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Speed and Torque Control Challenge of PMSM

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ABSTRACT

This paper presents modeling and implementation Challenge of speed toqrue rotor field oriented control of permanent magnet synchronous machine (PMSM)drive. An experimental setup consisting of IGBT inverters and a -TMS320LF240 DSP based digital controller is developed in the laboratory in IIT Kharagpur to implement the control algorithms. A voltage model based flux observer is used for estimating the speed and position of PMSM. In order to get good starting characteristics a rotor initial position algorithm is also implemented in the control algorithm. For control purpose PMSM is consider like dc motor. The torque and speed in the dc motor can be controlled independently by controlling armature current and field current respectively ensures that dc motor has good dynamic performance.

KEYWORDS: *Permanent magnet synchronous machine (PMSM),Digital signal process(DSP),Insulated gate bipolar tranistor(IGBT).*

I. INTRODUCTION

This paper shows Power consumption by electric motor in Worldwide, lots of the electricity is consumed by motors used in powers industrial facilities. According to report, the motor systems are responsible for 63% of all electricity consumed by industry and electric bill represents more than 97% of total motor operating costs. Rapidly increasing energy cost and global interest in reducing carbon dioxide emissions are encouraging industry to pay more attention to high-efficiency motors.

Permanent Magnet (PM) motors have higher efficiency than induction motors because there are no copper losses of the rotor. But widespread use of the PM motors has been discouraged by price and requirement of a speed encoder. Low-cost high-performance CPUs and establishment of the speed sensor less control theory. demand for permanent magnet motors is increasing because of their high efficiency, wide driving range, high output torque per unit volume, etc. The materials used for making permanent magnets are Alnico (AlNi), Samarium Cobalt, Neodymium Iron Boron (NdFeB) etc. Of these materials Neodymium magnets has the highest flux density per unit volume.

Synchronous motor drives are suitable for constant speed applications and its speed of operation depends only on the frequency of its stator supply. Synchronous motor with permanent magnet rotor is a good choice for applications like machine tool, robotics, electric vehicles, Traditional AC motor servo application, In field of wind energy generation, aerospace, etc.
The advantages of PMSM over other motors are Higher Efficiency Higher torque to inertia ratio Compact size

II. MODELING OF PERMANENT MAGNET SYNCHRONOUS MACHINE

The permanent magnet synchronous motor consists of three phase stator similar to that of an induction machine and a rotor with permanent magnets. The machine characteristics depend on the type of the magnets used and the way they are located in the rotor.
According to the type of rotor construction PMSM are classified as

1) Surface mounted PMSM
2) Inset magnet PMSM
3) Interior magnet PMSM

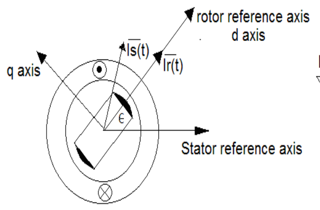
The surface mounted PMSM is the simplest and widely used configuration. As the relative permeability of the permanent magnet material is almost equal to air, the surface mount PMSM is almost similar to a uniform air gap machine. For interior PMSM the permanent magnets are kept inside the rotor structure and therefore the air gap is not uniform.

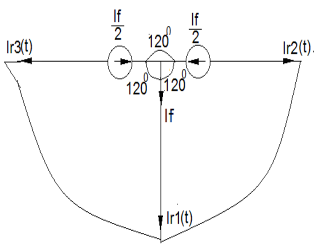
The control is very similar to that of the vector control of induction machine. Only difference is that the position of rotating reference frame can be directly sensed unlike that of the induction machine. The main features of closed loop control can be summarized as follows,

1)Torque control requires to be controlled.
2) field normally kept at zero for minimum stator current operation.
3) For rotor field orientation, the instantaneous position of rotor is required. This can be done by using speed sensor or position estimation technique in sensor less control.
4) Using the rotor position the sensed stator current can be transformed to d-q axis currents.

The assumptions made in the modeling of PMSM are

1) Magnetic saturation is neglected
2) The induced emf is sinusoidal
3) All the losses are negligible





The space phasor of the rotor currents in rotating coordinates is given

$$i_r^r(t) = i_{rr}(t) + i_{ry}(t)e^{j120} + i_{rb}(t)e^{j240} \quad (1)$$

$$i_r^r(t) = i_f - \frac{i_f}{2}e^{j120} - \frac{i_f}{2}e^{j240} \quad (2)$$

Since there is no mmf sources along the q axis the imaginary part of the above equation is zero and hence

$$i_r^r(t) = \frac{3}{2} i_f \quad (3)$$

The voltage equation for a general ac machine is given by

$$\vec{v}_s = r_s \vec{i}_s + L_s \frac{d}{dt}\vec{i}_s + L_0 \frac{d}{dt}(\vec{i}_r e^{j\epsilon}) \quad (4)$$

$$0 = r_r \vec{i}_r + L_r \frac{d}{dt}\vec{i}_r + L_0 \frac{d}{dt}(\vec{i}_s e^{-j\epsilon}) \quad (5)$$

Since for PMSM rotor is permanent magnet, the rotor side equation is insignificant. Using eqn (4) in (5)

$$\vec{v}_s = r_s \vec{i}_s + L_s \frac{d}{dt}\vec{i}_s + L_0 \frac{d}{dt}(\frac{3}{2} I_f e^{j\epsilon}) \quad (6)$$

Taking $L_o \frac{3}{2} I_f = \psi_f$ (7)

$$\vec{v}_s = r_s \vec{i}_s + L_s \frac{d}{dt}\vec{i}_s + \psi_f \frac{d}{dt}(e^{j\epsilon}) \quad (8)$$

Rotor field orientation

In rotor field orientation the rotating d axis coincides with the rotor field axis. The voltage equation for rotor field orientation can be obtained from eqn (8) by multiplying it with $e^{-j\epsilon}$ and separating the real and imaginary parts.

$$v_{sd} = r_s i_{sd} + L_s \frac{d}{dt} i_{sd} - \omega_e L_s i_{sq} \quad (9)$$

$$v_{sq} = r_s i_{sq} + L_s \frac{d}{dt} i_{sq} + \omega_e L_s i_{sd} + \omega_e \psi_f \quad (10)$$

The electromagnetic torque a P pole machine developed by the machine is given by

$$m_d = \frac{2}{3}\frac{p}{2}\psi_f i_{sd}\psi_s = L_s \bar{i}_s + L_o \bar{i}_r e^{j\varepsilon} \quad (11)$$

Complete dynamic model of PMSM

The dynamic equations are given below

$$v_{sd} = r_s i_{sd} + L_s \frac{d}{dt} i_{sd} - \omega_e L_s i_{sq} \quad (12)$$

$$v_{sq} = r_s i_{sq} + L_s \frac{d}{dt} i_{sq} + \omega_e L_s i_{sd} + \omega_e \psi_f \quad (13)$$

$$J \frac{d}{dt}\omega_m = \frac{2}{3}\frac{p}{2}\psi_f i_{sq} - m_l \quad (14)$$

$$\frac{d\varepsilon}{dt} = \omega_e \quad (15)$$

CONTROL METHOD: -

(a) Sensorless control
(b) Sensor control through resolve

A) sensor less control

$$\overrightarrow{\psi_s} = L_s \vec{i_s} + \psi_f e^{j\in} \qquad (16)$$

$$\psi_{s\alpha} = L_s i_{s\alpha} + \psi_f \cos \in \qquad (17)$$

$$\psi_{s\beta} = L_s i_{s\beta} + \psi_f \sin \in \qquad (18)$$

Voltage equation in αβ references

$$v_{s\alpha} = r_s i_{s\alpha} + \frac{d}{dt}\psi_{s\alpha} \qquad (19)$$

$$v_{s\beta} = r_s i_{s\beta} + \frac{d}{dt}\psi_{s\beta} \qquad (20)$$

$$\psi_{s\alpha} = \int (v_{s\alpha} - r_s i_{s\alpha})dt \qquad (21)$$

$$\psi_{s\beta} = \int (v_{s\beta} - r_s i_{s\beta})dt \qquad (22)$$

rotor position is given by

$$\in = \tan^{-1}\left(\frac{(\int (v_{s\beta} - r_s i_{s\beta})dt) - L_s i_{s\beta}}{(\int (v_{s\alpha} - r_s i_{s\alpha})dt) - L_s i_{s\alpha}}\right) \qquad (23)$$

$$\frac{d\in}{dt} = \omega_e \qquad (24)$$

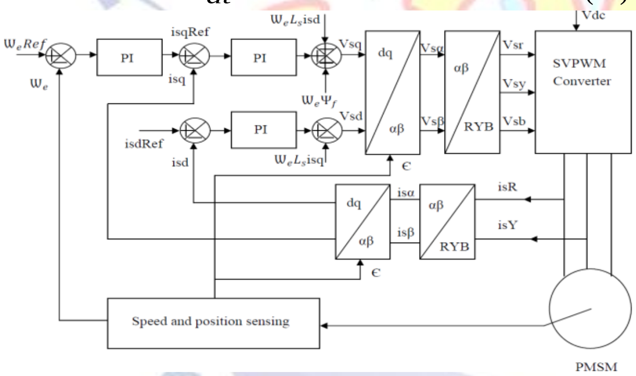


Fig 1. Matlab model of the scheme.

III. Space Vector Modulation

The Space Vector Modulation is used to generate the voltages applied to the stator phases. It uses a special scheme to switch the power transistors to generate pseudo sinusoidal currents in the stator phases. For sinusoidal excitation the voltage space vector traces a circle with constant speed. With PWM the switching average voltage space vector will traces a circle with constant

Simulation result

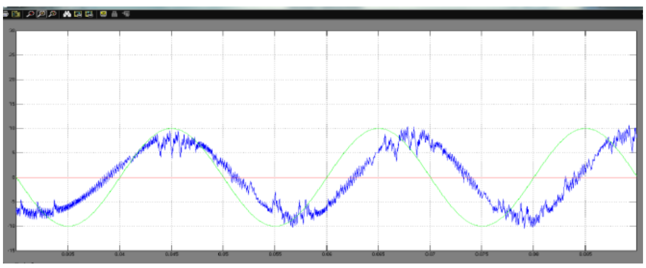


Fig.2 Plot between reference sine to actual sine

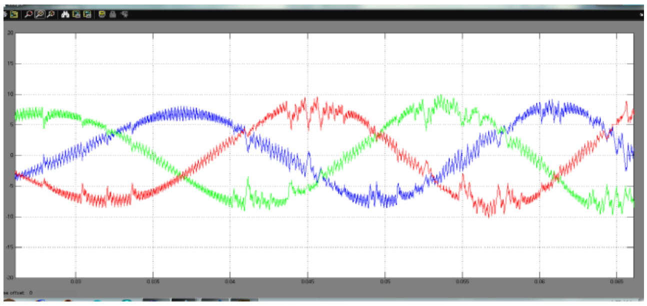


Fig 3. Voltages VsR, VsY, VsB

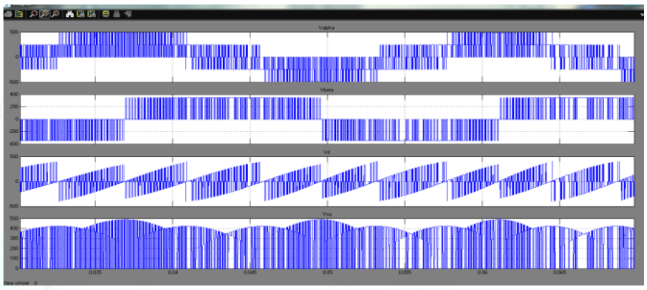


Fig 4. V(alpha),V beta,Vd,Vq

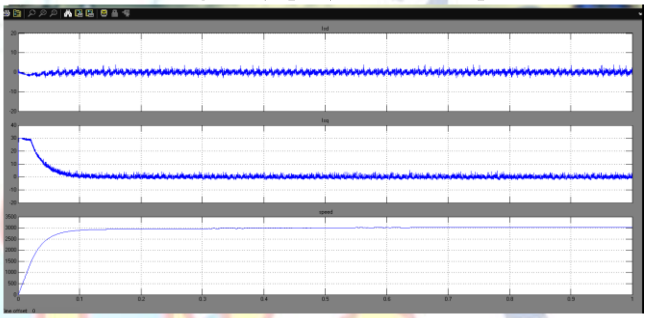


Fig 5. Speeds at 3000 rpm (isd, isq)

IV. Development of High Speed Model

Field weakening through voltage error method.

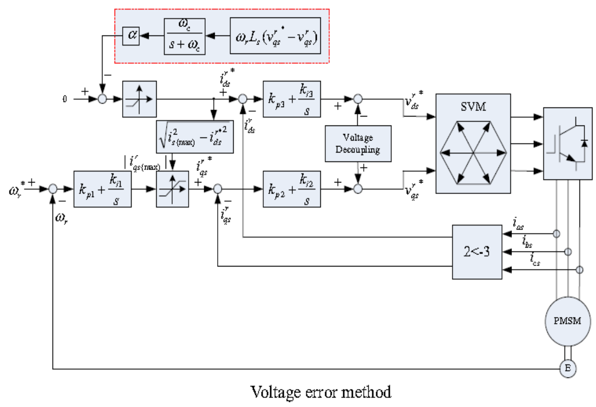
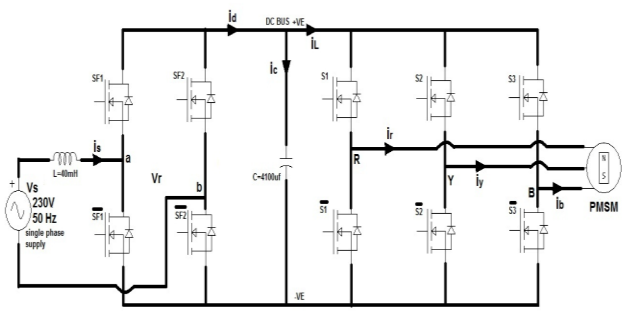


Fig 6. Mathematical model of voltage error method.



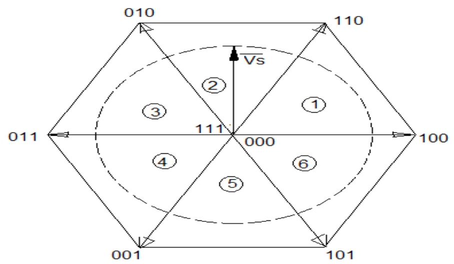


Fig 7. Simulation model of voltage error method and IGBT response.

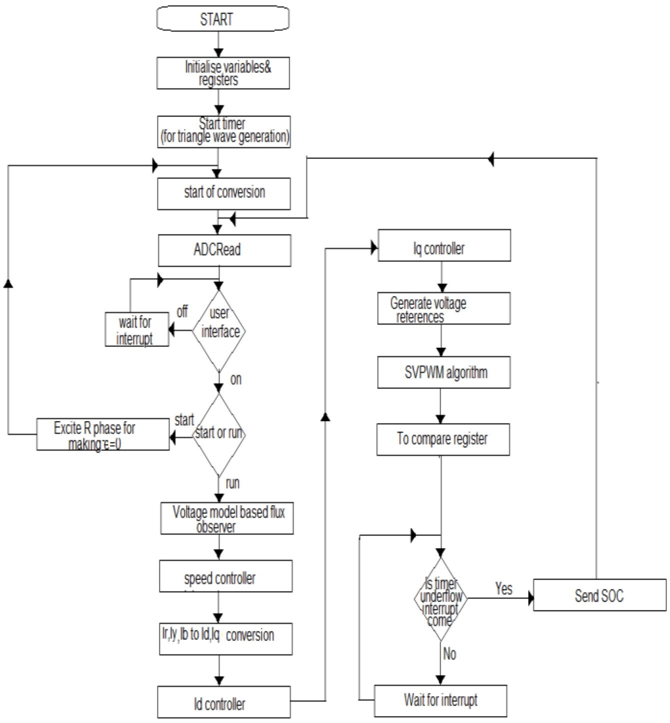


Fig 8. Flow Chart of the scheme.

V. Results

Figure below shoes the Experimental and simulation result.

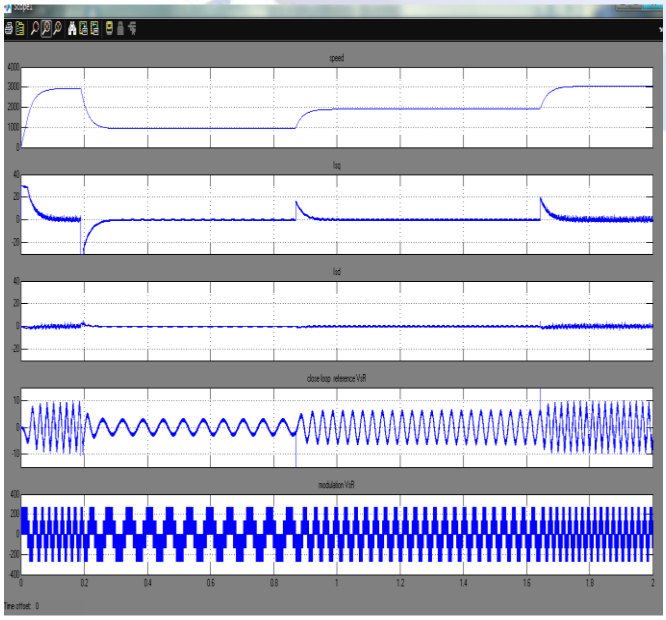


Fig 9. Matlab simulation (speed,isq,isd,closeloop reference, modulated line voltage)

VI. Conclusion

A high performance position and speed Sensorless control method has been implemented using a tms320f2407 DSP chip in order to achieve the high performance such as the vector controller, the svpwm scheme and current controller of the pmsm drives are in dsp chip the assembly language programming for implementation on dsp has resulted in use of reduced hardware. Experimental results also demonstrate that in step command response and speed command response, the rotor position of pmsm can fast track and dynamic response very good at no load. Modifications in control structure are easily possible by changing the software to meet the requirement of specific applications, this application can be used in industrial servo application. But problem comes when we load high rated machine, not possible to run smoothly machine. This is the major issue in PMSM motor in running condition.

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