Certain Investigations on Model Predictive Controller for PMSM Drive

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Abstract:- **This paper investigates the application of the model predictive control (MPC) approach to control the speed of a permanent magnet synchronous motor (PMSM)** , which is, at present, among the motors with the highest power efficiency and then very attractive for energy-saving applications. **This motor attracting the interest of researchers and industry for use in many speed control applications. Hysteresis current controller was developed for inner loop current control and MPC controller for outer loop speed control. This is a simple, low cost, provides good dynamic performance, and effective technique to be implemented as modulation process. This design achieved fast response, high performance and accuracy of the speed control scheme. The simulation is developed using MATLAB/SIMULINK. The effectiveness of the proposed control method is verified by results point out the powerful capabilities of the MPC in the electrical drives field.**

Keywords: **- PMSM, MPC controller, Hysteresis current controller, MATLAB/Simulink**

1. INTRODUCTION

Recent developments in rare earth Permanent Magnet (PM) materials and power electronics have created new opportunities for the design, construction, and application of Permanent Magnet Synchronous Motors (PMSMs). The PMSMs are preferred over other motors used for ac servo drives due to their high efficiency, high torque-to-current and torque-to-volume ratios, compact structure, and fast dynamic response. These motors are adopted in several residential and industrial applications. However, many of such applications require minimum torque ripple, and reduced vibration and acoustic noise.

In many applications, such as robotics and factory automation, require precise control of speed and position. Closed Loop speed control systems have fast response, Speed Control Systems allow one to easily set and adjust the speed of a motor. The control system consists of a speed feedback system, a motor, an inverter, a controller and a speed setting device. A properly designed feedback controller makes the system insensible to disturbance and changes of the parameters. The purpose of a motor speed controller is to take a signal representing the demanded speed, and to drive a motor at that speed.

2. PMSM DRIVE SYSTEM

2.1. Modeling of PMSM

PMSM is composed of three phase's stator windings and permanent magnets mounted on the rotor surface (surface mounted PMSM) or buried inside the rotor (interior PMSM). It means that the excitation flux is set-up by magnets; subsequently no magnetizing current is needed from the supply. The electrical equations of the PM synchronous motor can be described in the rotor rotating reference frame, written in the (dq) rotor flux reference frame.

The mathematic model of PMSM is based on the following assumptions:
(1) Neglecting the saturation of armature;
(2) Neglecting the wastages of eddy and magnetic hysterics;
(3) There is no rotor damp resistance.
The relations of voltage, torque and flux of surface mounted
PMSM are described as follows:

$$\frac{d}{dt}\begin{bmatrix} i_q \\ i_d \end{bmatrix} = \begin{bmatrix} -R/L & -\omega_r \\ \omega_r & -R/L \end{bmatrix}\begin{bmatrix} i_q \\ i_d \end{bmatrix} + \begin{bmatrix} 1/L & 0 & 0 \\ 0 & 1/L & -\omega_r/L \end{bmatrix}\begin{bmatrix} v_q \\ v_d \\ \lambda_f \end{bmatrix} \quad (1)$$

where i_d and i_q are the d and q axis stator currents, R and L are the stator phase resistance and inductance respectively; the d-axis self inductance (L_d) and the q-axis self inductance (L_q) are all equal to L; ω_r is the rotor

electrical speed; V_d and V_q are the stator voltages expressed in the dq reference frame and λ_f is the flux linkage established by rotor permanent magnets.
The inverter frequency is related as follows

$$\omega_s = P\,\omega_r \qquad (2)$$

where P is the number of pole pairs.
The electromagnetic torque is given by

$$T_e = 3/2\ P\,[\lambda_f\ i_d + (L_d - L_q)\ i_d\ i_q\ ] \qquad (3)$$

The basic principle in control of PMSM drive is based on field orientation. The flux position can be determined by the shaft position sensor because the magnetic flux generated by permanent magnet is fixed in relation to the rotor shaft position. To ensure the vector control of the PMSM, the technique i_d=0 is the optimal strategy where the motor produce the maximum torque. If i_d is forced to be zero by closed loop control, then:

$$T_e = k_t\, i_q \qquad (4)$$

With,

$$Kt = (3/2)\ P\ \lambda_f \qquad (5)$$

Since λf is constant, the electromagnetic torque is then directly proportional to current $i_{q.}$ The torque equation is similar to that of separated excited DC motor. This feature can simplify the controller design of the PMSM, which is used in the controller simulation experiment in this paper.
The equation of the motor dynamics is

$$T_e = T_L + B\omega_s + J(d\omega_s/dt) \qquad (6)$$

T_L stands for external load torque. B represents the damping coefficient and J is the moment of inertia of the rotor.
It is evident from equations (4) and (6) that the speed control can be achieved by controlling the q-axis current component i_q as long as the d-axis current i_q is maintained at zero. The equations (1) and (6) constitute the whole control model of the PMSM.
A system configuration of a MPC controlled PMSM drive system block diagram is shown in Figure 1.

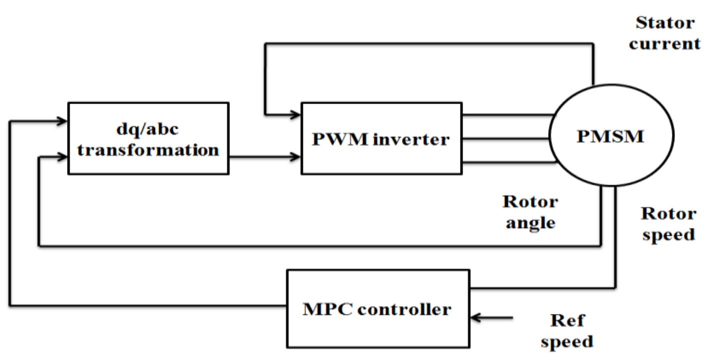

Fig.1 Block diagram

2.2. MPC Controller

MPC uses the current plant measurements, the current dynamic state of the process, the MPC models, and the process variable targets and limits to calculate future changes in the dependent variables. These changes are calculated to hold the dependent variables close to target while honoring constraints on both independent and dependent variables. The MPC typically sends out only the first change in each independent variable to be implemented, and repeats the calculation when the next change is required.

2.3. Vector Transformation dq/abc

The dynamic d q modeling is used for the study of motor during transient and steady state. It is done by converting the dqo variables to three phase currents by using inverse Parks transformation Converting the phase currents variables i* dqo to i*abc variables in rotor reference frame the following equations are obtained.

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \begin{bmatrix} \sin(\theta_r) & \cos(\theta_r) & 1 \\ \sin(\theta_r - 2\pi/3) & \cos(\theta_r - 2\pi/3 & 1 \\ \sin(\theta_r + 2\pi/3) & \cos(\theta_r + 2\pi/3) & 1 \end{bmatrix} . \begin{bmatrix} f_q \\ f_d \\ f_0 \end{bmatrix}$$

2.4. Hysteresis Current Controller

Hysteresis current controller can also be implemented to control the inverter currents. The controller will generate the reference currents with the inverter within a range which is fixed by the width of the band gap. In this controller the desired current of a given phase is summed with the negative of the measured current. The error is fed to a comparator having a hysteresis band. When the error crosses the lower limit of the hysteresis band, the upper switch of the inverter leg is turned on. But when the current attempts to become less than the upper reference band, the bottom switch is turned on.

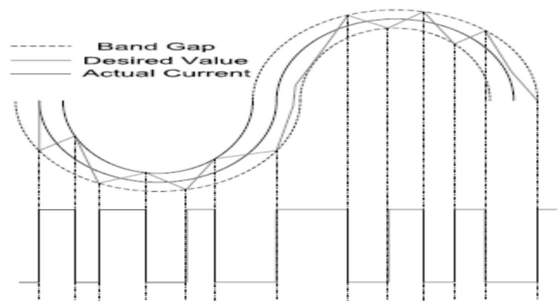

Fig.2 Hysteresis controller

Figure 2 shows the hysteresis band with the actual current and the resulting gate signals. However, the simulation with hysteresis current controller allows faster simulations with reduced time and computational resources.

2.5. Implementation of the Speed Control Loop

Speed controller calculates the difference between the reference speed (ω*) and the actual speed (ω) producing an error, which is fed to the MPC controller. MPC controllers are used widely for motion control systems. Speed control of motors mainly consist of two loops the inner loop for current (band hysteresis current controller) and the outer loop for speed (speed controller) as shown in Figure 1. The order of the loops is due to their response, how fast they can be changed. This requires a current loop at least 10 times faster than the speed loop. Rotor quantities (dq) of the motor have been transformed on to the Stator (abc) using inverse Park’s transformation. For high performance drives in hysteresis current controllers are used to ensure that the actual currents flowing in to the stator windings of the PMSM are as close as possible to the sinusoidal reference value. The hysteresis band is chosen as to limit the switching frequency of the devices within its specified range. The obtained current is converted into equivalent voltages by controlled voltage source. Thus controlled voltage is fed through PMSM. Hence speed is controlled by feedback closed loop.

3. SIMULATION IMPLEMENTATION IN SIMULINK

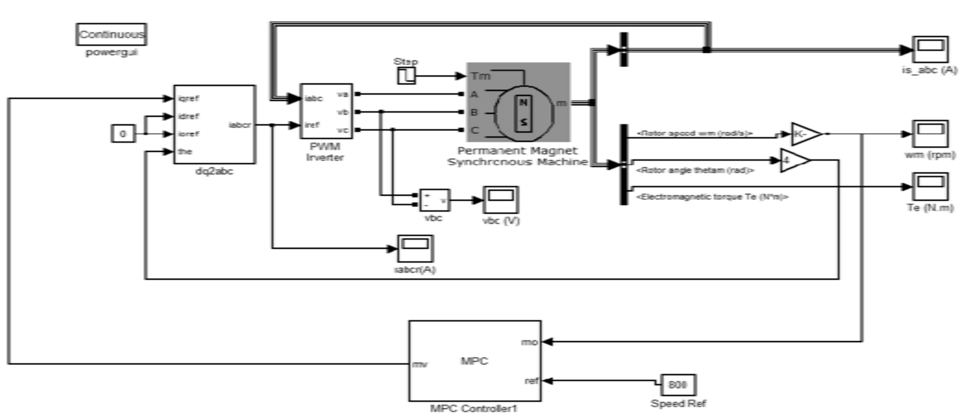

Fig.3 Simulink schematic of system level implementation

Simulink has the advantages of being capable of complex dynamic system simulations, graphical environment with visual real time programming and broad selection of tool boxes. The simulation environment of Simulink has a high flexibility and expandability which allows the possibility of development of a set of functions for a detailed analysis of the electrical drive. Its graphical interface allows selection of functional blocks, their placement on a worksheet, selection of their functional parameters interactively, and description of signal flow by connecting their data lines using a mouse device. System blocks are constructed of lower level blocks grouped into a single mask able block. Simulink simulates analogue systems and discrete digital systems.

(Figure 3) is basically a Simulink model of the system level implementation or system schematic showing the various interconnected components such as MPC controller, Conversion of 2-Phasevariables into 3-Phasevariable, PWM inverter, calculation torque and speed. Each of these components would be elaborated upon in complete detail assisted by illustrations

3.1. Conversion of 2-phase variables into 3-phase variable

The dqo variables transformation to abc variables is built using Inverse Parks transformation. Where the functions are as follows

Fcn = u(1)*cos(u(4)) + u(2)*sin(u(4)) + u(3)

fcn1 = u(1)*cos(u(4)-2*pi/3) + u(2)*sin(u(4)-2*pi/3) + u(3)

fcn2 = u(1)*cos(u(4)+2*pi/3) + u(2)*sin(u(4)+2*pi/3) + u(3)

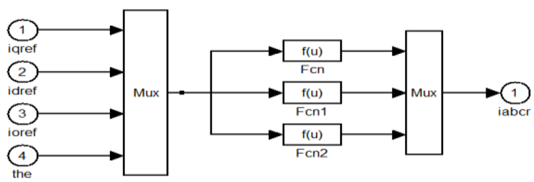

Fig.4 Simulink model of dq to abc transformation

The inputs to the above model are as follows:

1. iqref, which is a manipulated variable from MPC controller
2. idref which is held at zero
3. ioref, held at zero
4. theta, is the rotor angle

The above signals are given to a multiplexor (mux) and then fed to the three functions shown in the above figure 4. These functions are actually a result of the inverse Park transformation as explained above. The resulting three signals are again fed to a mux in order to produce a three phase reference current signal.

3.2. Switching gate signal generator

The switching circuitry employs a unique form of a current comparator and gating signal generator. The current comparator works on two input current signals, the reference current signal (generated as a result of the dq-to-abc transformation block) and the actual current. This is well explained in the following illustration (Figure 5).

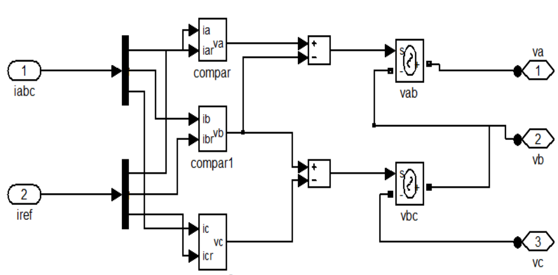

Fig.5 Switching gate signal generator

It can be observed in the above figure that the three-phase current signals go through a demultiplexor (demux) and produce individual phase currents. These currents pass through the current comparator to generate an equivalent voltage signal. The outputs become the reference signals called as Va, Vb and Vc. Thus the PWM inverter output voltage (va, vb and vc) is fed to PMSM motor.

3.3. Hysteresis current comparator

The current comparator of (Figure 5) for one phase is constructed as shown in (Figure 6). *ia* and *iar* are the actual and reference current values respectively. Differences of those values are determined by add sum2 block. The output of the sum2 is passes through a block called Relay block.

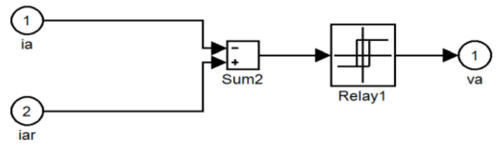

Fig.6 Hysteresis current comparator

The Relay block allows its output to switch between two specified values. When the relay is on, it remains on until the input drops below the value of the Switch off point parameter. When the relay is off, it remains off until the input exceeds the value of the Switch on point parameter. The block accepts one input and generates one output. The output here is a small voltage signal *va* which was also observed earlier in (Figure 3.5).

4. ANALYSIS OF SIMULATION RESULTS

Figure 7 shows the Dynamic performance for a step variation of the reference speed from 0 RPM to 800 RPM with a torque load of about 1 Nm. The steady state speed is the same as that of the commanded reference speed. The motor starts from zero speed and with a small over shoot, the motor speed settles down to the commanded speed i.e., 800 rpm.

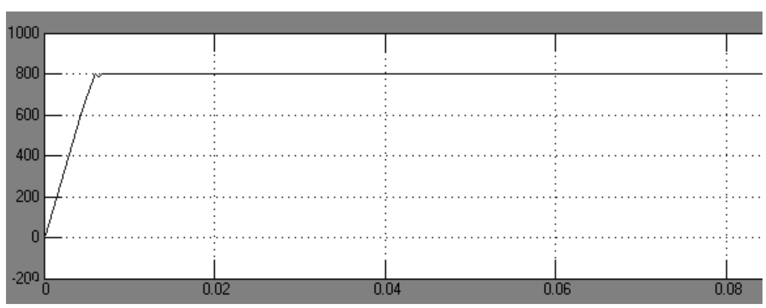

Fig.7 Speed Curve

The accuracy of speed control of the drive is shown in Figure 8.

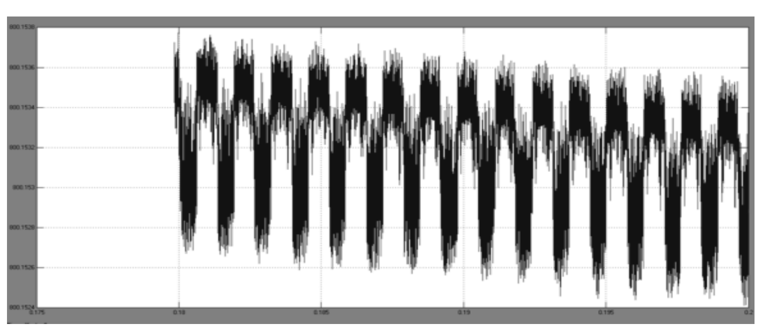

Fig.8 Speed ripples at 800 RPM

Speed error plot for hysteresis current control by using MPC controller is about 800.1524 RPM to 800.1538 RPM. Thus the drive speed loop operates to maintain the command speed within an error represented in the speed error plot.

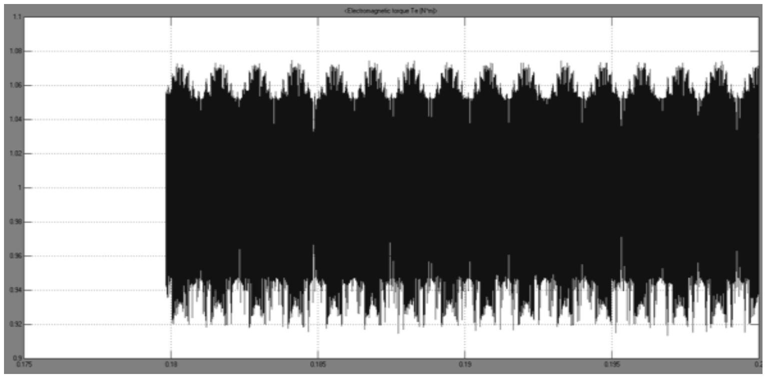

Fig.9 Developed electromagnetic torque of the PMSM

Figure 9 shows the developed torque of the motor. The starting torque is the rated torque. The steady state torque is about 1 Nm.

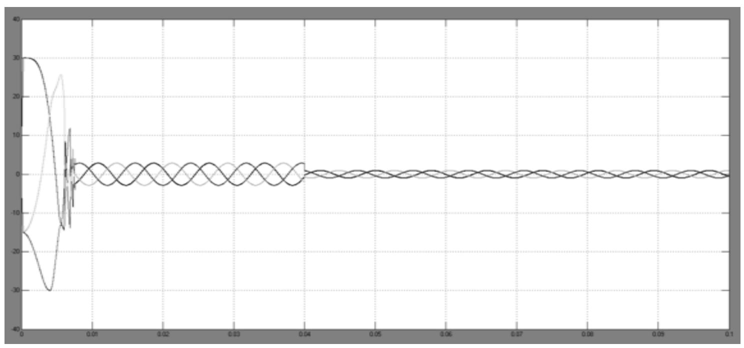

Fig.10 Three Phase Input Stator Currents

Figure 10 shows the real three phase currents drawn by the motor as a result of the hysteresis current control. It is clear that the current is non sinusoidal at the starting and becomes sinusoidal when the motor reaches the controller command speed at steady state.

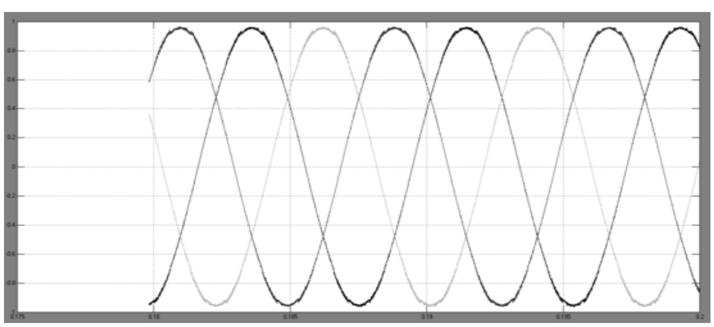

Fig.11 Reference Currents

The reference currents (iabcr) are obtained using Park's reverse transformation is shown in figure 11. This reference current is compared with actual current in hysteresis current controller.

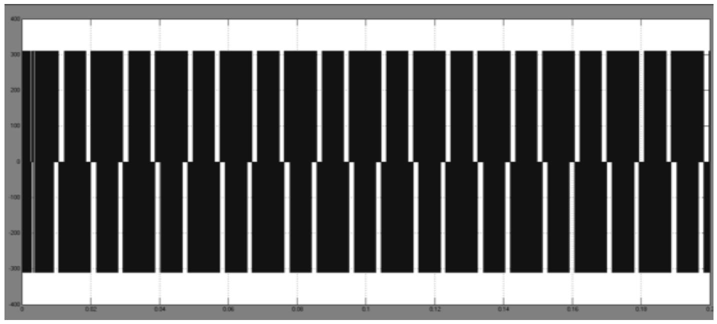

Fig.12 Inverter Output voltage

Further, Figure 12 shows the corresponding Output Voltage curve drawn by the motor as a result of the hysteresis current control, when the motor speed is 800 rpm with an electromagnetic torque of 1 Nm

Thus the results show the speed accuracy is obtained by 0.001 (800.1524 to 800.1538 RPM) variations of reference speed of 800 RPM and it achieves steady state by short time of 0.18 sec is obtained by MPC algorithm. Thus the simulated speed control of PMSM by closed loop system has a fast response with accuracy obtained by MPC controller.

5. CONCLUSIONS

In proposed method the error between the speed command and the actual speed is greatly reduced. Speed response accuracy and fast response is obtained with the MPC speed controller waveform is better. It is highlighted that the waveform that generated by the new technique is efficient, fast and more accurate with the MPC controller. Thus the speed controller has been designed successfully for closed loop operation of the PMSM drive system so that the motor runs at the commanded or reference speed.

The overall system performances are quite good in terms of dynamic, transient and steady-state responses. Simulation results show that the proposed control scheme guarantees stable and robust response of the PMSM drive, under a wide range of operating conditions. Subsequently, it can be utilized in high performance motion control applications. This will be implement in DSP processor as the speed control circuit we can achieve high accuracy of speed response of the PMSM while constructing the hardware.

REFERNCES

[1] Abdel-Karim Daud, Basim Alsayid, and Arafat Zaidan (2012) ‘DSP Based Simulator for Field Oriented Control of the Surface Permanent Magnet Synchronous Motor Drive’, International Journal of Circuits, Systems and Signal Processing, Vol 6, Issue 1, pp 29-37

[2] Abdulhakim Karakaya and Ercument Karakas (2008) ‘Performance Analysis of PM Synchronous Motors Using Fuzzy Logic and Self Tuning Fuzzy PI Speed Controls’, The Arabian Journal for Science and Engineering, Vol. 33, No. 1B, April, pp 153-177

[3] Alireza Davari.S, Davood Arab Khaburi, and Ralph Kennel (2012) ‘An Improved FCS–MPC Algorithm for an Induction Motor with an Imposed Optimized Weighting Factor’, IEEE transactions on power electronics, Vol 27, No. 3, March, pp 1540 -1551

[4] Amar Nath Tiwari (2011) ‘Controller Design and Simulation of PMSM Drive’, International Journal of Engineering Science and Technology (IJEST), Vol. 3 No. 4, April, pp 3357-3365

[5] Ronald S. Rebeiro, and M. Nasir Uddin (2012) ‘Performance Analysis of an FLC-Based Online Adaptation of Both Hysteresis and PI Controllers for IPMSM Drive’, IEEE transactions on industry applications, Vol 48, No. 1, January/February, pp 12-19

[6] Sinivas Rao.J, Chandra Sekhar.S, Raghu.T (2012) ‘Speed Control of PMSM by Using DSVM -DTC Technique’, International Journal of Engineering Trends and Technology, Vol. 3 No. 3, pp 281-285

[7] Ying Wu, Hang Jiang, and Min Zou (2012) 'The Research on Fuzzy PID Control of the Permanent Magnet Linear Synchronous Motor', International Conference on Applied Physics and Industrial Engineering, Vol 24, pp 1311 – 1318