

MODEL PREDICTIVE SPEED CONTROL FOR THREE PHASE INDUCTION MOTOR

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Abstract: In this paper an alternative method to the classical control of the induction motor drive system is proposed. More exactly, a model predictive control (MPC) for the rotor speed of the induction motor is presented. The numerical simulation is done using Simulink and then the results are compared with a classical approach (PI controller).

Keywords: model predictive control, three phase induction motor, Matlab / Simulink.

1. INTRODUCTION

The induction motor drive system (IMDS) is highly appreciated and utilized in industry because of some key factors: reliability and relatively low cost, simple construction and less maintenance (Merabet, 2012). Moreover, IMDS can be used in stressful environment because there are no risks of corrosion or sparks (Șolea, *et al.*, 2013).

One key domain is the metallurgic one (for example the cold rolling mills subdomain). Initially, the DC drives were very popular, but with the years they were replaced with IMDS because of their advantages (Roman, 2011).

However, the IMDS is a multivariable nonlinear system, time varying, so the control problem is still a challenging problem.

A milestone in the control of IMDS has been established by Blaschke in 1972 when he proposed the field oriented control method.

Along the years, various control methods for the IMDS had been proposed. Of course, the classical ones, involving PI controllers (Leonhard, 2001) remain most popular because of the decent

performances combined with the easiness in the implementation. However, sometimes the disadvantages of the PI controllers, like poor rejection of external disturbances and load changes could be very annoying. So, alternative approaches had been proposed: optimal control (Veerachary, 2002) or sliding mode control (Chen, *et al.*, 2003), (Utkin, *et al.*, 1999).

In this paper the MPC (Garcia, *et al.*, 1989) of the speed of IMDS is investigated. The paper is structured as follows: in section 2 the mathematical model of the IMDS is presented, in section 3 some of the MPC basics are shown, section 4 is dedicated to implementation of MPC and simulation results and the last section draws some conclusions.

2. THE MATHEMATICAL MODEL OF THE IMDS

The mathematical model of the IMDS consists of the differential equations of the induction machine in rotor field based coordinates:

$$\begin{aligned}
 \tau_R \frac{di_{mR}}{dt} + i_{mR} &= i_{sd} \\
 m_e &= \frac{2}{3} p \frac{M}{1 + \sigma_R} i_{mR} \cdot i_{sq} \\
 \frac{J}{p} \frac{d\omega_e}{dt} &= m_e - \frac{F}{p} \omega_e - m_l \\
 \frac{dq}{dt} &= \frac{1}{p} \omega_e + \frac{i_{sq}}{\tau_R \cdot i_{mR}}
 \end{aligned}
 \tag{1}$$

where:

- i_{sd} the flux component current;
- i_{sq} the torque component current;
- i_{mR} the magnetizing current;
- ω_e the instantaneous electrical angular velocity of the rotor;
- m_e electromagnetic torque of the induction motor;
- m_l load torque;
- q the angular positions of the rotor field;
- J the combined inertia of the motor and load;
- F the viscous friction coefficient;
- M mutual inductance between the stator and rotor d,q equivalent windings;
- τ_R the rotor time constant;
- σ_R the rotor leakage factor;
- p the number of pole pairs.

By using the field oriented control and introducing the adequate terms, the decoupling torque and flux control loops are obtained. Through the adequate control of the power converter the rotor magnetizing current, i_{mR} , is maintained at the constant value. Therefore, the mathematical model of the IM becomes linear:

$$\begin{aligned}
 \begin{bmatrix} \dot{\omega}_m(t) \\ \dot{q}(t) \end{bmatrix} &= \begin{bmatrix} -\frac{F}{J} & 0 \\ 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} \omega_m(t) \\ q(t) \end{bmatrix} + \begin{bmatrix} \frac{K_m}{J} \\ \frac{1}{K_q} \end{bmatrix} \cdot i_{sq}(t) \\
 &+ \begin{bmatrix} -\frac{1}{J} \\ 0 \end{bmatrix} \cdot m_l(t)
 \end{aligned}
 \tag{2}$$

with specific constants

$$k_q = \frac{1}{\tau_R i_{mR}}, \quad k_m = \frac{2}{3} p \frac{M}{1 + \sigma_R} i_{mR}, \quad k_F = \frac{p}{F}$$

or in the standard state space form

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t) + \mathbf{G}\mathbf{w}(t),$$

in which the state vector

$$\mathbf{x}(t) = \begin{bmatrix} \omega_m(t) \\ q(t) \end{bmatrix}$$

(ω_m the instantaneous mechanical angular velocity of the rotor, q the angular position of the rotor field), the

control vector $\mathbf{u}(t) = [i_{sq}(t)]$ (i_{sq} the torque component current) and the perturbation vector $\mathbf{w}(t) = [m_l(t)]$ (load torque).

3. MODEL PREDICTION CONTROL BASICS

As is shown in Morari, *et al.*, (1991) the MPC is recommended to be used when: the processes have a large amount of dead time, the control objectives of a process are changed, a process with a large number of manipulated and controlled variables (this is the case of IMDS), a process with constraints on the manipulated and / or controlled variables or even when an equipment or a sensor from the process fail.

The main advantages of the MPC (Morari, *et al.*, (1991) are the fact that isn't required an explicit process identification procedure, so you don't need a state-space or transfer function of the process; an online optimization procedure is usually used so we can deal with disturbances or sensor failures. The main drawback (Hugo, 2000) is that all the constraints and control objectives must be incorporated into a single criterion function which must be optimized.

Predictive control is based on three types of actions:

- obtaining a process model to make a prediction of its output in a given time horizon;
- computing a control sequence on a specific time horizon by minimizing a criterion function;
- applying to the process only the first value from the control sequence, then update prediction horizon and repeat the optimization procedure.

The principles highlighted above can be seen in fig. 1:

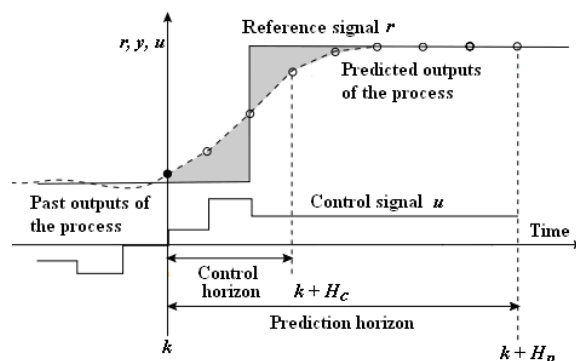


Fig.1 Predictive Control (Babuska, 1998)

The future outputs of the process are predicted on a time horizon H_p based on the process model. The predicted outputs, $\hat{y}(k+i)$, $i = 1, \overline{H_p}$, depends of the state of the process at time k and the control

signals $u(k+i)$, $i = \overline{1, H_c - 1}$, where $H_c \leq H_p$ is the control horizon. The control signals are changing only in the control horizon. Outside this horizon, the control signals don't change anymore:

$$u(k+i) = u(k + H_c - 1), \quad i = \overline{H_c, H_p - 1}.$$

The sequence of the control signals $u(k+i)$, $i = \overline{1, H_c - 1}$ is computed, usually, by optimizing a quadratic criterion of the form:

$$(6) J = \sum_{i=1}^{H_p} \|r(k+i) - \hat{y}(k+i)\|_{P_i}^2 + \sum_{i=1}^{H_c} \|\Delta u(k+i-1)\|_{Q_i}^2$$

The first term from the criterion minimizes the difference between the process' output and the reference, while the second term penalizes the control effort. The matrices P_i , Q_i are positive definite and they are weighting the two terms from the criterion. For systems with dead time or non-minimum phase additional terms could be introduced in the criterion.

4. SIMULATION RESULTS

In order to show the performance of the proposed MPC the simulation results are presented in this Section.

The simulation scheme is presented in Figure 2. The scheme is detailed in Costin *et. al.* (2009).

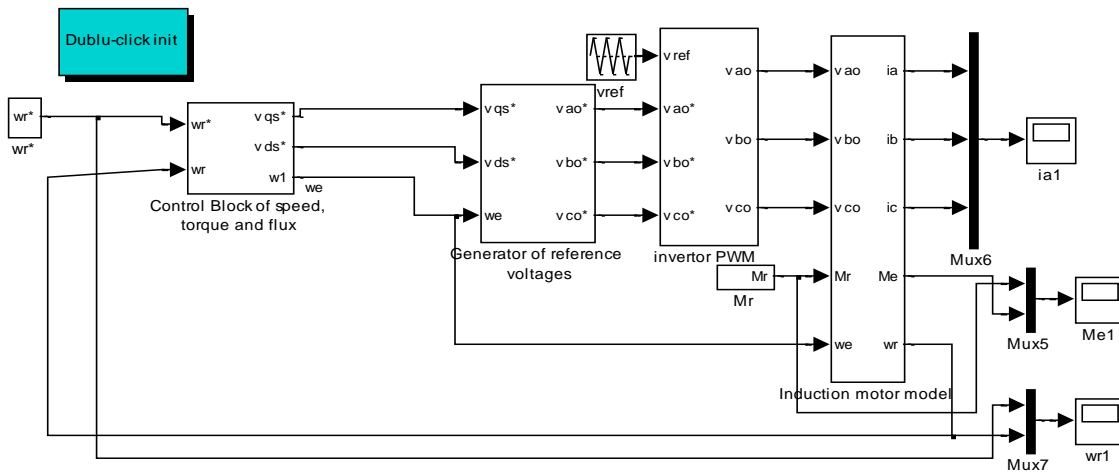


Fig.2 The Simulink scheme of IMDS (Costin, 2009)

The control block, which is our main interest, is detailed in Figure 3. The control structure is composed by three controllers: one MPC (for the rotor speed) and two PI controllers (for the torque and flux regulation). The methodology of PI controllers tuning is not covered by this paper. Their

implementation is already detailed in Costin *et. al.* (2009) and Găiceanu *et. al.* (2013). The MPC controller has been developed using the Simulink Self-Tuning Predictive Controllers Library (Chalupa, 2009).

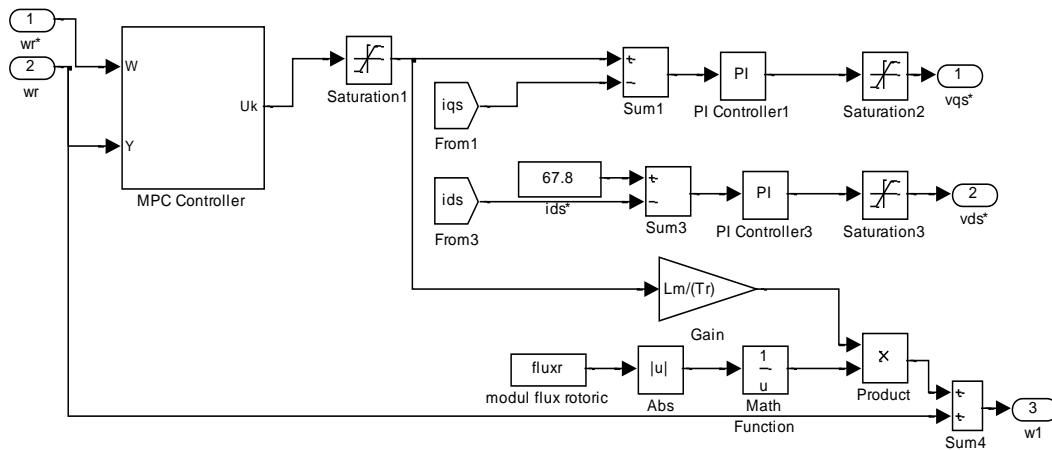


Fig.3 The detailed control block

In this paper the following quadratic criterion was used:

$$J = \sum_{i=1}^{H_p} \|w(k+i) - \hat{y}(k+i)\|_{\lambda e}^2 + \sum_{i=1}^{H_c} \|\Delta u(k+i-1)\|_{\lambda du}^2 + \sum_{i=1}^{H_c} \|u(k+i-1)\|_{\lambda u}^2$$

where:

w – is the reference speed, y – is the actual speed, u – is the control signal provided by the MPC controller and $\lambda e, \lambda du, \lambda u$ – are the weighting terms. Other criterions with good results are the linear one (sum of absolute values) or min-max (minimization of maximal absolute value) (Chalupa, 2009).

After few numerical simulations and tuning procedures the following values of the MPC parameters have been choose:

Table 1 MPC parameters

Symbol	QUANTITY	Value
H_p	Horizon prediction	10
H_c	Horizon control	5
λe	Control error weight	30
λdu	Control signal differences weight	0.1
λu	Control signal weight	0.1

The model of the controlled process is chosen to be of the ARX (Auto Regressive with Exogenous input) type. The online identification of the model is done using Recursive Least Squares Method with adaptive directional forgetting (Chalupa, 2009).

At the time 0.2s the 20Nm step load torque is initiated (Fig. 4), the both electrical drive system, based on PI and MPC controllers tracks very well the imposed reference speed (steady state error becomes zero-Fig.6).

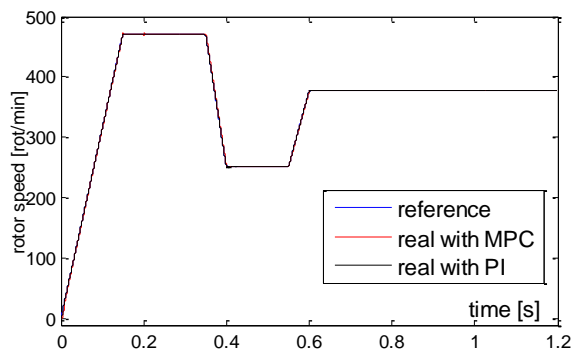


Fig.4 The reference and real rotor speed signals

However, by using an adequate time scale (Fig. 5) some differences between the control methods of the rotor speed (MPC and PI) are depicted.

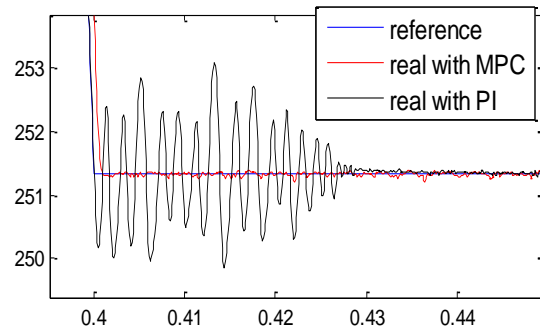


Fig.5 Reference and real rotor speed signals (magnified)

The rotor speed error signal is depicted in Figure 6.

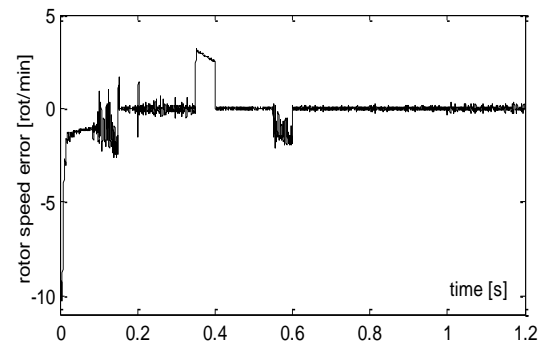


Fig.6 Rotor speed error signal

5. CONCLUSIONS

In this paper a model predictive speed control for a three phase induction motor was proposed. Simulation results, made with Simulink software, show that the alternative MPC has very good performances.

Also, the control scheme shows good robustness when an external disturbance (load torque) becomes active.

In future works the authors will extend the predictive control for torque and flux regulation.

Acknowledgment

The work was supported by a grant of the Romanian National Authority for Scientific Research, CNDI-UEFISCDI, Project number PN-II-PT-PCCA-2011-3.2-1680.

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