Session 3: *Engineering Education and Practice*

Induction Machine Control Algorithm Implementation with MSK28335 Digital Platform

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Abstract: This paper presents possibilities of a Technosoft digital platform MSK28335 in control algorithm implementation of an induction machine. The educational aspect of a MSK28335 digital platform is emphasised and how it can gain students' knowledge and understanding of induction machine control principles through course of control of electric drives. Several control algorithms are presented and explained as well as MATLAB integration possibility which allows Rapid Control Prototyping option. This feature gives users to develop, implement and test new control algorithms in a simple and effective manner without having any advanced programming skills. The graphical results of each presented control algorithm are presented, followed by proper discussion.

Keywords: *MSK28335; IM control algorithms; Field oriented control; Rapid control prototyping; lab. setup.*

1. INTRODUCTION

The rapid development of electronics in the end of 80's years last century enabled to use the AC motors in applications where it required a high dynamics response. AC motors whose greatest advantages are robustness and reliability with the help of modern power converters have approached the great control capabilities of DC motors. Behind of using modern electronic components for the development of better control capabilities AC motors it's worthy to mention use of modern digital technologies. It refers to usage of fast digital signal processors (DSP) which allow implementation different algorithms for controlling AC motors [1]. Some more complex principles of control AC motors in relation to DC motors require more effort in understanding their operating principles. Different types of mathematical transformations, controller, types of power converters, microprocessor systems represent a complex system for understanding and mastering advanced control algorithms of control AC machines. For this reason, this paper presents Technosoft 's solution for testing induction motor control structures based on the use of the MSK28335 digital platform [2]. The MSK28335 digital platform basically consists of two main parts: the APCM750 v3.4 power module and the TMS320F28335 DSP control module. The MSK28335 platform comes with 5 implemented control algorithms where you can easily modify existing or implement new types of control AC motors. This makes it much easier for students to understand the principles of operation of modern algorithmic drive structures with AC machines. Also, the connection with the MATLAB software enables the avoidance of traditional programming in C language and easy and fast testing of new algorithms by applying Rapid Control Prototyping (RCP) principles. Lately, Rapid Control Prototyping has become quite popular and attractive in electric drive control algorithms development [3]. Quick and easy design of control algorithms allows engineers to test and enhance control methods and develop final prototypes in a simple and effective manner without advanced programming knowledge [4, 5].

2. Experimental setup description

Experimental laboratory setup with MSK28335 digital platform is shown in Fig. 1.
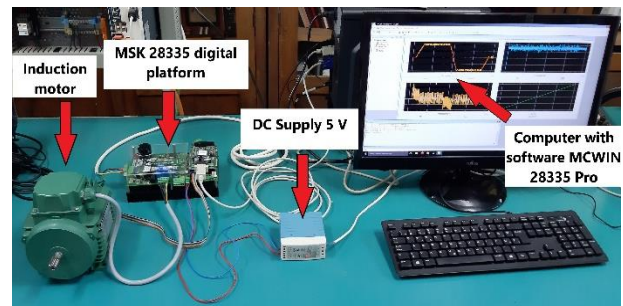
Figure 1. *MSK28335 experimental digital setup*

Induction machine – SIEBER L71 three phase induction machine, 750 W, with embedded encoder (500 ppr) on the rotor shaft and parameters given in appendix.

DC power supply – 5V DC logic power supply.

PC – computer with installed Technosoft software *MCWIN2833x PRO* and *DCM Developer Pro*.

MSK28335 – digital platform with Texas Instruments floating point processor F28335, 150MHz.

Fig. 2 shows main connectors and how the MSK28335 platform is connected to the rest of the experimental setup.
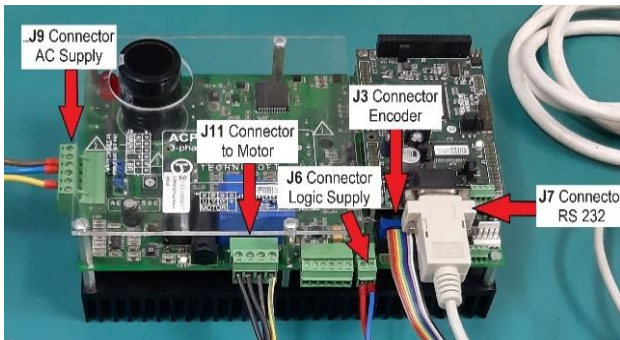
Figure 2. *MSK28335 main connectors*

J9 AC supply – power converter supply, AC 3ph - 110V or AC 1ph - 230V.

J6 logic supply – 5V DC logic power supply

J11 – 3ph induction motor connector

J3 – incremental encoder connector.

J7 – RS 232 serial communication with PC [9].

Technosoft's software package for control induction motor installs on windows environment and consists of:

- MCWIN28335 Pro. Contains: serial monitor for real-time communication, PROCEV2833xx processor evaluation software, DMCD28x-Pro Digital Motion Control Developer software for application development, compilation, code downloading and testing of digital management algorithms.
- DMCode-MS (IM) which contains a complete MATLAB library for digital control of an induction motor (measuring blocks, transformations, controllers for position, speed, torque, voltage control, etc.).
- DMCode-S (IM), ready applications of current, speed, position regulation and voltage control of inverters based on Field Oriented Control
- TI software tools - software tools from Texas Instruments. Contains: assembler, linker and C - compiler [10].

3. THEORETICAL BACKGROUND OF THE IMPLEMENTED ALGORITHMS

Each implemented control algorithm has an identical kernel structure according to which machine control algorithm executes and it is presented in Fig. 3.

Main algorithm steps for all control algorithm implemented in MSK28335 are as follows: First, the

ACPM750 power module errors is reset if it exists → hardware is initialized → interrupt aspects for time base are initialized → current and speed controllers are initialized → PWM generation is started → current measurements are obtained → measurement is started from encoder → after all calculations based on the obtained measurements, the interruptions related to the transistors are activated.
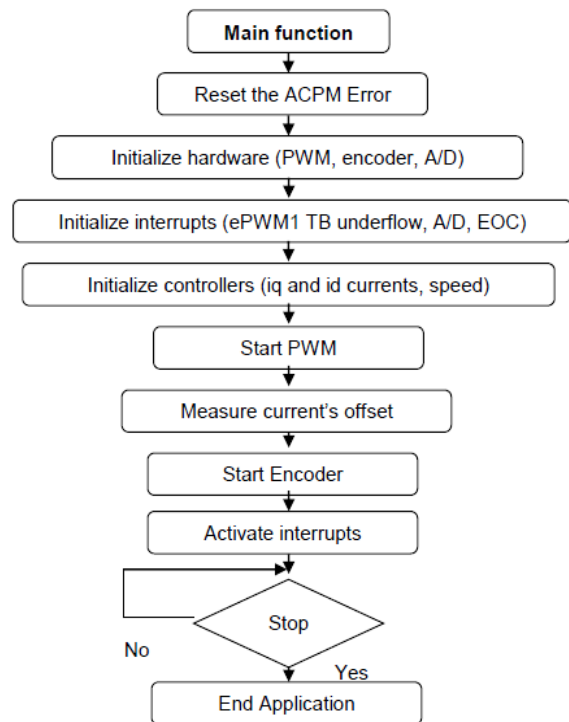

Figure 3. *Kernel structure*

The main function essentially calls blocks that represent structures/functions written in the C - programming language necessary for proper algorithm execution. By opening and studying these blocks, the student can understand how to perform: analog-to-digital conversion (ADC.c), a transformation of the three-phase *abc* in the two-phase *dq* system (Tabcdq.c), obtaining the speed and position from the encoder (Encoder.c), position estimation rotor field (EFP.c), the inverse transformation of the dq in the abc system (Tdqabc.c), PWM generation (PWM.c), etc.

2.1. Three phase motor voltage generation

This laboratory exercise should enable students to understand the principles of voltage generation by Pulse Width Modulation (PWM) technique. Realization of the given voltage reference at the inverter output is done in the transformed *dq* coordinate system. The idea is to set the voltage in the *d* - axis to a constant value and the voltage in the *q* - axis to follow a given reference, then performed coordinate transformations and PWM voltage generation.

When performing this exercise, the student can understand the principle and necessity of

coordinate transformations in a three-phase induction machine as well as the principles of PWM voltage generation. This is the simplest way to control the machine speed in an open loop system.

The results obtained after testing this control method (voltage reference and the resulting voltage on inverter outputs) are shown in Fig. 4.
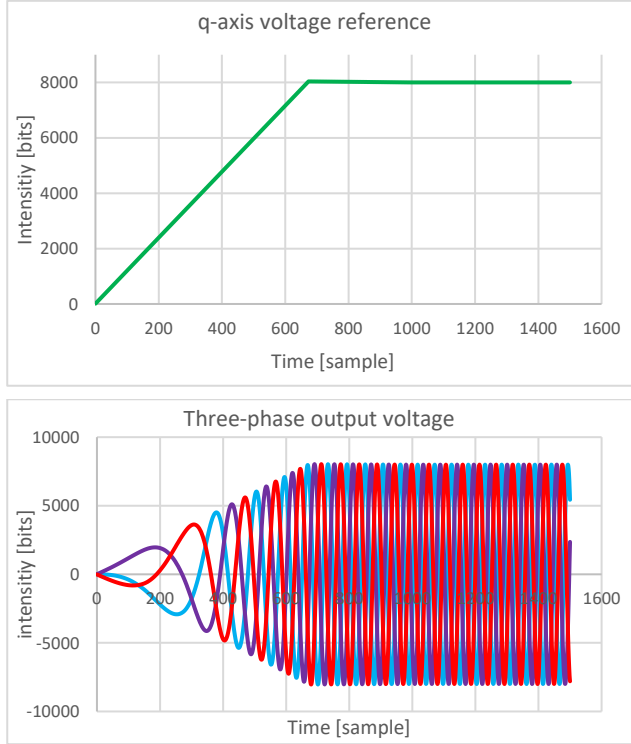

Figure 4. *q-axis component of voltage reference (top) and three-phase output voltage (bottom)*
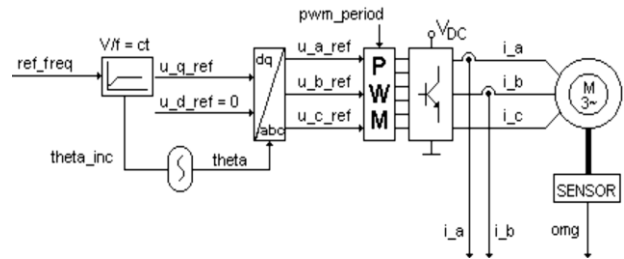
2.2. U/f control

U/f control belongs to the group of scalar control methods. Unlike the vector control, U/f method involves changing the voltage and frequency of the power supply of an AC machine without affecting their current phase position. In order to make the speed change below synchronous speed possible and avoid the saturation of the machine it is necessary to change the voltage proportionally to the stator frequency. For higher speeds, above the synchronous, it is necessary to increase the frequency while the voltage is limited to its nominal value in order to prevent possible endangerment of the machine insulation. The relation between stator voltage and frequency is given by well-known equation (1) and shown graphically in Fig. 5 (red line).

$$u_s = \begin{cases} \dfrac{U_{sn}}{f_{sn}} f_s & , \text{ for } f_s < f_{sn} \\ U_{sn} & , \text{ for } f_s \geq f_{sn} \end{cases} \quad (1)$$
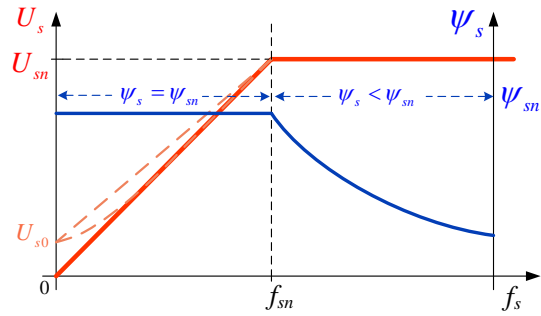

Figure 5. *U/f control principle*

This theoretical U/f control background is implemented as a C code application with block structure showed in Fig. 6.

Figure 6. *U/f control block structure*

During this exercise, the student can expand his knowledge by understanding digital implementation of scalar control with transformed model of an induction machine. According to Fig. 6 scalar control can be realized by controlling the voltage in the *d* axes and *q* axes and determining the angle (theta) of the transformed *dq* coordinate system. When performing this exercise, the student can understand why a constant ratio U/f is necessary in subsynchronous speed region and what the relation between the voltage in the *q* - axis and the resulting angle theta should be.
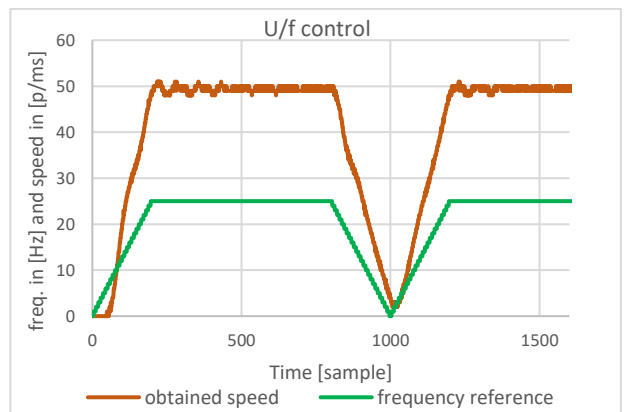

Figure 7. *Experimental results for reference frequency and obtained motor speed.*

In Fig. 7 reference frequency is set in Hz (25 Hz) while the speed is presented in encoder pulses per one speed control loop (1 ms). That means 25 Hz corresponds to motor speed closed to 1500 rpm.

2.3. Decoupled stator current control

This laboratory exercise focus is on control of the stator currents based on the principles of Field-Oriented Control (FOC). During this exercise, the student is introduced to the principle of decoupled rotor field-oriented control, its main requirements and characteristics.

The block structure shown in Fig. 8 represent a closed loop control. In order to realize field-oriented control, it is necessary to provide independent control of motor torque and motor flux. This is achieved by using a decoupled machine model and controlling the stator currents in the *d* - axes and *q* - axes, and it is necessary to determine precise orientation of the rotor field.
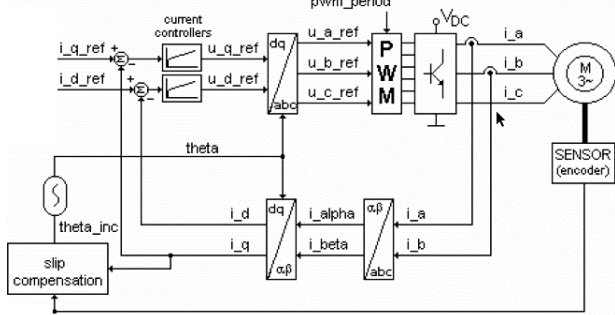
Figure 8. Decoupled stator current control block *structure*

Digital platform allows decoupled control of an induction machine. MSK28335 platform provides motor current measurement in two phases (current in the third phase is obtained by calculation of previously measured two currents), the mathematical transformation coordinate system of three-phase into two-phase system is performed, and the orientation of the rotor field is obtained by estimation, knowing mechanical position of the rotor and rotor frequency. By having an insight in C - programming language code, the student is able to understand the whole control algorithm and how it is executed in detail.

In this control algorithm the stator current in the *d*-axis is maintained at a constant value because it represents the flux of the machine, and the current in the *q*-axis, which represents the torque, follows the given reference. Finally, stator currents responses in *d*-axes and *q*-axes, shown in Fig. 9, reflects the principle of this type of control.

The motor field position is determined based on the "theta" angle increment. The theta increment is calculated as the sum of the mechanical angle of the rotor and the rotor frequency resulting with final "theta" angle of the *dq* coordinate system. Theta increment is computed as follows:

$$\omega_r = \frac{1}{T_r} \frac{i_{qs}}{i_{ds}} \qquad (1)$$
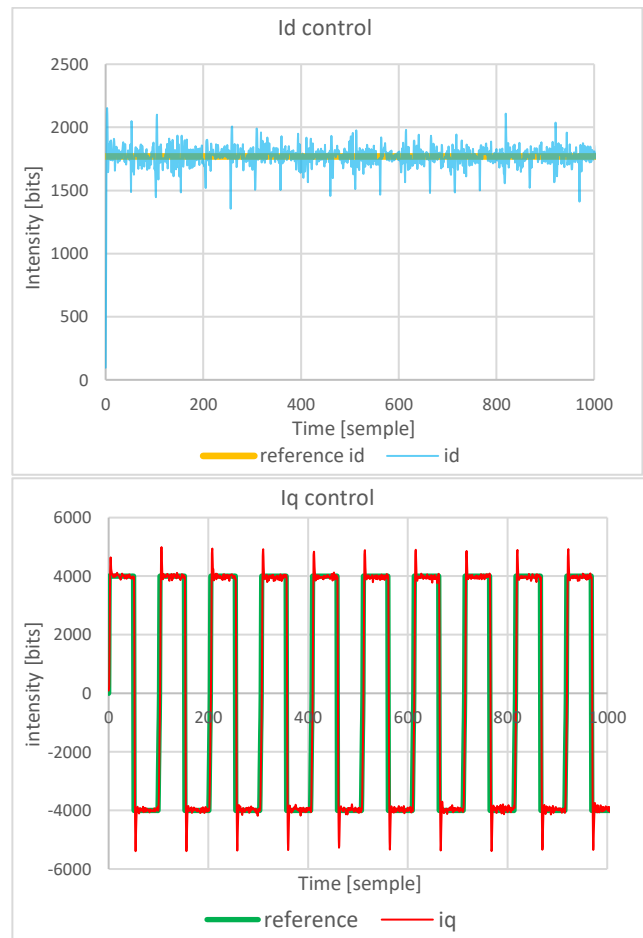
$$theta\_inc = \omega + \omega_r \qquad (2)$$

Where:

ω - mechanical angle of the rotor shaft

ω_r – rotor circuit frequency

T_r – rotor time constant

theta_inc – increment of "theta" angle

Consequently, the resulting "theta" angle is further used for the sine and cosine calculation needed for the implementation of coordinate (abc2dq) transformations [9].

Figure 9. *Reference and obtain current in d-axes and q-axes*

PI controllers are used for current control loops in the *d* and *q* axes. Rise and settling time of the current responses can also be analysed from the obtained results. PI controller parameters influence on current responses can also be observed and appropriate conclusion can be drawn.

2.4. Speed control

This control principle is also based on FOC, and is practically an upgrade to the previously explained current control. It is realized by adding a speed controller (PI) in front of the current regulators making a cascade control which can be seen in the following block diagram. The block structure of the speed control algorithm is shown in Fig. 10.
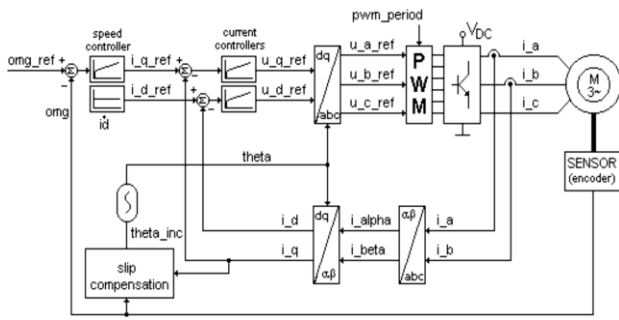
Figure 10. *Block diagram of speed control*

When performing this exercise, the student has the opportunity to get familiar with the cascade operation of two controllers in two loops. The speed control calculations are done in a slow loop that is executed every 1ms and the current controller operates in a fast loop that is executed every 100µs. It can be seen (as in current control) that the flux or current in the *d* - axis is maintained at a constant level and the current in the *q* - axis controls the motor speed. Current reference *q* - axis value is obtained from the speed controller output. Fig. 11 (top) shows the speed response with its reference value. Stator currents in *dq* coordinate system with its references are shown in Fig. 11 (bottom).
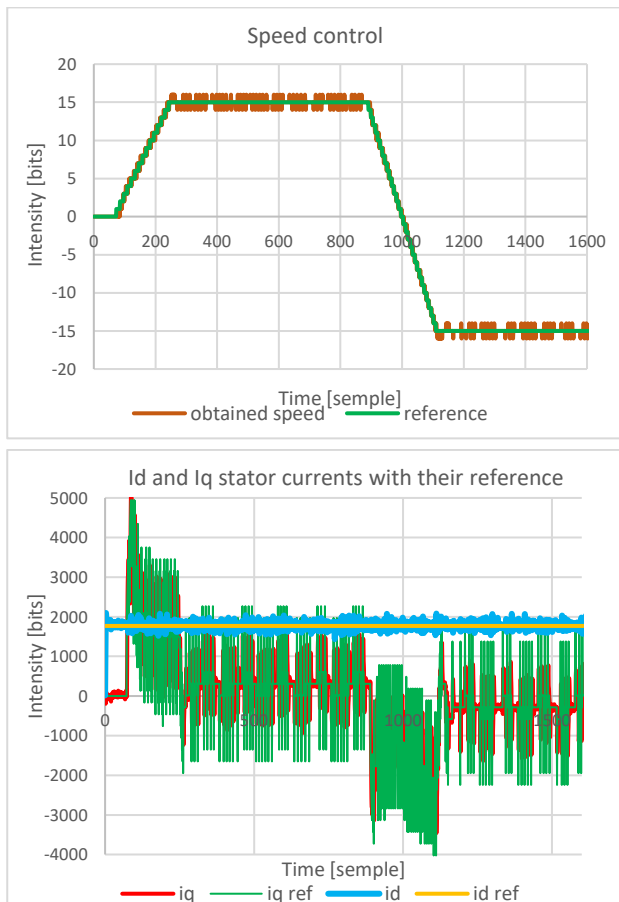

Figure 11. Speed response (top) and stator currents in *qd* reference frame (bottom)

2.5. Position control

This control type aims to control the position of machine rotor shaft according to the set reference. In this exercise, instead of a speed (PI) controller, there is a position (PID type) controller. Here, the student can get familiar with the principle of achieving the given position of the induction motor rotor shaft. Compared to the speed control, position controller has additional derivate (D) gain. Position control is a very common demand in industrial processes and appropriate PID controller tuning is of great importance in order to achieve a quick motor position response. Fig. 12 shows a block diagram of positional control.
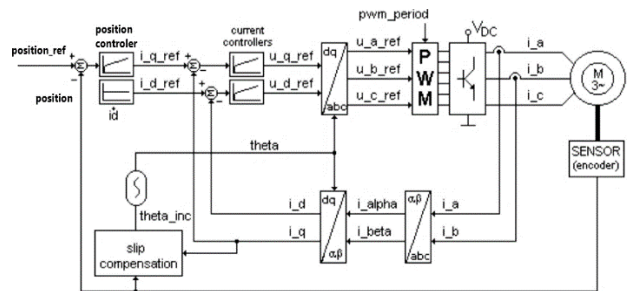

Figure 12. *Block diagram of position control*

As in the previous case, there are two loops, in the slow loop (1ms) the position control is performed and in the fast loop (100µs) the current control is performed. Fig. 13 shows the given references and the obtained response motor position and currents in *d* and *q* axes.

The student can calculate the jumps and settling times for the used controller from the obtained results.
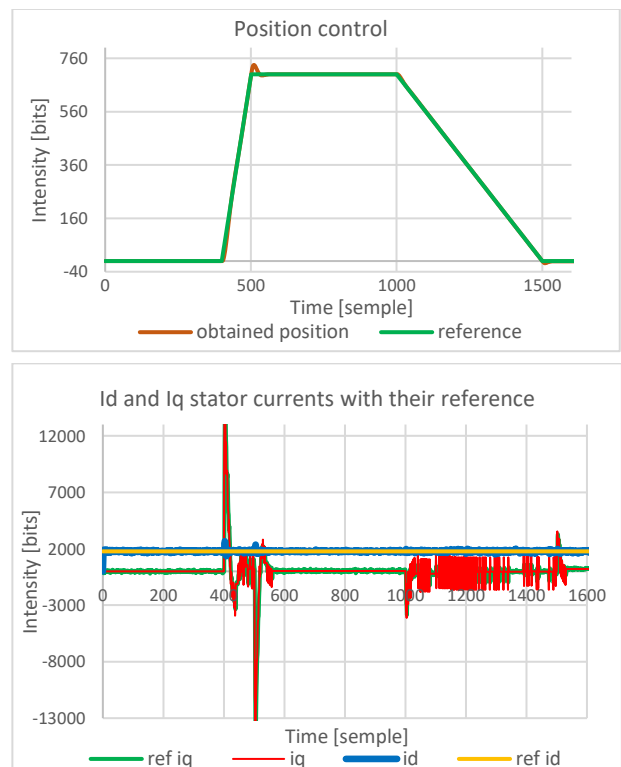

Figure 13. Position response (top) and stator currents in *qd* reference frame (bottom)

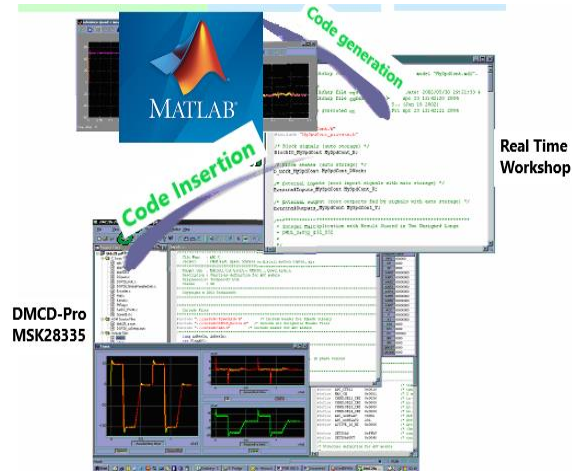## 2.6. MATLAB simulation and code generation

One of the main possibilities of MSK28335 digital platform is a MATLAB library integration option. With MATLAB/Simulink it is possible to in sample manner model appropriate control algorithms with already prepared blocks for coordinate transformation, PI control, PWM, AD conversion, encoder readout etc. from F28335 existing library. Then algorithm can be tested and tuned until satisfactory results are obtained. This option allows users to compile the Simulink model to C code and directly download it to the digital platform processor with one click.

In that way students can develop and test their control algorithms by Rapid Control Prototyping principle which makes the development process much faster and easier. The Simulink code generation principle is shown in Fig. 14.

Control algorithm development in this way doesn't require advanced programming skills of the user which drastically reduce implementation and testing time of new algorithms. After successful

simulation in MATLAB by choosing the option "Build project" user generate and compile appropriate C code which is automatically downloaded to the MSK28335 digital platform. The example of MATLAB/Simulink project was shown in Fig. 15.

Figure 14. *Automatic code generation from Simulink model*
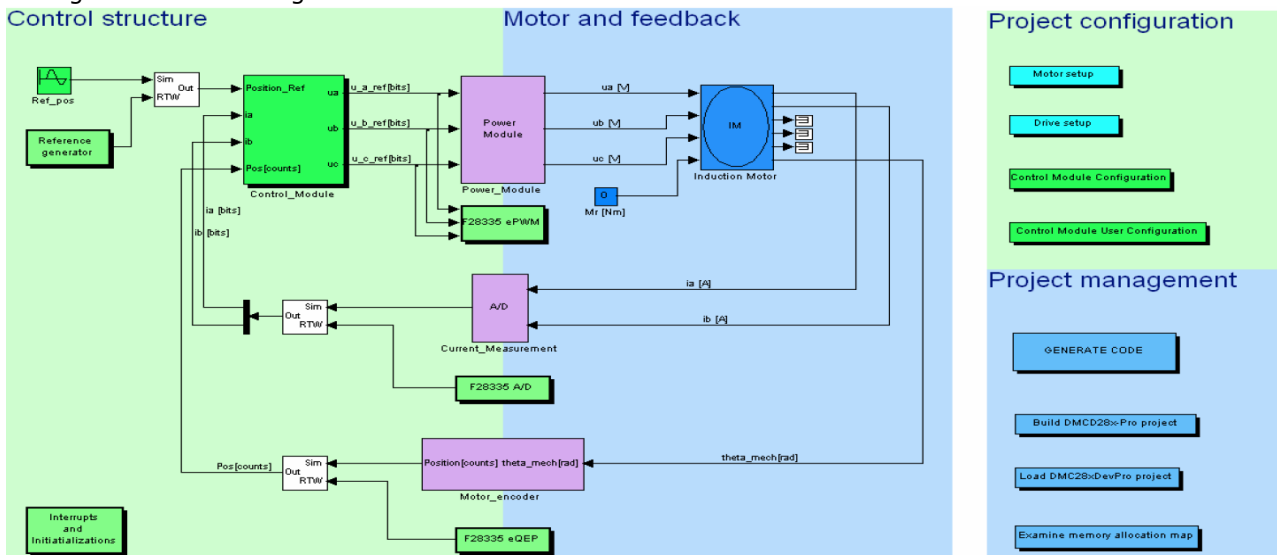
Figure 15. *MATLAB/Simulink simulation control structure of induction machine speed control*
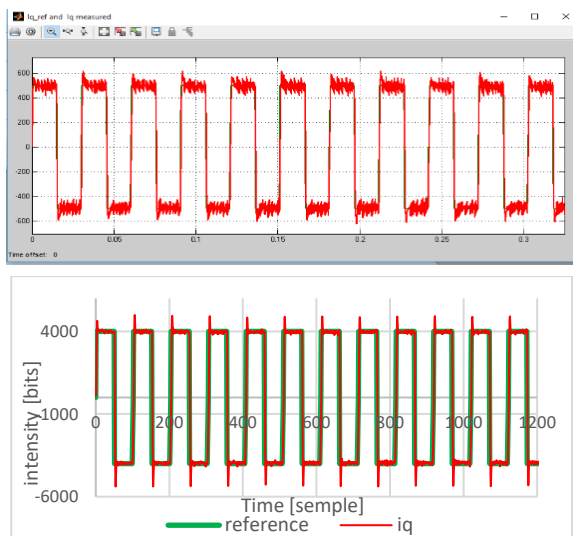
Figure 16. Comparison of simulation and experimental results for current control method

Afterwards, the implemented algorithm is ready to be tested in real-time experimental setup after which the results obtained by simulation and experiment can be compared (Fig. 16).

ACKNOWLEDGEMENTS

APPENDIX

Table 1. *Induction motor SIEBER L71 parameters*

U_n [V]	400	R_s [Ω]	24.6	L_s [H]	1.48
I_n [A]	0.95	R_r [Ω]	16.1	L_r [H]	1.48
P_n [W]	370	n_n [min⁻¹]	2860	L_m [H]	1.46

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