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# Direct Torque Control Of Permanent Magnet Synchronous Motor

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*Abstract—The DTC of PMSM is a kind of self control mode for its stator flux linkage and torque. It is very important that if stator flux linkage can be observed well and because the accuracy of the observer for stator flux linkage directly affects the performance of the DTC system of PMSM.*

*In this paper, for a torque drive with hysteresis controller in the current control loop will be implemented by writing a MATLAB program.*

## I. INTRODUCTION

The permanent magnet synchronous motor 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 power 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. The proposed scheme is modeled by writing the program in MATLAB.

## II. MATHEMATICAL MODEL OF PMSM:

### Vector Diagram of PMSM:

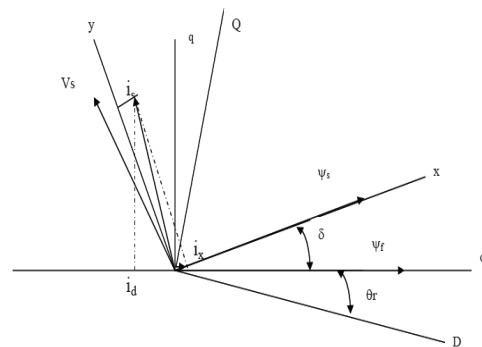


Fig 1. Vectors of PMSM

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

direction of d is the direction of rotor flux. The x-y 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  $\Psi_d$  and  $\Psi_q$  are the stator flux linkages,  $u_d$  and  $u_q$  are phase voltages,  $i_d$  and  $i_q$  are currents,  $L_d$  and  $L_q$  are inductances in the rotational d-q coordinate respectively. and  $R_s$ ,  $\omega$ ,  $\phi_f$ ,  $T_e$ ,  $N_p$ ,  $\delta$ ,  $\theta$  and  $p$  are stator resistance, angular velocity, permanent rotor flux linkage, electromagnetic torque, pairs of poles, load angle, rotor position and differential operator respectively.

**Vector control of PMSM drive system:**

According to the classical theory of electrical machines ,the PMSM drive system is equivalent to that of the dc motor when a decoupling 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 d-q model. considering the currents as inputs. the phase currents are given by

$$I_a = I_m \sin(\omega_{rt} + \delta)$$

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

$$I_c = I_m \sin(\omega_{rt} + \delta + 2\pi/3)$$

Where  $\delta$  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  $\omega_r$ . using park's transformation the q and d axis currents are constants in the rotor reference frame .since  $\delta$  is a constant for a given load torque. solving by using park's transformation, we get

$$I_q = I_m \sin \delta$$

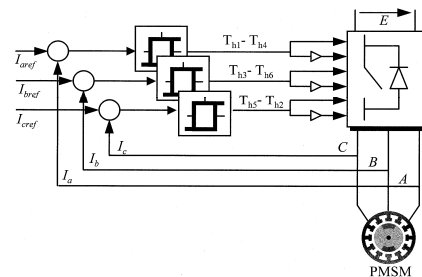
$$I_d = I_m \cos \delta$$

From the above equations electromagnetic torque is obtained by

$$T_e = (3/2)(p/2)[1/2(L_d - L_q) I_m \sin 2\delta + \phi_f I_m].$$

**CURRENT CONTROLLER DESIGN:**

**HYSTERESIS CURRENT CONTROLLER:**



Fig(1)

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 hysteresis current controller, load current  $i_a$ ,  $i_b$  and  $i_c$  are forced to follow the reference currents  $i_a^*$ ,  $i_b^*$  and  $i_c^*$  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.

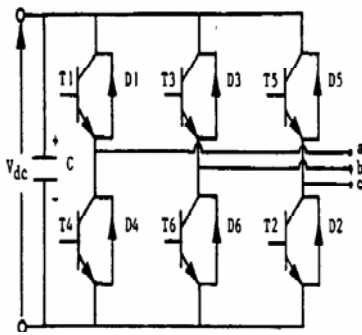
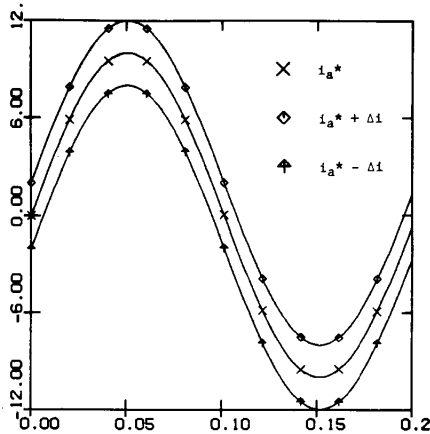


Fig 2 Power circuit

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  $i_a$  and  $i_b$  that are flowing into the motor are measured. From this  $i_c$  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  $i_a$  to exceed or be less than the reference value by  $\Delta i$ . Similar logic applies to the other two phases.

**CONCLUSION:**

The PMSM modeled in MATLAB by writing the program with the parameters in APPENDIX.

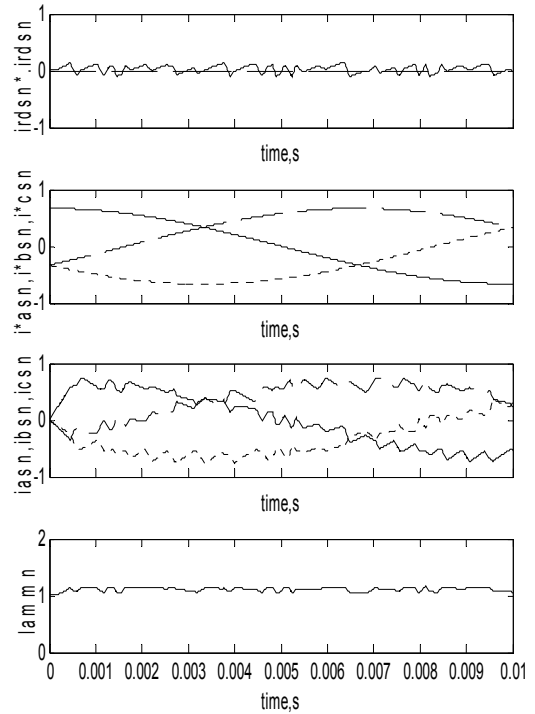
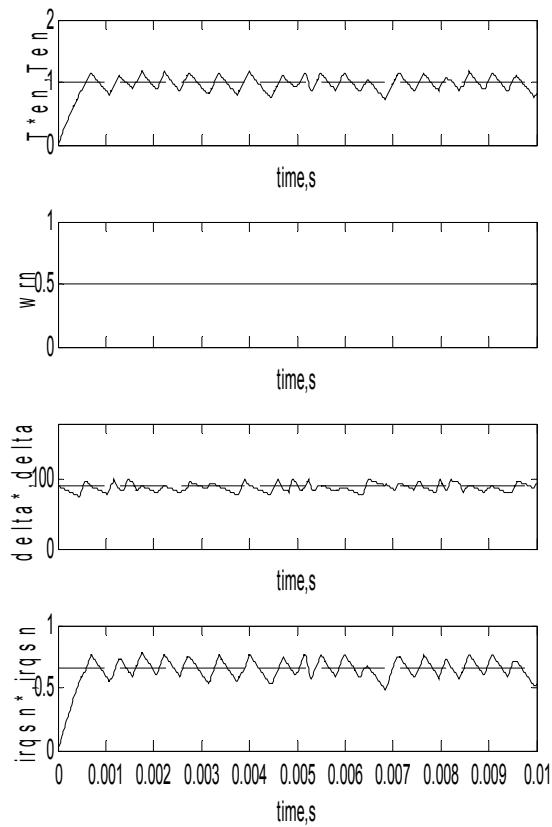
The simulation results for a torque drive, maintained at a speed 0.5p.u. is shown in fig. with a hysteresis controller in the current control loop. The current window is set at 0.1p.u. rather a large value but very handy to illustrate the pulsations in torque. Because of the high current ripple on the 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.

**APPENDIX**

1	P	6
2	Rs	1.4
3	Ld	0.0056
4	Lq	0.009
5	Lamaf	0.1546
6	B	0.01
7	J	0.006
8	Vdc	285
9	W <sub>r_ref</sub>	314.3

**SIMULATION RESULTS:**

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



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