HARDWARE IMPLEMENTATION OF MTPA FOR SPMSM-DSP BASED

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Abstract:- *In this paper, the maximum torque per ampere (MTPA) using vector control (VC) has been implemented on a surface permanent magnet synchronous motor (SPMSM). A complete hardware setup based on the digital signal processor (DSP) has been constructed to verify the MTPA concept. Texas F28335 DSP will be used for executing the control algorithm and MATLAB Target Support Package has been used to write the code. A serial communication will be used for sending the desired value of the speed and to collect the readings via the DSP. In addition to executing the MTPA concept, the DSP has been used to act as a data acquesition to collect those data that don't need high scan rate.*

Key words: PMSM, MTPA, DSP, MATLAB.

1. Introduction

Due to the advantages of the Permanent Magnet Synchronous Motors (PMSM) the application of PMSMs has greatly broadened [1]. The zero rotor copper loss is that results in higher efficiency, the high torque and output power/volume that results in compact design and the simplicity in construction and maintenance are some of the PMSM advantages. Robotics, aerospace, power tools, generation with renewable energy source, various medical equipment and electric/hybrid vehicles etc are some of the applications that can be established based on PMSM. Because of its many advantages, the permanent magnet machines are preferred over other traditional machines such as brush commutated DC motor, synchronous motor and induction motor especially for highly efficient servo and variable speed drive applications [1]. PMSM control can be controlled using different approaches; scalar control and vector control are possible methods for PMSM motors control [2-7].

2. PM Machines Configurations

In a Permanent Magnet (PM) machine, the field excitation comes from the permanent magnet pole pieces. Depending on working principles, the PM machine can be categorized broadly into three main groups; brush commutated PMDC machines, brushless PMDC machine and brushless PMAC or PM Synchronous Machine (PMSM). The brush-commutated PMDC machine is the DC machine in which electromagnetic field has been replaced by the permanent magnet field. In such machines, permanent magnet poles are situated on the rotating part and the stator consists of three-phase windings that are fed with square waveforms from three-leg converters. The switching of the converter is controlled in such a way that at one time only two phases conduct. This electronic commutation scheme is functionally equivalent to the mechanical brush commutation of the DC machine. Hence, this type of PM DC machines is known as brushless PMDC machines or square-wave PMDC machines. The brushless PM DC machine is preferred for many applications because of its low maintenance, high efficiency and relatively simple switching scheme. The brushless PM AC machine also has permanent magnet poles in the rotating part and the stator or armature consists of the three-phase, sine-distributed windings. The machine operates with the principle of synchronous rotating magnetic field, hence, they are also known as PM Synchronous Machine (PMSM) [5].

3. PMSM rotor configurations

The PM synchronous machines are built with a number of rotor configurations. Among them, interior and surface magnet rotors are the two most commonly used configurations. In the interior permanent magnet (IPM) structure, magnet poles are buried inside the rotor where as in the surface magnet rotor, the magnet poles are glued to the rotor surface as shown in the Fig. 1 (a) and (b). In this paper implementation of CPSR on the surface-PMSM will be discussed, however same concept can be modified and implemented for IPM also.

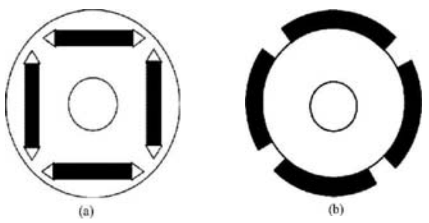

Fig. 1. Cross-section of the (a) IPM rotor (b) Surface Permanent Magnet rotor.

4. MATHEMATICAL MODEL OF A PMSM FOR VECTOR CONTROL

The mathematical model of a PMSM drive can be described by the following equations in asynchronously rotating rotor d-q reference frame as [2-5],

$$v_d = R_s i_d + \frac{d\phi_d}{dt} - \omega_e \phi_q \tag{1}$$

$$v_q = R_s i_q + \frac{d\phi_q}{dt} + \omega_e \phi_d \tag{2}$$

And,

$$\phi_d = (L_{ld} + L_{md}) i_d + \phi_{PM}$$
$$\phi_d = L_d i_d + \phi_{PM} \tag{3}$$

$$\phi_q = (L_{lq} + L_{mq}) i_q = L_{lq} i_q \tag{4}$$

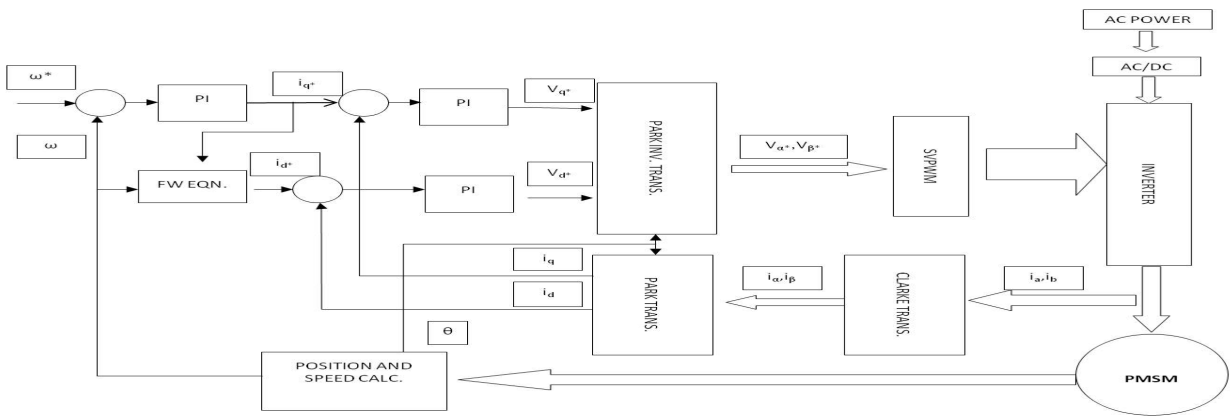

Fig. 2. Basic scheme of the FOC.

R_s : Stator winding resistance [Q]

i_d, i_q : d and q axes currents [A]

v_d, v_q : d and q axes voltages [V]

ϕ_d, ϕ_q : d and q axes stator flux linkage [Wb]

L_{ld}, L_{lq} : d and q axes leakage inductance[H]

L_{md}, L_{mq} : d and q axes magnetizing inductance [H]

L_d, L_q : d and q axis stator inductances [H]

ω_e : Electrical speed in rad/sec

ω_r : Mechanical rotor speed in rad/sec

P : number of pole pairs

Equations 1 and 2 can be rewritten as;

$$v_d = R_s i_d + L_d \frac{di_d}{dt} - \omega_e L_q i_q \tag{5}$$

$$v_q = R_s i_q + L_q \frac{di_q}{dt} + \omega_e L_d i_d + \omega_e \phi_{PM} \tag{6}$$

Where;

$$\omega_e = P\omega_r \tag{7}$$

At steady state;

$$v_d = R_s i_d - \omega_e L_q i_q \tag{8}$$

$$v_q = R_s i_q + \omega_e L_d i_d + \omega_e \phi_{PM} \tag{9}$$

The well-known electro-magnetic torque equation of the electric machine in the d-q synchronous reference frame is;

$$T_e = \frac{3}{2} p (\phi_d I_q - \phi_q I_d) \tag{10}$$

This equation can be expressed in terms of machine parameters of the PM machine as:

$$T_e = \frac{3}{2} p [\phi_{PM} I_q + (L_d - L_q) I_d I_q] \tag{11}$$

In surface PMSM L_d=L_q=L_s, equation 11 can be reduced to:

$$T_e = \frac{3}{2} p \phi_{PM} I_q \tag{12}$$

5. Simulation Results of MTPA Using Vector Control

FOC scheme shown in figure 2 has been implemented using MATLAB. Step-up speed set-point has been applied to the motor, and then the rated torque has been applied after 2 seconds. Figure 3 shows the simulation results. It can be seen that the rated speed has been achieved quickly and when the load has been applied the controller has changed the i_q set-point as shown to develop the required torque. The change in the applied torque and how it has been achieved is shown also. The change in the stator current from the no load value to the rated value once the torque has been requested can be seen. i_d still zero in all cases that achieving the MTPA for the SPMSM.

6. Hardware Implementation of MTPA Using Vector Control

Figure 2 shows the basic scheme of the field oriented control. As equation 3 shows that the delivered torque by the PMSM is based on the quadrature current only the MTPA can be achieved by forcing the direct current to be zero. Using the basic sheme shown in figure 2, i_q reference will be deduced from the speed controller while i_d reference will be set to zero. FOC block diagram shown in figure 2 have been implemented using the MATLAB Target Support Package software to execute the applications on Texas F28335 eZdsp. Figure 3 shows the block diagram of the FOC as implemented in MATLAB and deployed to the DSP. The DSP serial communication cababilities have been used for sending the speed setpint from the PC and for collecting the reference and actual reading of the speed, reference and actual reading of i_q and finally thereference and actual reading of i_d. Figure 4 shows the complete hardware setup as it has been used.

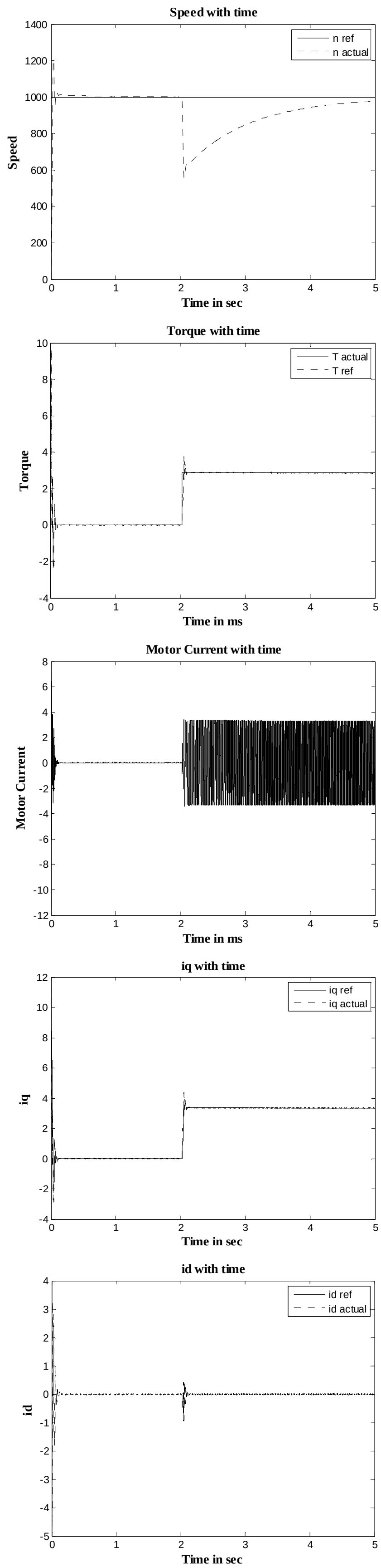

Fig. 3. Simulation results.

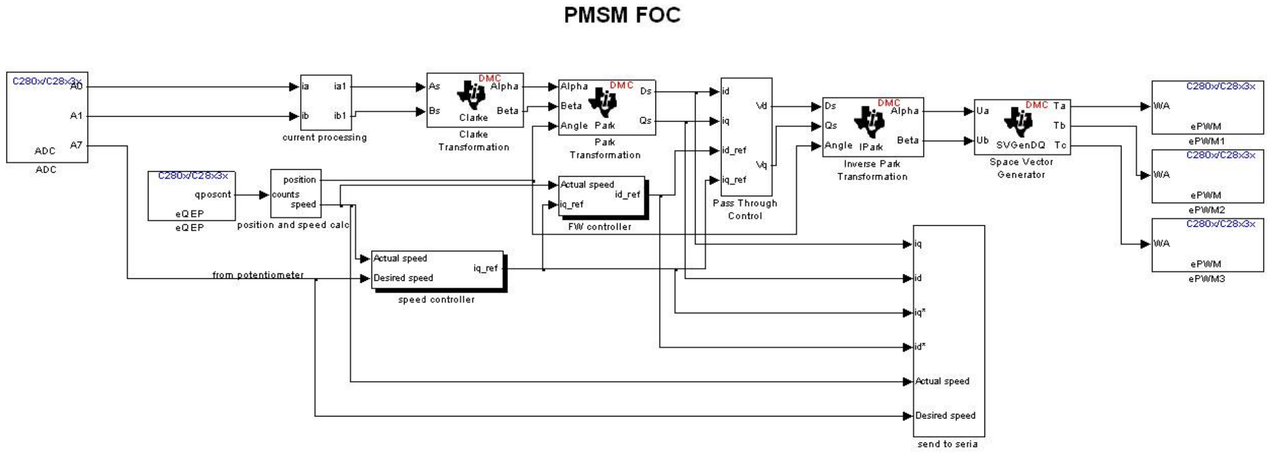

Fig. 4. FOC block diagram in MATLAB .

Table 1 Motor parameters

Motor rated power Rated (P_r)	3-phase, 300watt
Rated current	2.5A
Rated speed	1000 rpm
Pole pair number (P)	5
Stator inductance, L_s($L_q = L_d = L_s$)	14.29 mH
Stator resistance, R	1.06Ω
Magnetic flux constant, ϕ_{PM}	42.5V/1000 rpm

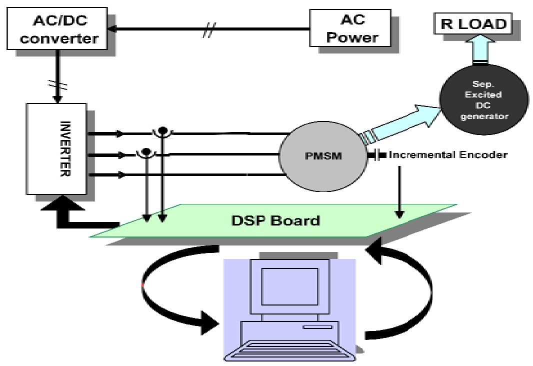

Fig. 5. Complete Hardware setup.

7. Experimental results

PMSM with those parameters listed in table 1 has been coupled with a DC generator as shown in figure 4. This setup has been deriven using the DSP where the MATLAB program has been deployed. Figure 5 shows a step-up change in the speed and the effect on i_d and i_q. it can be noticed that there is no change in i_d however i_q increased slightly. Figure 6 shows a step-down change in the speed and the effect on i_d and i_q. it can be noticed that there is no change in i_d however i_q decreased slightly. Figure 7 shows the motor speed at two instants, as the load has been added and as it has removed. As it can be seen that the speed decreased as the motor increased, however the controller increased the i_q reference as to return the motor to the requered speed. It is important to note that i_d still equalls to zero and the motor delivered the required torque which means that the MTPA concept is verified. Motor loading has been doubled and the instant of adding the load is shown in Figure 8, however the instant of removing the load is shown in Figure 9. Same response as figure 7 can be noticed in both figure 8 and figure 9.

8. Conclusions

A complete hardware implementation has been constructed to verify the MTPA on a surface permananet magnet synchronous motor bsed on the FOC. Theory of the FOC has been verified at different speeds and at both loading and no-loading cases. Doftware has been implemented using MATLAB Target Support Package and deployed on the Texas F28335 DSP. DSP Serial port has been used to send the speed setpoint and to collect the reading which is saving time. Readings have shown that; controller has succeed to achieve the required speed by changing i_q to develop the required torque, however i_d has been kept at zero level for all conditions to keep motor running with the MTPA.

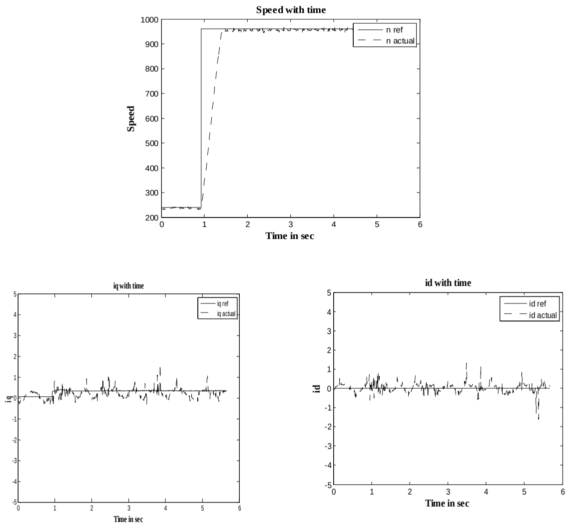

Fig. 6. Speed, i_d and i_q - Speed step-up change at No-load

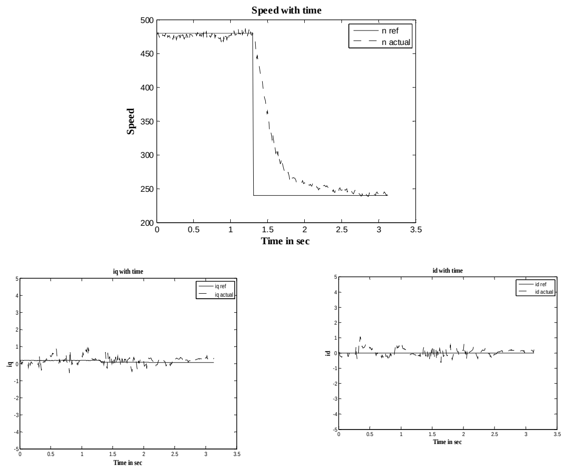

Fig. 7. Speed, i_d and i_q - Speed step-down change at No-load

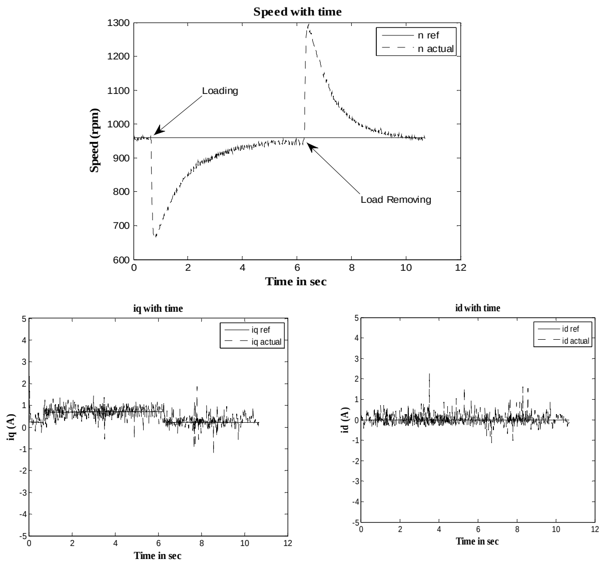

Fig. 8. Speed, i_d and i_q - Speed change adding load

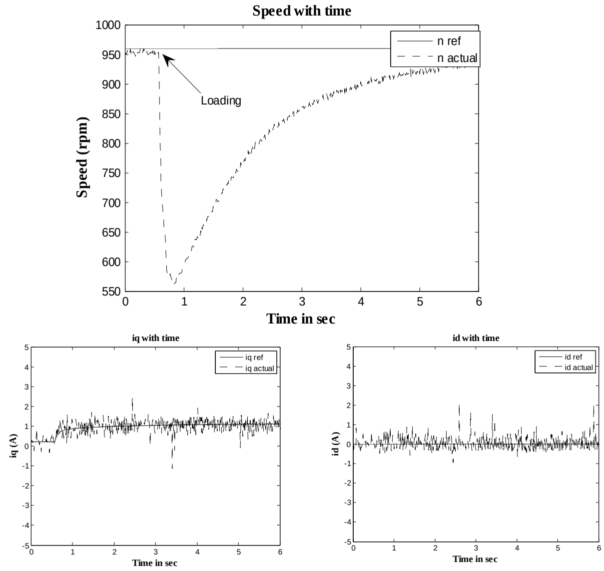

Fig. 9. Speed, i_d and i_q - Speed –removing load

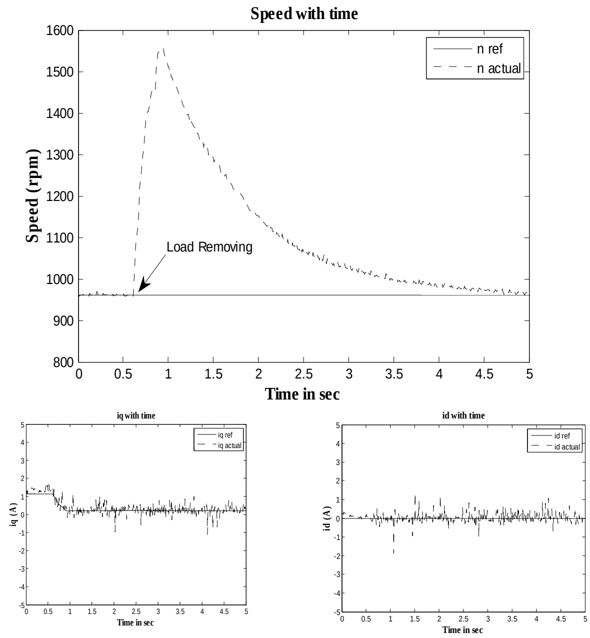

Fig. 10. Speed, i_d and i_q - Speed –adding load @900rpm

REFERENCES

[1] Pillay, P. and Krishnan, R. “Application characteristics of permanent magnet synchronous and brushless DC motors for servo drives” Journal of ELECTRICAL ENGINEERING, VOL. 27, NO. 5, 1991, 986 - 996, ISSN 0093-9994.

[2] Marek Stulrajter, Val´eria Hrabovcov´a, and Marek Franko, “permanent magnets synchronous motor control theory” Journal of ELECTRICAL ENGINEERING, VOL. 58, NO. 2, 2007, 79–84, ISSN 1335-3632.

[3] Kaewjindam W Konghirun, M. “A DSP - Based Vector Control of PMSM Servo Drive Using resolver Sensor” TENCON 2006. 2006 IEEE Region 10

Conference, 14-17 Nov. 2006, pages 1-4, ISBN: 1-4244-0548-3.

[4] Kye-Lyong Kang, Jang-Mok Kim, Keun-Bae Hwang and Kyung-Hoon Kim, “Sensorless control of PMSM in high speed range with iterative sliding mode observer” Applied Power Electronics Conference and Exposition, 2004. APEC '04. Nineteenth Annual IEEE, VOL. 2, 1111 – 1116, ISBN: 0-7803-8269-2.

[5] Rukmi Dutta, “A Segmented Interior Permanent Magnet synchronous Machine with Wide Field-Weakening Range”, PhD thesis, The University of New South Wales, August, 2007.

[6] Osama Mohammed “Sensorless Control Of Brushless Dc Motor”, PhD thesis,Cairo University, September, 2004.

[7] Bimal K. Bose, “Modern Power Electronics and AC Drives”, ISBN 0-13-016743-6,2002.