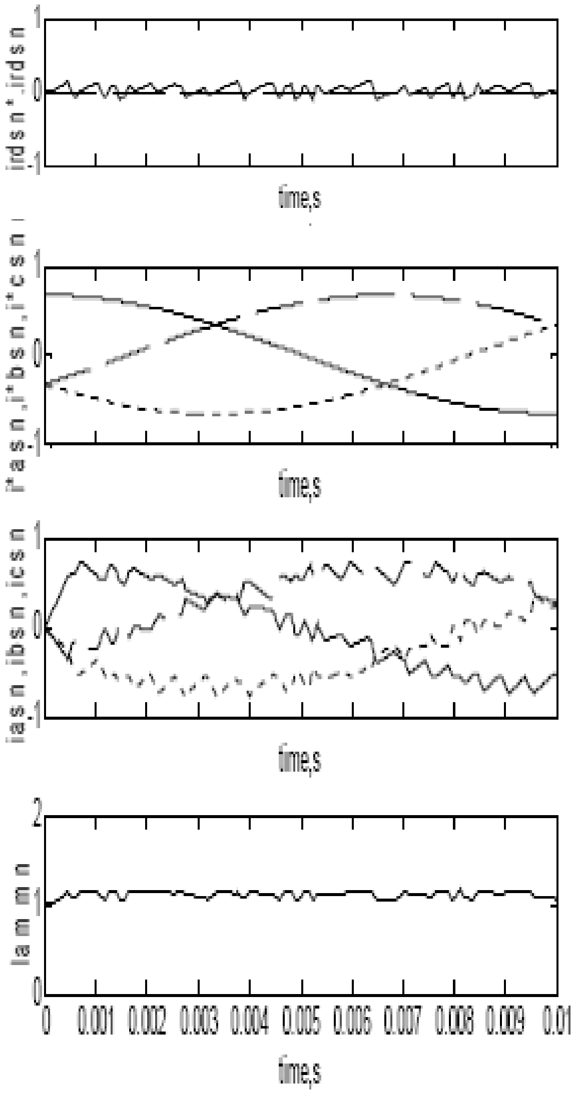

Fig. 6: Simulation Result for Stator Currents

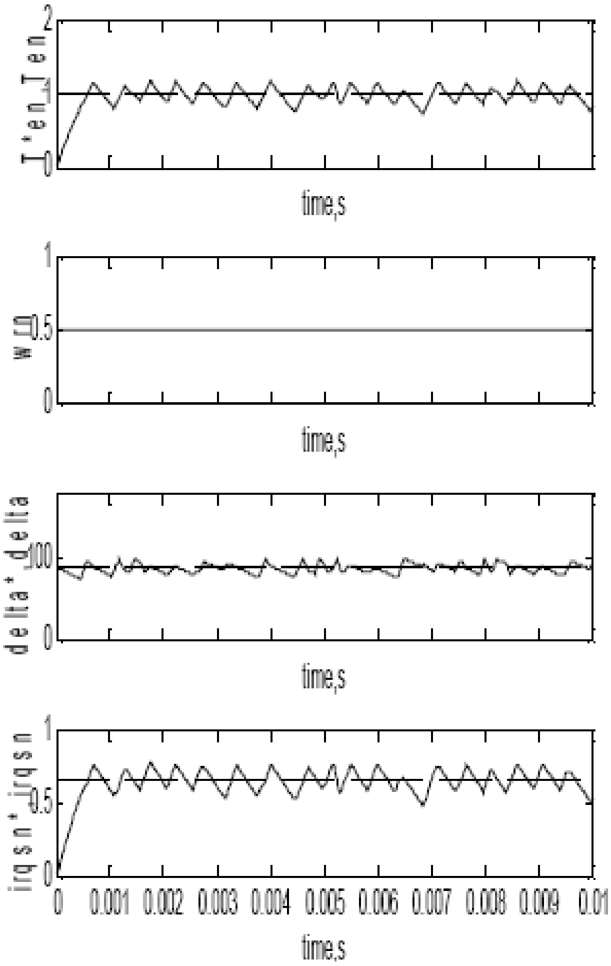

Fig. 7: Simulation Result for Torque, speed, load angle

VI. CONCLUSION

The PMSM modeled in MATLAB by writing the program with the parameters in APPENDIX. The simulation results for a torque drive, maintained at a speed 0.5p.u. is shown in fig. with a hysteresis controller in the current control loop. The current window is set at 0.1p.u. rather a large value but very handy to illustrate the pulsations in torque. Because of the high current ripple on the q axis current, the torque ripple is also high in proportion. The current controllers force the currents to follow their respective references with very little delay, a distinct advantage with the hysteresis current controller.

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APPENDIX

S No.	Parameter	Values
1	P	4
2	R_s	1.4
3	L_d	0.0032
4	L_q	0.007
5	L_{amaf}	0.152
6	B	0.01
7	J	0.007
8	V_{dc}	285
9	W_{r_ref}	314.3