

Sensorless A.C. Drive with Vector Controlled Synchronous Motor

Ondřej Fišer

VŠB-Technical University of Ostrava, Faculty of Electrical Engineering and Informatics,
Department of Power Electronics and Electrical Drives,
17.listopadu 15, 708 33 Ostrava-Poruba, Czech Republic
ondrej.fiser@vsb.cz

Abstract. In the paper a method for speed and position estimation for the permanent magnet synchronous motor (PMSM) were described. By using monitored stator voltage and currents and Kalman observers, it is possible to implement high dynamic performance PMSM drives without position and speed sensors. An Extended Kalman Filter (EKF) is a recursive optimum state estimator which can be used for the joint state and parameter estimation of a nonlinear dynamics system in real time. The mathematical model of the vector controlled drive system in Matlab Simulink was used for simulation. The simulation results are in the end presentation.

1 Introduction

At present adjustable speed A.C. drives with synchronous motors which utilize the permanent magnets instead of the field windings, start to play still more important role. Synchronous motors in the power range of hundreds kW have been developed using the new magnetic materials on the basis of compounds Samarium-Cobalt (SmCo_5) and Neodym-Boron-Ferrum (NdBF_e). The permanent magnet synchronous motors are fed by frequency converters with an intermediate D.C. circuit. The power unit of frequency converter is built with modern power transistors IGBT for low and middle power ranges.

To give a permanent magnet synchronous motor the same dynamic performance as a D.C. motor two control principles may be applied: the vector control method or the direct torque and reactive power control method.

2 Mathematical model of the drive system

Voltage equations in rotor reference frame:

$$\begin{aligned} u_{sd} &= R_s i_{sd} + \frac{d\psi_{sd}}{dt} - \omega_r \psi_{sq} \\ u_{sq} &= R_s i_{sq} + \frac{d\psi_{sq}}{dt} + \omega_r \psi_{sd} \end{aligned} \quad (1)$$

$$i_{s\alpha} = i_{sd} \cos \Theta_r - i_{sq} \sin \Theta_r \quad (2)$$

$$i_{s\beta} = i_{sd} \sin \Theta_r + i_{sq} \cos \Theta_r$$

$$u_{s\alpha} = u_{sd} \cos \Theta_r - u_{sq} \sin \Theta_r \quad (3)$$

$$u_{s\beta} = u_{sd} \sin \Theta_r + u_{sq} \cos \Theta_r$$

$$u_p = \omega_r \Psi_f$$

System equations for Extended Kalman Filter (EKF):

$$\begin{aligned} \frac{di_{sd}}{dt} &= \frac{u_{s\beta} \sin \Theta_r}{L_s} + \frac{u_{s\alpha} \cos \Theta_r}{L_s} - \frac{R_s}{L_s} i_{sd} + \omega_r i_{sq} \\ \frac{di_{sq}}{dt} &= \frac{u_{s\beta} \cos \Theta_r}{L_s} - \frac{u_{s\alpha} \sin \Theta_r}{L_s} - \frac{R_s}{L_s} i_{sq} - \omega_r i_{sd} - \frac{u_p}{L_s} \end{aligned} \quad (4)$$

$$\frac{d\omega_r}{dt} = k i_{sq} = k i_{s\beta} \cos \Theta_r - k i_{s\alpha} \sin \Theta_r$$

$$\frac{d\Theta_r}{dt} = \omega_r$$

$$k = \frac{1}{J_c} (T_e - T_{km}) = \frac{1}{J_c} \left(\frac{3}{2} p \Psi_f - T_{km} \right) \quad (5)$$

$$J_c = J_m + J_{km}$$

By using eqn. (2,4,5) we can write:

$$\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu}$$

$$\frac{d}{dt} \begin{bmatrix} i_{sd} \\ i_{sq} \\ \omega_r \\ \Theta_r \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \omega_r & 0 & 0 \\ -\omega_r & -\frac{R_s}{L_s} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \omega_r & 0 \end{bmatrix} \cdot \begin{bmatrix} i_{sd} \\ i_{sq} \\ \omega_r \\ \Theta_r \end{bmatrix} + \begin{bmatrix} \frac{\cos \Theta_r}{L_s} & \frac{\sin \Theta_r}{L_s} & 0 \\ \frac{\sin \Theta_r}{L_s} & \frac{\cos \Theta_r}{L_s} & -1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} u_{\alpha} \\ u_{\beta} \\ u_p \end{bmatrix} \quad (6)$$

$$\mathbf{y} = \mathbf{Cx}$$

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} = \begin{bmatrix} \cos \Theta_r & -\sin \Theta_r & 0 & 0 \\ \sin \Theta_r & \cos \Theta_r & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} i_{sd} \\ i_{sq} \\ \omega_r \\ \Theta_r \end{bmatrix} \quad (7)$$

Where
 $\mathbf{x} = [i_{sd}; i_{sq}; \omega_r; \Theta_r]^T$ is the state vector,
 $\mathbf{y} = [i_{s\alpha}; i_{s\beta}]^T$ is the output vector,
 $\mathbf{u} = [u_{s\alpha}; u_{s\beta}; u_p]^T$ is the input vector,
 \mathbf{A} is the state matrix, \mathbf{B} is the input matrix and \mathbf{C} is the transformation matrix.

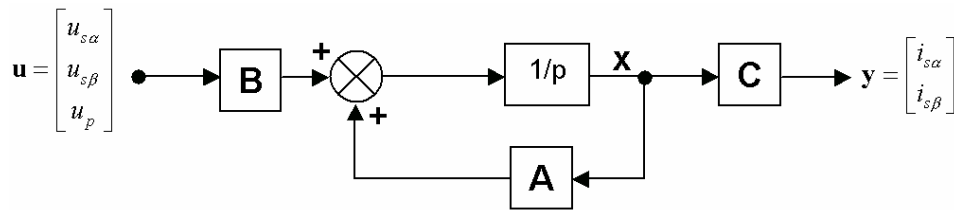


Fig. 1. Model of the PMSM

Next steps

- discretization of the machine model ($\mathbf{A} \Rightarrow \mathbf{A}(k)$; $\mathbf{B} \Rightarrow \mathbf{B}(k)$; $\mathbf{C} \Rightarrow \mathbf{C}(k)$)
- determination of the noise and state covariance matrices \mathbf{Q} , \mathbf{R} , \mathbf{P} .
- implementation of the discretized EKF algorithm

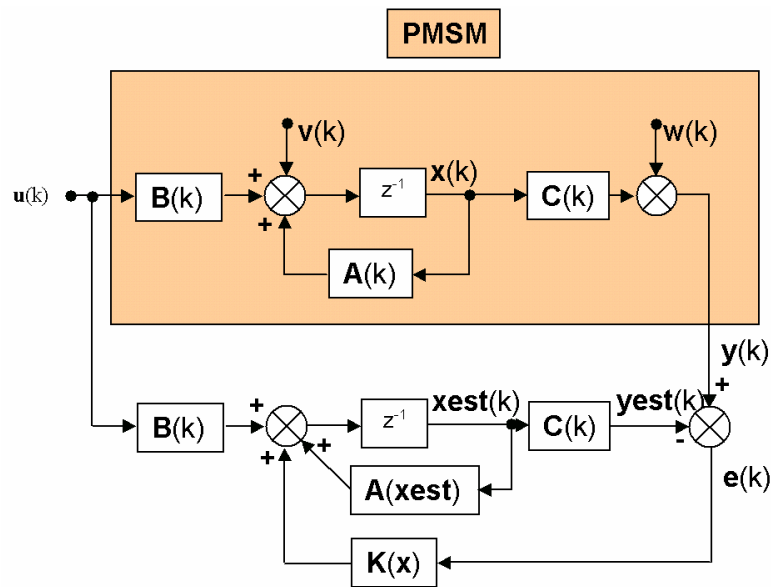


Fig. 2. System of the EKF

3 Extended Kalman Filter

The goal of the Kalman filter (Fig.2) is to obtain unmeasurable states (speed and rotor position) by using measured states and also statistics of the noise and measurements (covariance matrices \mathbf{Q} , \mathbf{R} , \mathbf{P} of the system noise vector, measurement noise vector and system state vector (\mathbf{x}) respectively). In general, by means of the noise inputs, it is possible to take account of computational inaccuracies, modelling errors, and errors in the measurements.

The filter estimation (\mathbf{x}_{est}) is obtained from the predicted values of the states (\mathbf{x}) and this is corrected recursively by using a correction term, which is the product of the Kalman gain (\mathbf{K}) and the deviation of the estimated measurement output vector and the actual output vector ($\mathbf{y} - \mathbf{y}_{est}$). The Kalman gain is chosen to result in the best possible estimated states [3].

4 Simulation results

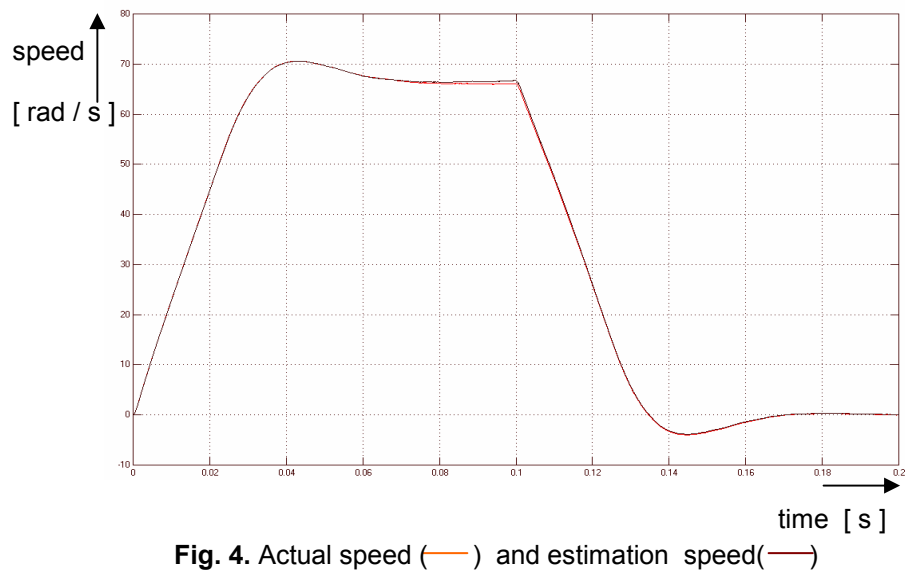
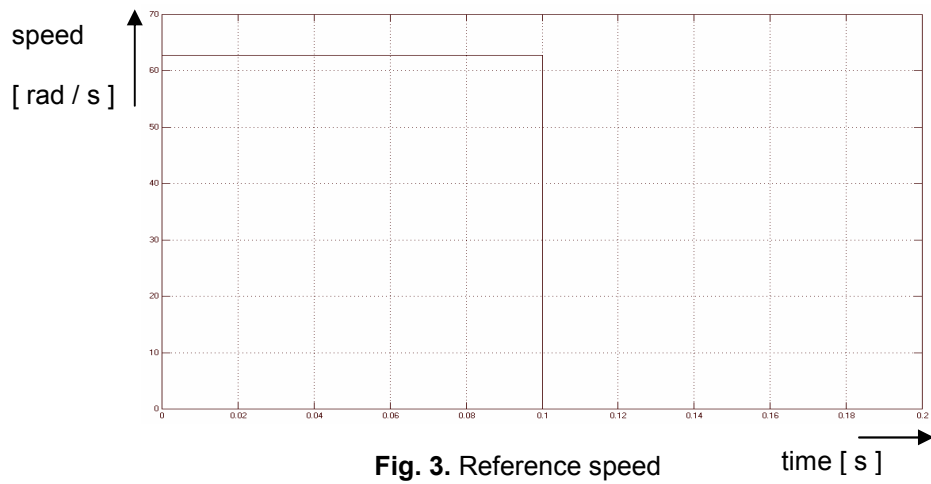
The A.C. drive has been simulated in program MATLAB-Simulink. The simulations were done for the drive system with the PMSM with the following parameters:

$$\begin{aligned}P_n &= 890 \text{ W}, \quad T_n = 17 \text{ Nm}, \\ \omega_n &= 52.3 \text{ rad/s}, \quad p = 3, \\ P_n &= 890 \text{ W}, \quad \omega_{\max} = 209.3 \text{ rad/s}, \\ \Psi_F &= 0.378 \text{ Wb} \\ J_m &= 0,0104 \text{ kgm}^2, \quad J_{km} = 0 \text{ kgm}^2, \\ T_{km} &= 0 \text{ Nm}, \quad U_{sn} = 78/45 \text{ V}, \\ I_{sn} &= 16 \text{ A}, \quad T_{km} = 0 \text{ Nm}, \\ R_s &= 0.14 \text{ } \Omega, \quad L_d = L_q = 1.29 \text{ mH}\end{aligned}$$

Reference and actual angular speed responses, actual and estimation position of the rotor, torque component of the stator current vector I_q responses of A.C. drive are shown in Fig. 3, 4, 5, 6.

Acknowledgement

In the paper are the results of the project CEZ:J17/98:272400014, which was supported by The Ministry of Education of Czech Republic. This research was supervised by Prof. Ing. Pavel Brandštetter, CSc.



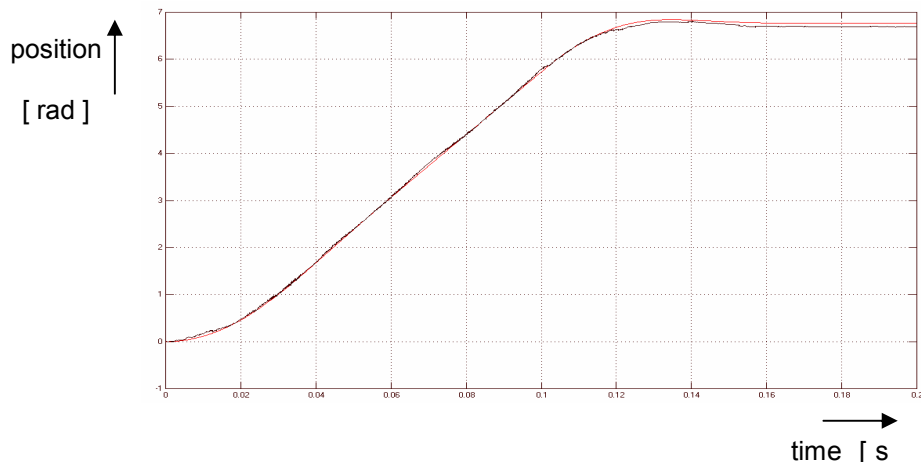


Fig. 5. Actual(—) and estimation (—) position of the rotor

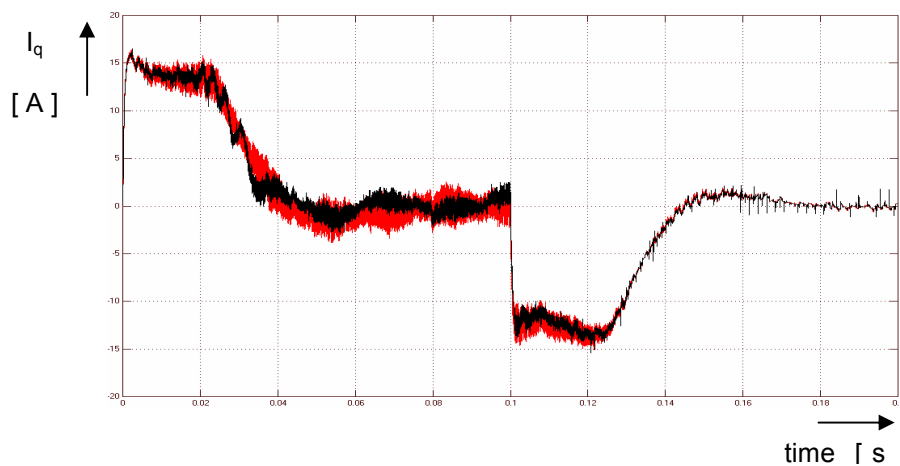


Fig. 6. Actual I_q (—) and estimation I_q (—)

References

1. Brandštetter, P.: *A.C. Control Drives – Modern Control Methods*. VŠB-Technical University of Ostrava, 1999. ISBN 80-7078-668-X.
2. Neborák, I.: *Modelling and Simulation of Electrical Control Drives*. VŠB-Technical University of Ostrava, 2002. ISBN 80-248-0083-7.
3. Vas, P.: *Sensorless Vector and Direct Torque Control*. Oxford University Press, 1999. ISBN 0 19 856465 1.