

PREDICTIVE CONTROL OF INDUCTION MOTOR DRIVE USING DSPACE

P. Karlovský, J. Lettl

Department of electric drives and traction, Faculty of Electrical Engineering, Czech Technical University in Prague

Abstract

Since the induction motor drives have gained its popularity among regulated drives area, the great effort is put on increasing their efficiency. The use of predictive algorithm to control their speed is becoming a popular approach that preserves high efficiency. This paper presents implementing predictive control on the dSPACE DS1103 system, where the dSPACE is the control part of the system, drives the outputs of the power IGBTs and provides online communication with computer through ControlDesk.

1 Induction motor drive

Induction motors (IM) are nowadays thanks to their simplicity, price, robustness and high reliability the most widely used motors in the area of regulated drives and are displacing DC motors. IM consists of two main parts, the stator and the rotor. The stator is made of a three phase winding circuits and the individual windings are positioned in a way to create a rotating magnetic field when AC voltage is connected to its terminals. The rotor consists of cylindrical core with parallel conductors from copper or aluminum that are short circuited by the end rings.

When the stator winding is connected to a 3 phase AC source, it creates a rotating magnetic field at an angular speed of the AC source. As the rotor winding in an induction motor is directly shorted by end ring an emf is according to Faraday's law induced in the rotor and a current flows through the rotor. The rotor current then creates its own magnetic field. Here the relative velocity between the rotating stator flux and rotor flux is the cause for torque generation. So the rotor will rotate in the same direction to reduce the cause, in this case the relative velocity. Therefore, it can be observed that the rotor can not reach the speed of the stator flux. If the speeds equals, there would be no difference in velocities, so no induction in the rotor and no current would be flowing. Therefore, no torque would be generated.

The induction motor can be described by a few sets equations. The equations used for model in this application are provided in [1]. The first two equations describe generation of stator and rotor flux from AC voltage source and from rotor currents respectively. The third and fourth describe linkage between fluxes and currents and the fifth equation describes a torque generated by the IM.

$$u_s = R_s \cdot i_s + \frac{d\Psi_s}{dt}$$

$$0 = u_r = R_r \cdot i_r + \frac{d\Psi_r}{dt} - \omega \cdot \Psi_s$$

$$\Psi_s = L_s \cdot i_s + L_m \cdot i_r$$

$$\Psi_r = L_r \cdot i_r + L_m \cdot i_s$$

$$M = \frac{3}{2} \cdot p_p \cdot k \cdot \Psi_s \times \Psi_r \tag{1}$$

where u is voltage, i is a current, ψ is a magnetic flux, R is a resistance, L is an inductance, ω is a speed, M is a torque, p_p is a number of pole pairs and k is a constant. The subscripts mean whether the variable is for a rotor (r) or a stator (s).

2 Predictive method

The main disadvantage in IM use lies in difficult speed regulation when compared to the DC motors. The speed of IM is dependent on frequency of the power source. Earlier, the generation of variable frequency was the main problem limiting their use. But many effective possible ways of controlling them have been developed since the modern power semiconductors were invented. However, high switching frequency is required in order to keep the drive in desired state. The increase of switching frequency is not desirable due to the switching losses on transistors, which generates heat. This heat has to be dissipated and it is problematic in some applications. The great attention is nowadays being paid to predictive algorithms that can precalculate behavior of the system and are able to adjust the outputs for transistor in order to prevent unnecessary switching.

As mentioned in chapter 1, the torque generated by motor is strongly dependent on the angle between the stator magnetic flux and rotor magnetic flux. The stator flux amplitude and angle can be easily controlled by stator voltage and the rotor flux then follows the stator flux with certain delay. Common methods calculate the fluxes in every step of the controller and then choose the voltage vector according to the actual values. The predictive control proposed in this paper precalculates the state of the fluxes for the next period and according to that it tries to choose better voltage vector to achieve desired state of IM.

The predictive method consists of a model, controller and a voltage calculation. At first, the model is calculated and tells the current state of the motor. This calculation is based on the motor equations presented in chapter 1. The inputs for this model are taken from measured values as well as from previous commands for inverter. The outputs are torque and rotor flux (needed for predictive controller) and the stator flux vector (needed for comparison with future state).

Then the predictive controller estimates future values. The result of this controller is the stator flux vector for next step that is then compared with actual values. The vector is calculated according to the Figure 1, where the composition of fluxes in an IM is depicted. The future angle of stator flux is calculated as a sum of red colored curves. They are the actual angle of rotor flux (estimated in model), difference between actual and future rotor flux angle (as stated in chapter 1 the rotor flux is changing with certain delay) and difference between rotor and stator flux angle in future. The first two parts are easily calculated from the model presented in chapter 1, but the third part of the equation is more complicated. It is based on the reverse calculation related to the first model. It calculates what the angle should look like in order to reach the desired values in the next step. The inputs are the current state calculated by first model and desired values and the output is what the stator flux should look like in order to operate in the desired values.

Then the models are compared and from the difference the best voltage for inverter is chosen and applied. The voltage information is then also used as input in model for next step as previous values and together with measured values the process starts again.

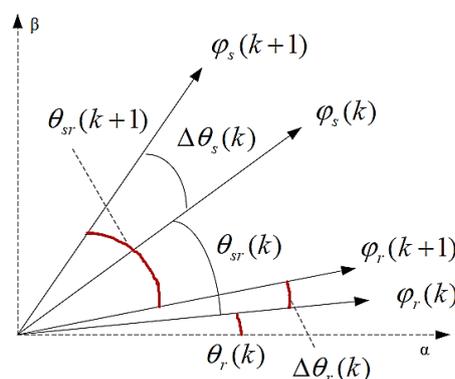


Figure 1: Composition of fluxes in an IM

3 Implementation

However, such control algorithm as described in chapter 2 is very sophisticated and requires a lot of computational power. As dSPACE is a suitable platform for these applications, it was chosen for the implementation of the predictive control. The scheme of workplace and algorithm executed by dSPACE is presented in the Figure 2 and the photo of workplace is in the Figure 3. It consists of power part where power source, diode rectifier, DC link, IGBT inverter, induction motor (4-pole IM with 5.5 kW output power) and load are assembled, of dSPACE that models the process, predicts future state and generates commands for inverter and of ControlDesk communicating with dSPACE.

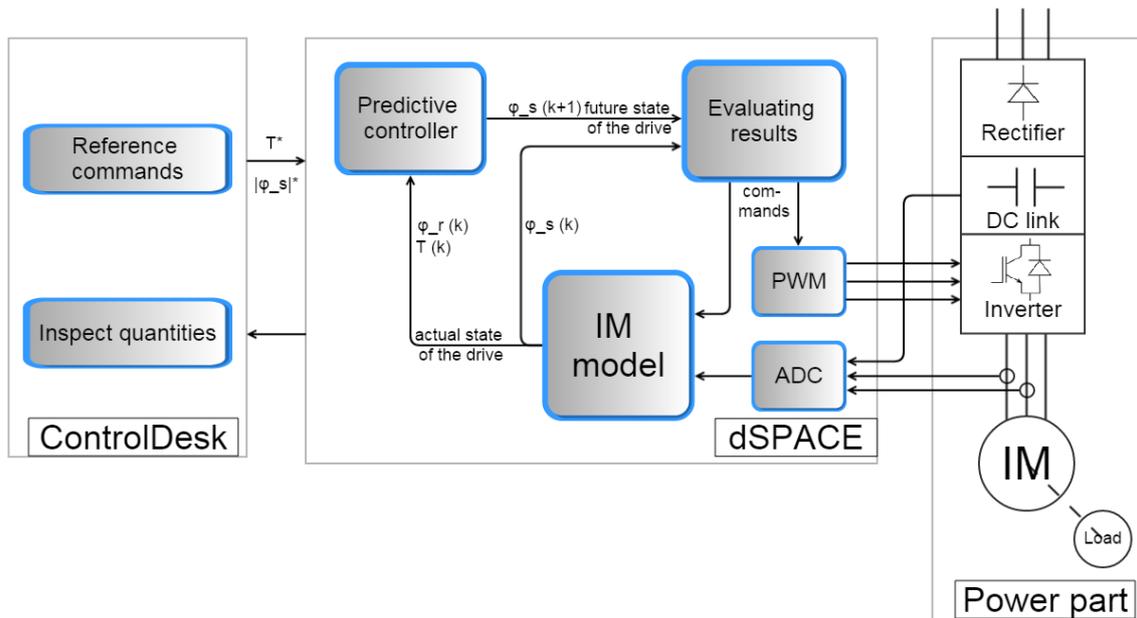


Figure 2: Scheme of workplace



Figure 3: Photo of workplace

As the the control application for the drive calculates switching commands for the transistors, it has to run in real time. Debugging and stopping of the code execution could destroy controlled power electronics and therefore it is not possible. Because of this, the testing of the code is much more problematic. For this purpose, Matlab Simulink environment was used. In the environment, the model of the whole drive including supply, indirect frequency inverter, motor and load was created. The functionality of this model was tested in this simulation environment at first. After that the predictive control part was realized and tested on this model. The results of simulation tests are presented in the left side of Figure 6.

Then the control algorithm was implemented on real drive. In the implementation a few changes needed to be done in the created model. The model of the drive was removed from scheme and its signals were replaced with A/D converter for measured quantities and PWM outputs for inverter commands. The components from dSPACE real time toolbox were used. Three A/D converter inputs were used. They were the current of two phases was connected flowing to the motor and a voltage

level in DC link. All three variables were measured with 10 kHz frequency. The maximal allowed frequency of changing commands for PWM block was also set at 10 kHz, but most of the time the predictive control kept it at lower switching frequency. In Figure 4, the control algorithm is seen. The code was then loaded into dSPACE DS1103. The control algorithm in dSPACE ran at 20 kHz (50 μ s calculation loop). The results of run on this hardware are shown in the right side of Figure 6.

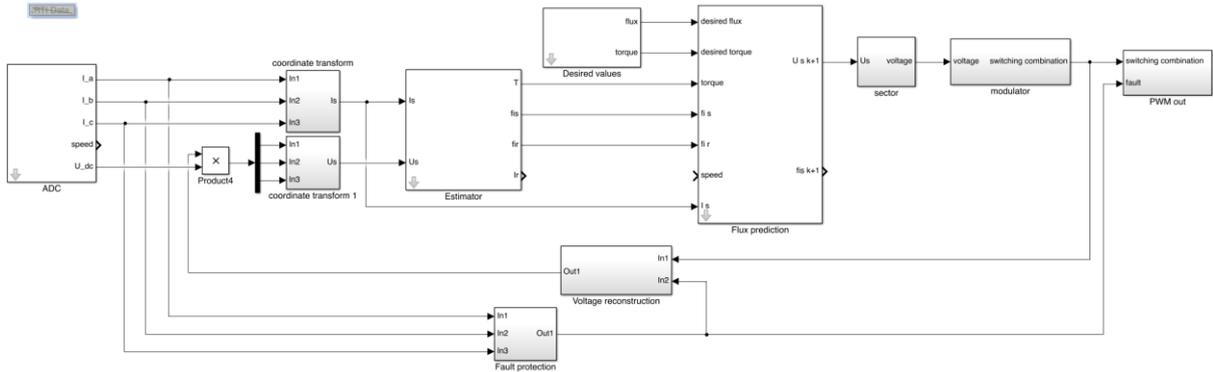


Figure 4: Control algorithm in dSPACE

The system communicates with the computer via ControlDesk through LAN over RJ-45 cable. ControlDesk gives reference commands for the control algorithm such as desired electromagnetic torque and magnetic flux in the motor. It also observes variables calculated by the algorithm and visualizes them online, so only minimum of other equipment like oscilloscopes and probes was needed for developing. The evaluation of the correct behavior of the predictive controller could be performed and the functionality of the controlled drive could be then with ControlDesk verified. An example of displayed variables and possible commands and settings are presented in Figure 5.



Figure 5: ControlDesk example

4 Results

In order to verify the control strategy, the proposed method was in the simulation environment Matlab Simulink realized and its behavior was tested on a 5.5 kW model of induction motor. Then it was further tested on real IM. The goal of the tests was maintaining torque value and flux amplitude value constant. In Figure 6 there can be the waveforms of torque, flux and phases currents seen for the Matlab Simulink (left side) and dSPACE (right side) run. The good match between simulated and measured waveforms of the variables can also be observed thanks to among others easy

implementation of the Simulink model into real hardware with dSPACE and online tuning in ControlDesk.

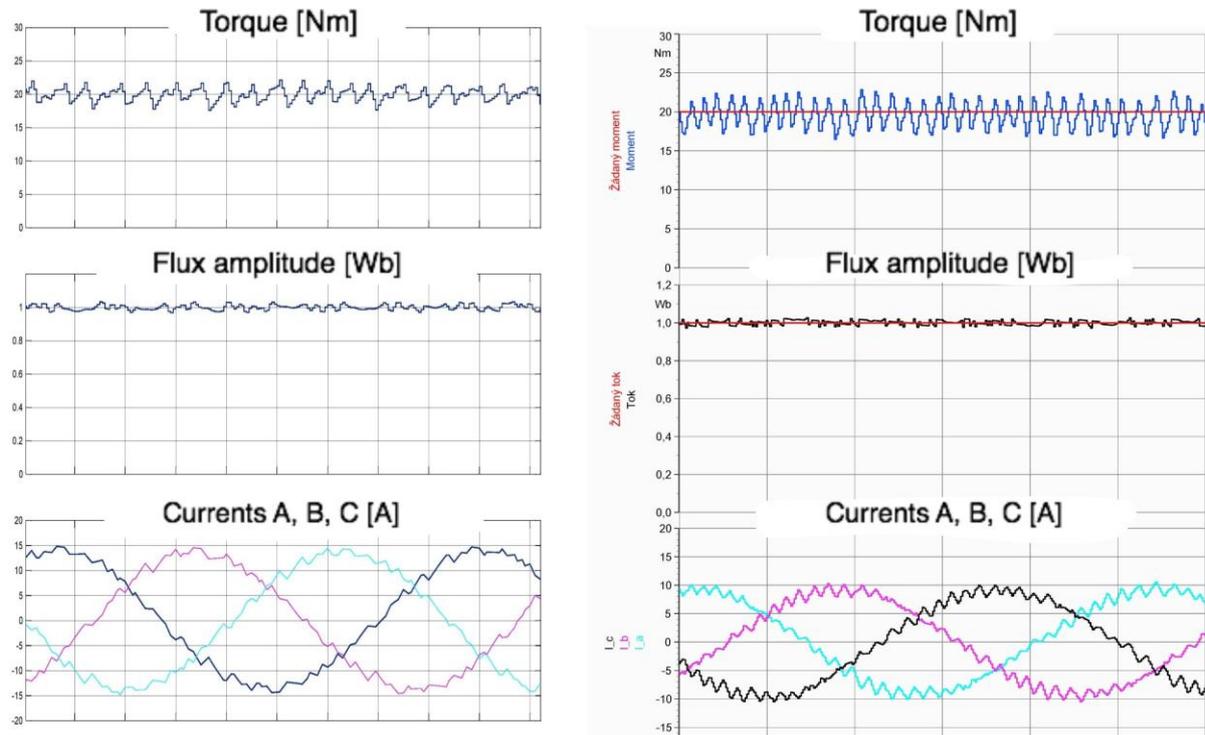


Figure 6: Simulation and experimental results

In Figure 7, there is a stator flux vector trajectory shown as a vector in the X-Y graph during one rotation of the motor. As the amplitude is being maintained constant the curve is circle. An ideal circle would be reached with infinite switching frequency of the inverter transistors and with lowering of switching frequency the curve becomes more uneven. On the right side of the picture the actual and predicted values of calculated flux vector were captured and are presented.

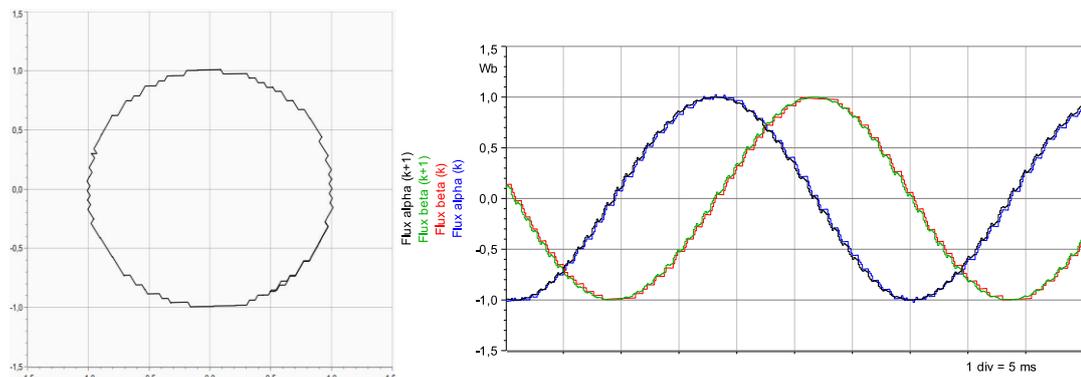


Figure 7: Flux prediction

5 Conclusion

A predictive control method of induction motor drive was introduced in this paper and the mathematical description of the system was provided. The controlled system model was created in the simulation environment Matlab Simulink and its behavior was tested. The predictive control strategy was implemented on the real induction motor drive with the dSPACE control system and the simulation results were verified by the experiment.

Acknowledgement

This work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS SGS15/078/OHK3/1T/13.

References

- [1] Lettl J., Karlovsky P., “*Induction Motor Drive Predictive Control Method Analysis and Comparison with Fundamental Direct Torque Control Method*,” in PIERS Proceedings, pp. 2510 - 2513, July 6-9, Prague, 2015
- [2] LINHART R., Přímé řízení momentu asynchronního motoru, bachelor thesis, ČVUT v Praze, 2014
- [3] FAN S., LUO J., HU Z., A voltage vector prediction direct torque control system for induction motor, International Conference on Electrical and Control Engineering (ICECE), 2011, ISBN 978-14244-8162-0

Pavel Karlovský

Czech Technical University in Prague, Faculty of electrical engineering, Department of electric drives and traction, karlopav@fel.cvut.cz

Jiří Lettl

Czech Technical University in Prague, Faculty of electrical engineering, Department of electric drives and traction, lettl@fel.cvut.cz