



Current Control of the DC motor

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ABSTRACT

The paper presents some aspects concerning the modelling and the simulation of the permanent magnet synchronous motor. On the base of this model three current control techniques (the conventional current control technique using a DSP, the extended current control technique using a DSP and the current control technique using a DSP and FPGA) were simulated and discussed. Also a comparison between the digital signal processors and the field programmable gate array were discussed. The frequency-characteristics of the current control loops corresponding to three techniques were compared. As it could be seen from the presented plots, the dynamic behavior of the system in the case of the first two control strategies is nearly similar, but a great improvement on the dynamic behavior of the system is obtained when the current is regulated using the FPGA technology.

KEYWORDS

Current, Control, Servo-Drives

INTRODUCTION

High performance AC servo drive depends on the well control of the currents; however, the strong coupling and nonlinear natures of the AC motors make it impossible to directly control the stator currents to obtain the desired performances as the behaviour of DC motors. Hence, a specific algorithm must be introduced to realize the decoupling of relevant variables. Fortunately this problem has been resolved by the vector control technology. The principle of vector control, often referred to as field-oriented-control, was first proposed by F. Blaschke in the early 1970s for controlling induction motors, and after several years of efforts this method had been developed into a complete theory system (Xue et al, 1995) [6]. In the latest twenty years, the vector control technology has been used wider and wider in high performance AC drives due to the rapid progress in power electronics, computer and microelectronics [2].

During the last years, the permanent magnet synchronous motor (PMSM) finds more and more wide applications in high performance servo drives such as numerically controlled machine-tools, robotics, handling systems etc.

In engineering practice, because of the complexity of servo control algorithm, it is basically implemented with software based on a DSP; this approach can provide a flexible skill, but suffers from a long period of development and exhausts many resources of the CPU. In recent years, a new design methodology has arisen, that is FPGA-based hardware implementation technology [4], [5].

THE MODEL of the AC SERVO DRIVE

The dynamic model of a nonsalient-pole permanent magnet synchronous motor is composed from the equation of equilibrium for the stator voltages, the flux linkage expressions in terms of the current, the expression of the torque and the equation of the mechanical equilibrium. The stator voltages equation in vector form can be given as (1).

$$\underline{u}_s = R_s \dot{i}_s + \frac{d\psi_s}{dt} \tag{1}$$

If the coordinate's axes rotate at synchronous speed ω , equation (1) can be written in d-q reference frame as follows:

$$\underline{u}_s = R_s \dot{i}_s + j\omega \psi_s + \frac{d\psi_s}{dt} \tag{2}$$

Because the case of a nonsalient-PMSM was considered, the next equality is true:

$$L_{sd} = L_{sq} = L_s \tag{3}$$

Thus, using (2) and (3) the direct and quadrature components of

the stator voltage are obtained:

$$u_{sd} = R_s i_{sd} - \omega L_s i_{sq} + L_s \frac{di_{sd}}{dt} \tag{4}$$

$$u_{sq} = R_s i_{sq} + \omega L_s i_{sd} + \omega \psi_e + L_s \frac{di_{sq}}{dt} \tag{5}$$

where subscripts 'd' and 'q' refer to the physical quantities that have been transformed in the d-q synchronous reference frame; R_s and L_s represent the resistance and the inductance of the stator.

The electromagnetic torque can be obtained from:

$$T_e = \frac{3}{2} p ((L_{sd} - L_{sq}) i_{sd} i_{sq} + \psi_e i_{sq}) \tag{6}$$

Taking into consideration of (3) and (6), the electromagnetic torque can be regulated by i_{sq} as presented below:

$$T_e = \frac{3}{2} p \psi_e i_{sq} \tag{7}$$

The last component of the dynamic model for the permanent magnet synchronous machine is represented by the equation of the mechanical equilibrium given as

$$T_e = J \frac{d\omega}{dt} + D\omega + T_r \tag{8}$$

where $J \frac{d\omega}{dt}$ represents the dynamic torque and J is the system inertia, $D\omega$ represents the torque corresponding to the viscous friction and T_r represents the resistant torque.

Basis on the equations (4), (5), (7) and adding the equation of the speed $\omega = \frac{d\lambda}{dt}$, the dynamic model of the motor is obtained and

presented by the system:

$$\begin{cases} u_{sd} = R_s i_{sd} - \omega L_s i_{sq} + L_s \frac{di_{sd}}{dt} \\ u_{sq} = R_s i_{sq} + \omega L_s i_{sd} + \omega \psi_e + L_s \frac{di_{sq}}{dt} \\ T_e = J \frac{d\omega}{dt} + D\omega + T_r \\ \omega = \frac{d\lambda}{dt} \end{cases} \tag{9}$$

Based on system (9) the Simulink model of the PMSM is obtained and presented in Fig. 1. and Fig.2.

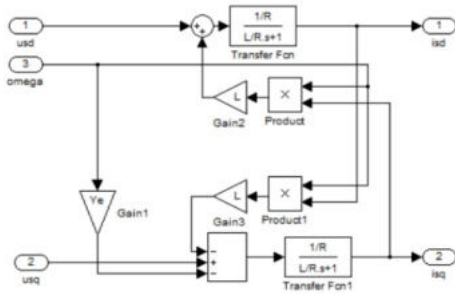


Figure 1: Electrical part of the PMSM

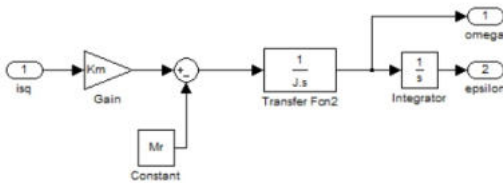


Figure 2: Mechanical part of the PMSM

THE CURRENT CONTROLLERS

At the present model, two current controllers will be added, one for the direct and respectively one for the quadrature component of the current. The two current controllers will be approximated by a PI controller whose control parameters are the proportional gain k_p and the integral gain k_i . The transfer function of this PI controller is presented below [3]:

$$G_{PI}(s) = k_p + k_i \frac{1}{s} \tag{10}$$

After several calculations, the parameters of the controller can be obtained. These are presented in (11)

$$\begin{cases} k_p = \frac{R \cdot T_i}{4 \cdot D^2 \cdot T_e} \\ k_i = \frac{R}{4 \cdot D^2 \cdot T_e} \end{cases} \tag{11}$$

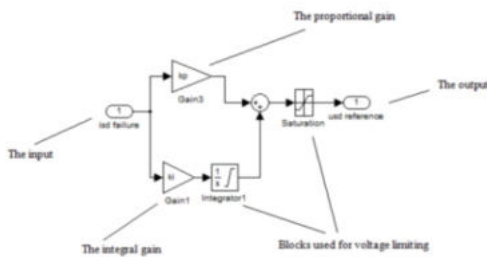


Figure 3: The current controller

At the controller's input the signal $i_{s_follower} = i_{s_reference} - i_s$ is applied with the goal to regulate the amplitude of the stator currents.

CURRENT CONTROL TECHNIQUES

This paragraph presents three current control strategies (techniques) as well as a comparison between them.

The first strategy, called *Conventional Current Control using a DSP*, represents the most usual implementation of the current control that is used in present. At this strategy, the current loop and the overlaid control loop (speed and position loops) are being calculated during a PWM-period (62.5 μs). The calculations of the loops will be available at the next symmetry-point which will become the next reference input. In this case the calculations of the current loop and of the overlaid control loops are made in the DSP.

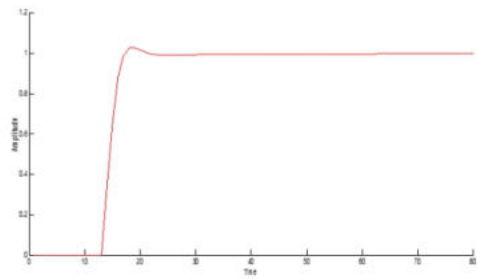


Figure 4: The step response of the system for the 1st strategy

For a damping factor of $D=707.0$, in Fig. 4 it is presented the step-response of the considered system. The settling time of the system can be obtained. Thus, when we use this strategy, the system will settle after $t_s=1,187$ ms.

The second control strategy is derived from the first control strategy. The principle of this control technique is based on the fact that every PWM signal has two symmetry points. The second control strategy can be achieved using a fast DSP or a FPGA. The advantage of this strategy in comparison with the first one is that the interval needed for calculations is half reduce; the control cycle rises from 16 kHz to 32 kHz. Using this strategy, the dynamic behavior of the current circuits can be improved.

From Fig. 5 the settling time of the system can be obtained. Thus, when we use the second strategy, the system will settle after $t_s=1$ ms.

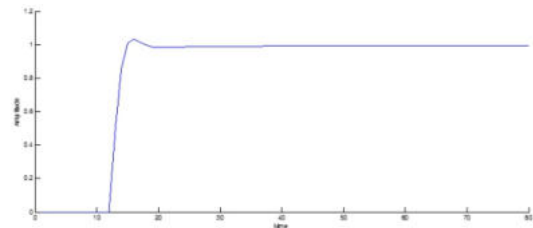


Figure 5: The step response of the system for the 2nd strategy

The third control strategy can be obtained only by using the FPGA technology and an AD converter. For this strategy, the overlaid control loops can be calculated through the DSP, while the current controllers/loops are calculated in the FPGA.

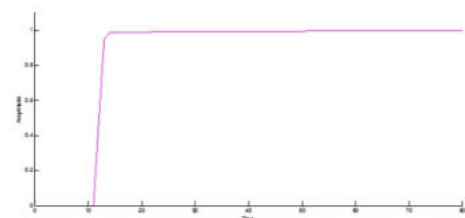


Figure 6: The step response of the system for the 3rd strategy

The control technique using a FPGA presents the big advantage that the time needed for the calculation in this case is extremely small. The step response of the system which uses this strategy is presented in Fig 6. From Fig. 6 the settling time of the system can be obtained. Thus, when we use the third strategy, the system will settle after $t_s=0.812$ ms.

In Fig. 7 there are presented the step-response of the discussed control systems.

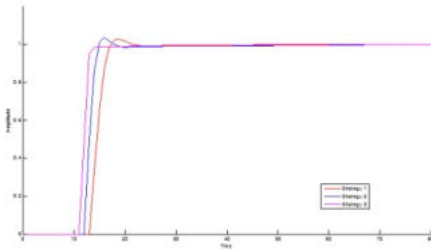


Figure 7: Comparison between the step responses for different strategies

From this plot it can be observed that the fastest response is obtained when the current is controlled using the FPGA technology. Also the system which is settling first is obtained when we use the third strategy.

The frequency-characteristics of the current control circuits corresponding to these techniques are presented in Fig. 8. As it can be seen from these plots, the dynamic behavior of the system in the case of the first two control strategies is nearly similar. A great improvement on the dynamic behavior of the system is obtained when the current is controlled using the FPGA.

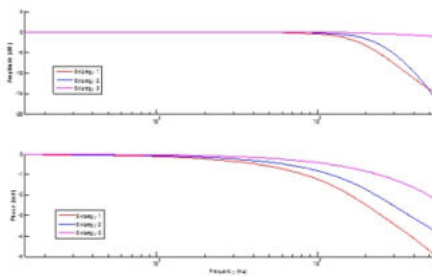


Figure 8: The Bode-plots of the discussed systems

CONCLUSIONS

Controlled servo drives are used in many areas of automation technology, robotics and handling systems as well as in the drive technology of production machines and machine tools. The requirements regarding dynamics, speed stability and rigidity demand ever increasing bandwidth in the control loops.

The frequency-characteristics of the current control loops corresponding to these three techniques were compared. As it could be seen from the presented plots, the dynamic behavior of the system in the case of the first two control strategies is nearly similar, but a great improvement on the dynamic behavior of the system is obtained when the current is regulated using the FPGA technology. Using this last, strategy the calculations of the loops is extremely fast. Thus, the new reference input will be available in 200 ns, which is a real improvement towards the first two strategies.

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