TESTING OF THE MATRIX CONVERTER INDUCTION MACHINE DRIVE CONTROL ALGORITHM IN MATLAB/SIMULINK

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Abstract

Simulation is nowadays common way how to develop and test control algorithm of a drive before its run up on the real converter. The main problem is that because the control algorithm of the drive has to run in real time and it usually calculates and then outputs switching commands for the transistors, debugging and stopping of the algorithm execution is not possible. Therefore the developed code has to be tested in another way before putting to the real controller. This paper describes development and testing of FOC algorithm for IM drive fed by matrix converter.

1 Matrix Converter

Matrix converter is a frequency converter, which does not contain a DC-link and therefore no bulky passive accumulation element are needed as it is common in indirect frequency con- verters. That makes matrix converter perfect candidate for applications, where the DC-link is not allowed because of the volume or where the weight of the device is more important than its price. It is to underline that this converter produces output voltage by direct switching of the proper input voltage to the output terminals. This fact limits maximal output voltage amplitude to 86.6% of the input voltage amplitude. In contrast this way of conversion offers abilities as regulation of input power factor and possibility of the work in all four quadrants.

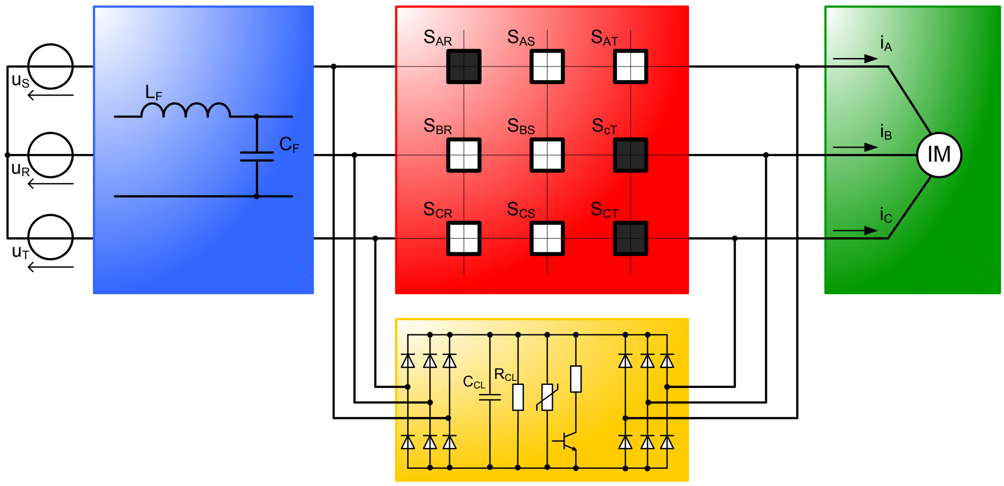

Figure 1: Matrix converter block diagram

Because of the absence of the DC link there exists several restrictions paced on the matrix converter's switching patterns:

- The input of the matrix converter can be considered as voltage source, therefore in every switching moment none of the input phases shall be shortcircuited.
- The load connected to the output of the converter has mostly inductive character. Any of the output phases of the converter cannot be disconnected.

With respect to these restrictions several modulation strategies has been developed. The indirect space vector modulation (ISVM) proposed by Huber and Borojevic belongs among them. The principle of ISVM is based on splitting of the converter virtually into two parts according to the function that they perform (Figure 2). The matrix converter can be taken as a combination of virtual current source rectifier and virtual voltage source inverter connected by virtual DC link. The virtual inverter then generates output voltage in same way as VSI. The virtual rectifier directs output current to input phases to consume sinusoidal currents with defined power factor. The switched voltage vectors are selected from space vectors available for both parts.

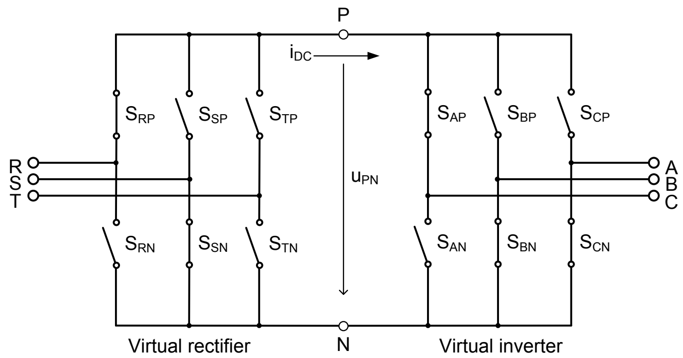

Figure 2: Matrix converter ISVM model

2 Induction Machine

The induction motors (IM) becomes recently spread ones in the area of regulated drives. Main advantage of the IM is its robustness, low maintenance, low cost and high reliability. However the speed regulation is more complicated compared to DC machines. Because of its principle the speed of IM depends directly on the frequency applied to its terminals. The generation of the voltage with variable frequency was the main limiting problem of IM application at the beginning. This problem was eliminated by arrival of power electronics and utilization of frequency converters.

In order to obtain maximum performance from the drive, a precise regulation al- gorithm is needed. These algorithms are based mostly on the regulation of machine flux, that can not be measured directly. For an estimation of the inner machine flux, the models based on machine equations, machine parameters from an equivalent circuit and measured values are used. The final accuracy of the equivalent circuit and herby controller as well depend on an exact knowledge of the equivalent circuit values.

The aim of vector control is not only the control of magnitude and frequency but also the control of orientation of the controlled variables in machine. Methods of vector control can be further divided according to many criterions e.g. if the flux is controlled directly or indirectly, or if the controlled variable is stator resp. rotor or air gap flux, according to incorporated type of modulator, etc. But all methods offers high dynamics of regulation and tries to decouple control of flux and torque, thus they can be controlled independently like separately excited DC machine. The vector control aims to split current space vector into flux producing current component i_{sd} and torque producing component i_{sq} and regulate these components separately. The flux producing component i_{sd} is always oriented with the reference flux vector (stator resp. rotor) and therefore the decomposition of the current space vector into current components depends on selected reference flux. Simple block schematics of the vector control structure is in Figure 3. The block with motor model is used for calculation of actual position of the flux, that is further used in transformations. Current components are separately regulated, decoupled, then transformed into values acceptable by modulator.

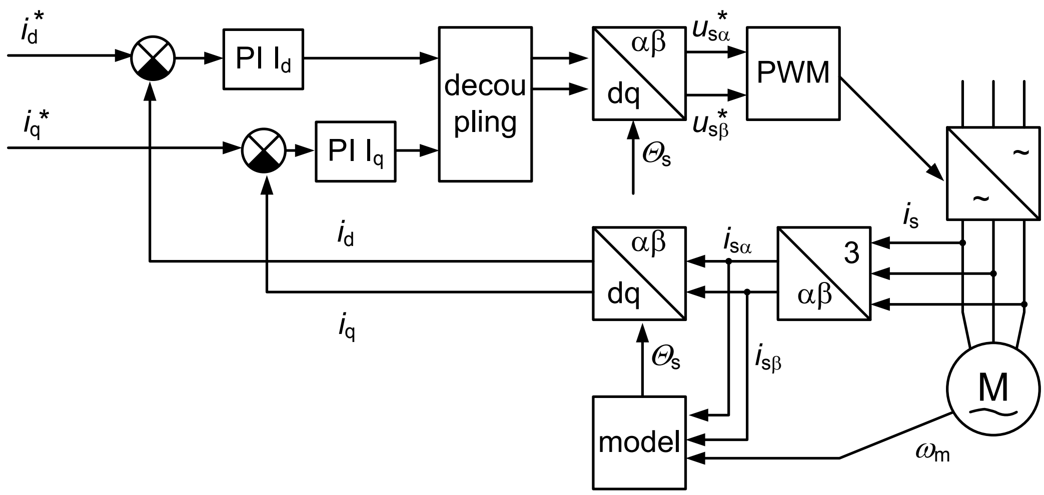

Figure 3: Vector control block diagram

Equations (1) and (2) describes behavior of the induction machine and are therefore used in the model of the IM in Figure 2.

$$\underline{u}_{\mathrm{s}}^{k}\mathbf{e}^{\mathrm{j}\theta_{\mathrm{k}}} = R_{\mathrm{s}}\underline{i}_{\mathrm{s}}^{k}\mathbf{e}^{\mathrm{j}\theta_{\mathrm{k}}} + \frac{\mathrm{d}}{\mathrm{d}t}\underline{\Psi}_{\mathrm{s}}^{k}\mathbf{e}^{\mathrm{j}\theta_{\mathrm{k}}}$$

$$0 = \underline{u}_{\mathrm{r}}^{k}\mathbf{e}^{\mathrm{j}\theta_{\mathrm{k}}-\theta_{\mathrm{r}}} = R_{\mathrm{r}}\underline{i}_{r}^{k}\mathbf{e}^{\mathrm{j}\theta_{\mathrm{k}}-\theta_{\mathrm{r}}} + \frac{d}{dt}\underline{\Psi}_{r}^{k}\mathbf{e}^{\mathrm{j}\theta_{\mathrm{k}}-\theta_{\mathrm{r}}} \tag{1}$$

$$\underline{\Psi}_{\mathrm{s}}^{k} = L_{\mathrm{s}}\underline{i}_{\mathrm{s}}^{k} + L_{\mathrm{m}}\underline{i}_{\mathrm{r}}^{k}$$

$$\underline{\Psi}_{\mathrm{r}}^{k} = L_{\mathrm{r}}\underline{i}_{\mathrm{r}}^{k} + L_{\mathrm{m}}\underline{i}_{\mathrm{s}}^{k} \tag{2}$$

3 Control Algorith Simulation

Because developed control application have to run in real time and it calculates switching commands for the transistors, debugging and stopping of the code execution is not possible. Therefore the code have to be tested in another way. For this purpose were used SW Matlab/Simulink and toolbox Plecs (Piece wise Linear Electrical Circuit Simulator). The Plecs is toolbox for simulating of electromechanical components within Matlab environment and is specially developed for simulations of power electronics and drives.

The model of the whole converter including supply, input filter, transistor matrix and load was created at first. The functionality of this model was firstly tested by continuous time solver and with predefined switching patterns. This testing ensures that the ISVM modulator works properly. Then parts of the model that should run with the fixed step e.g. control algorithm, data measurement were put into separate sub model and parts of the code were transformed into Plecs C-script block. C-script block enables to simulate parts of code written in C-language to be simulated in Plecs. However the interconnections of the code modules are still handled by Simulink ”virtual wires”. In order to test whole structure of the application with handling of data through pointers the Mex function compiler of Matlab was used (Figure 4). In this way were tested all parts of code together. The model of matrix converter was further extended to simulate behaviour of commutation, dead-time and minimal switching times.

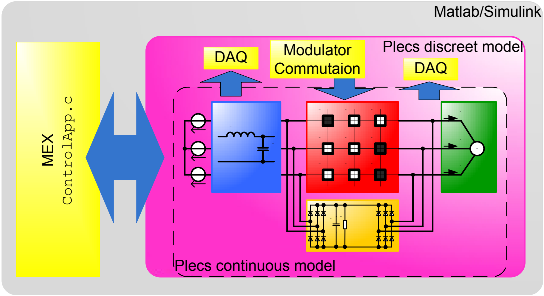

Figure 4: Vector control simulation

This sequence of the simulation model development was used further when developing the control strategies. The model of the IM controller was created from Simulink blocks at first, then transformed to the discreet time domain and finally implemented in Eclipse in C-language. The C-code was imported back into Matlab and connected to the model of matrix converter drive created in Plecs. All controller gains were tuned in Matlab/Simulink/Plecs simulations and only then the code put into the converter.

4 Results

As the first step when developing the control, simulation models of the drive in Matlab/Simulink, Plecs were created. Control algorithms written in C language were translated into Matlab Mex-functions and simulated. The power part of the converter and induction machine were simulated in Plecs toolbox.

To test the behaviour of the matrix converter control part field oriented control strategy was implemented. Induction machine was coupled to separately excited DC machine. Loading torque of the DC machine was controlled by variable resistor connected to armature terminals. Input and output currents are measured directly by the matrix converter. Speed is estimated by the controller. Comparison of the simulated waveforms and measured results are listed below.

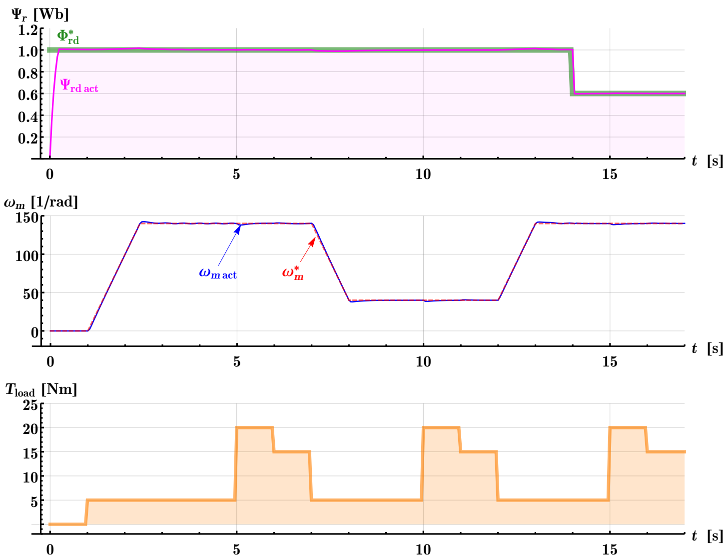

Figure 5: Vector control simulation

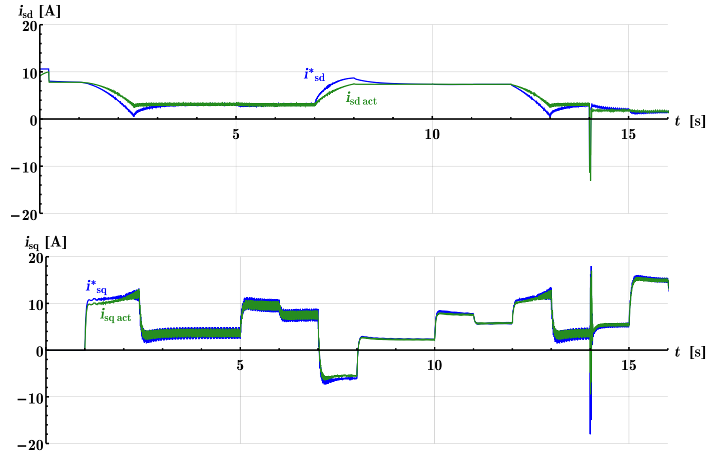

Figure 6: Vector control simulation – reaction to torque steps

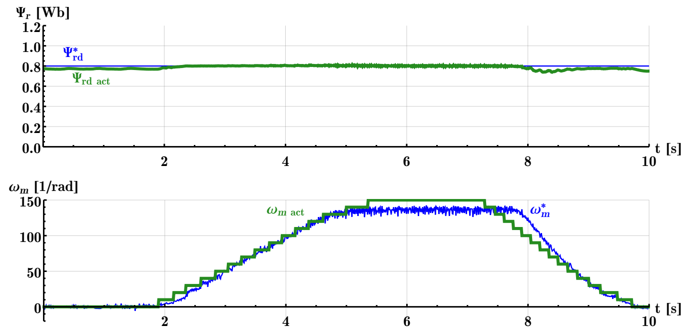

Figure 7: Vector control realization

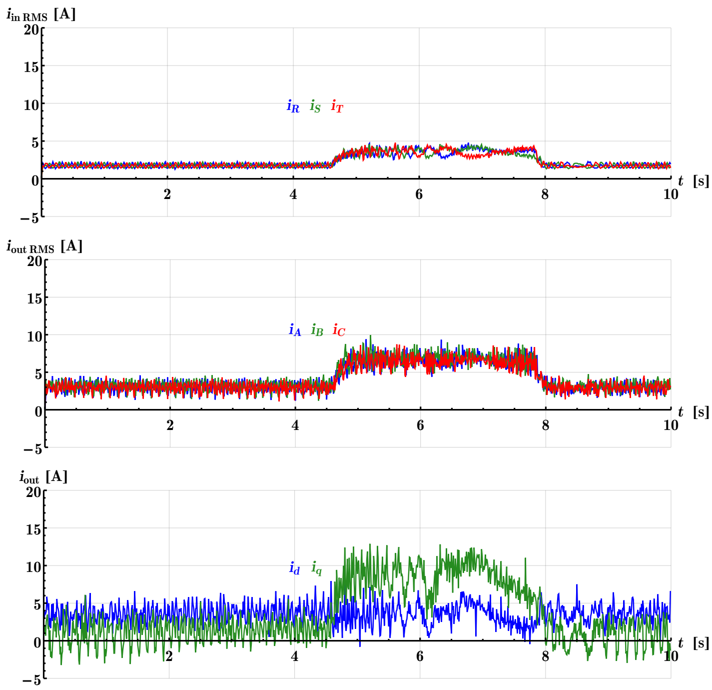

Figure 8: Vector control realization – reaction to torque step

From the simulated and measured results can be seen that they are in accordance. Testing of the developed C code of the control algorithm in Matlab/Simulink/Plecs environment was very helpful when designing own algorithm and also when tuning controller's gains. It was also much safer than testing of the algorithm on the real HW from the beginning.

Acknowledgement

This work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS SGS14/068/OHK3/1T/13.

References

[1] D. W. Novotny and Thomas A. Lipo, *Vector Control and Dynamics of AC Drive*, 1st ed., Oxford University Press, Oxford, 1996.
[2] B. K. Bose, *Power electronics and motor drives: advances and trends*, Academic Press, Amsterdam, 2006.
[3] P. W. Wheeler, J. Rodriguez, J. C. Clare, L. Empringham, and A. Weinstein, *"Matrix converters: a technology review,"* in IEEE Trans. on Industrial Electronics, 49(2):276–288, 2002.
[4] S. Fligl, *"Contribution to the mathematical description of the matrix converter power electronic topology,"* in Applied Electronics 2011 International Conference on, pages 1–4, 2011.
[5] L. Huber and D. Borojevic, *"Space vector modulation with unity input power factor for forced commutated cycloconverters,"* In Conference Record of the 1991 IEEE Industry Applications Society Annual Meeting, 1991, pages 1032–1041 vol.1, 1991.
[6] Lettl J., Fligl S., *"Matrix converter control system,"* in Proceedings of PIERS-05, pp. 395-398, Hangzhou, 2005.

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