RT-LAB AND DSPACE: TWO SOFTWARES FOR REAL TIME CONTROL OF INDUCTION MOTORS

ABDELHAKIM IDIR, MADJID KIDOUCHE

Key words: Induction motor, Discrete space vector modulation (DSVM), Real time simulation, Rapid prototyping, RT Lab, Direct torque control (DTC), dSPACE.

Real time RT-Lab and dSPACE softwares operate under Matlab/Simulink interface programming. They have fruitfully produced a fast prototyping tool which provides a way for the rapid development and control algorithms testing. This paper presents two powerful tools for the real time control of induction motors. Real time RT-Lab simulator is proposed for discrete space vector modulation (DSVM) of induction motor (IM) control. DSPACE DS1104 real time platform is proposed for implementation of direct torque control(DTC) based on hardware in the loop (HIL) simulation. Real time simulation and experimental tests have been carried out to show the performance of these powerful tools.

1. INTRODUCTION

The induction motor has found very wide industrial applications due to its advantages such as high reliability, low cost, easy maintenance and simple manufacturing [1]. The development of the power electronics technology, low cost digital signal processing, micro-controllers and the control techniques, have permitted to the induction motor to become an attractive component for the future high performance drive [2]. A number of commercial software packages such as PcPice, Matlab-Simulink, RT-Lab and dSPACE are well-known that they offer many other useful toolboxes for many electrical machines in engineering subjects [3]. The direct use of these software packages is a major advancement to simplify the simulation procedures for many practicing engineers as well as for undergraduate engineering students [4].

Recently, many software tools in real time simulation are available, especially for the motor drive control and the power converters application. The real time simulations are required by hardware in the loop applications and their use allows rapid prototyping and minimizing the design process cost. The hardware in the loop (HIL) [5,6], is totally different from rapid control prototyping

Applied Automation Laboratory, F.H.C., University of Boumerdes, 1 Av. de l'Independance, 35000 Boumerdes, Algeria, E-mail: idir_ah@yahoo.fr

Rev. Roum. Sci. Techn.– Électrotechn. et Énerg **59**, *2* , p. 205–214, 2014

(RCP). In RCP, the process is real and the control is simulated in real time, however in the HIL is reverse. The control algorithms developed using Matlab/ Simulink environment is loaded to a real-time prototyping system, instead of designing specific hardware. However, a real time platform is required to support a designer during the development of the control system, from the first step of editing model until the final step of code generation and execution model [7].

Nowadays, many studies are based only on dSPACE [7,8,9] or on RT-lab [10,11,12] for the rapid prototyping, but few studies has been published using the two real time software [13]. In this paper we present two powerful tools for the real time control of induction motors. Real time RT-Lab simulator is proposed for discrete space vector modulation (DSVM) of induction motor (IM) control and dSPACE DS1104 real time platform is proposed for implementation of direct torque control (DTC) based on hardware in the loop (HIL) simulation. The simulation and experiments have been conducted to verify the proposed method.

2. REAL TIME RT-LAB PLATFORM

RT-Lab [4] uses Matlab/Simulink as a front-end interface for editing graphic models in block-diagram format, which are afterwards used by this real-time simulator to generate the necessary C-code for real-time simulations on a single or more target processors running Quick unix (QNX).

Fig.1 below shows the concept of digital real-time simulation of an induction motor drive system [11].

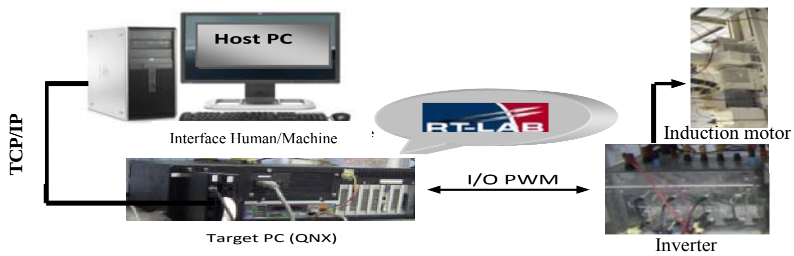

Fig. 1 – RT Lab real-time simulator architecture.

The test bench is equipped with an experimental platform using a three phase squirrel cage induction motor fed by a voltage source inverter (VSI) SEMIKRON insulated gate bipolar transistor pulse-width-modulated (IGBT PWM VSI). The load torque is controlled by a magnetic powder brake (FP3), RT-Lab Target (16 Analog input (OP5340),16 Analog output(OP5330), 32 Digital I/O (OP5311-5312) and a personal computer with Matlab/Simulink/RT-Lab software to design a simulate induction machine control. The simulator uses the following communication link transmission control protocol/internet protocol (TCP/IP) (Ethernet connection (100 Mb/s) between the hosts and target PC).

3. **INDUCTION MOTOR MODELING**

The induction motor model is described in the direct and quadrature frame *(d-q)* and given by equation (1).

$$\begin{cases} \dfrac{\mathrm{d}I_{ds}}{\mathrm{d}t} = -\left(\dfrac{1}{T_s\sigma} + \dfrac{R_r(1-\sigma)}{L_r\sigma}\right) I_{ds} + \omega_s I_{qs} + \left(\dfrac{1-\sigma}{L_m\sigma}\right)\omega_r\phi_{qr} + \dfrac{1}{\sigma L_s} V_{ds} \\ \dfrac{\mathrm{d}I_{qs}}{\mathrm{d}t} = -\left(\dfrac{1}{T_s\sigma} + \dfrac{R_r(1-\sigma)}{L_r\sigma}\right) I_{qs} - \omega_s I_{ds} + \left(\dfrac{1-\sigma}{L_m\sigma}\right)\omega_r\phi_{dr} + R_r\left(\dfrac{1-\sigma}{L_m L_r\sigma}\right)\phi_{qr} + \dfrac{1}{\sigma L_s} V_{qs} \\ \dfrac{\mathrm{d}\phi_{dr}}{\mathrm{d}t} = \dfrac{R_r L_m}{L_r} I_{ds} - \dfrac{R_r}{L_r}\phi_{dr} + \omega_{sl}\phi_{qr} \\ \dfrac{\mathrm{d}\phi_{qr}}{\mathrm{d}t} = \dfrac{R_r L_m}{L_r} I_{qs} - \dfrac{R_r}{L_r}\phi_{qr} + \omega_{sl}\phi_{dr} \\ \dfrac{\mathrm{d}\omega_r}{\mathrm{d}t} = -\dfrac{L_m}{L_r}\dfrac{P}{J}\left(I_{ds}\phi_{qr} - I_{qs}\phi_{dr}\right) - \dfrac{T_L}{J} - \dfrac{f}{J}\omega_r \ . \end{cases} \tag{1}$$

The electromagnetic torque T_e *is* expressed as follows

$$T_e = p\frac{L_m}{L_r}(\phi_{dr} I_{qs} - \phi_{qr} I_{ds}), \tag{2}$$

where *d, q*; direct and quadrature axes in Park frame; L_s, L_r, R_s, R_r and L_m – stator and rotor main inductances, resistances and mutual inductance respectively. J is the rotor inertia moment, σ is the dispersion factor and f is a friction coefficient. I_{ds}, ϕ_{dr}, I_{qs}, ϕ_{qr} are *d*-axis stator current, rotor flux and *q* – axis stator current, rotor flux respectively. p is the number of pole pairs. ω_s, ω_r and ω_{sl} are stator, rotor and slip angular speeds respectively, with $\theta_r = \int \omega_r \mathrm{d}t$ and θ_r is the rotor position.

3.1 PRINCIPLE OF DISCRETE SPACE VECTOR MODULATION

The principle of DSVM is based on space vector pulse width modulation (SVPWM) to get the appropriate voltage vector through basic voltage synthesis. The difference with DSVM is in the application time which does not need computation. In DSVM, the five voltage vectors are permuted and combined with three others as one group, and nineteen voltage vectors are formed in this way, as illustrated in Fig. 2. Each crossing point is the end of the synthesized voltage vectors. "23Z" is the vector synthesized by $V2$, $V3$ and zero (0) vectors. Thus, there are several optional voltage vectors synthesized with DSVM method, far more than the eight basic voltage vectors in traditional method.

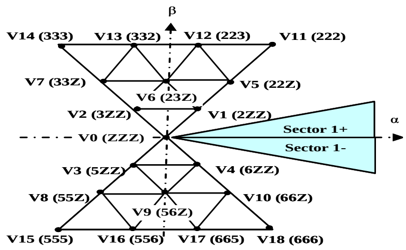

Fig. 2 – The DSVM voltage vector of first sector.

3.2. REAL TIME RT-LAB SIMULATION OF DSVM FOR AN IM

Fig. 3 shows the real time model of DSVM for an induction motor (IM) drive as implemented in RT-Lab environment. RT-Lab allows the modelling of the subsystem in Matlab/Simulink environment with some own rules and perform automatic code generation and transfer of the Simulink model to the field-programmable gate array (FPGA) implementation.

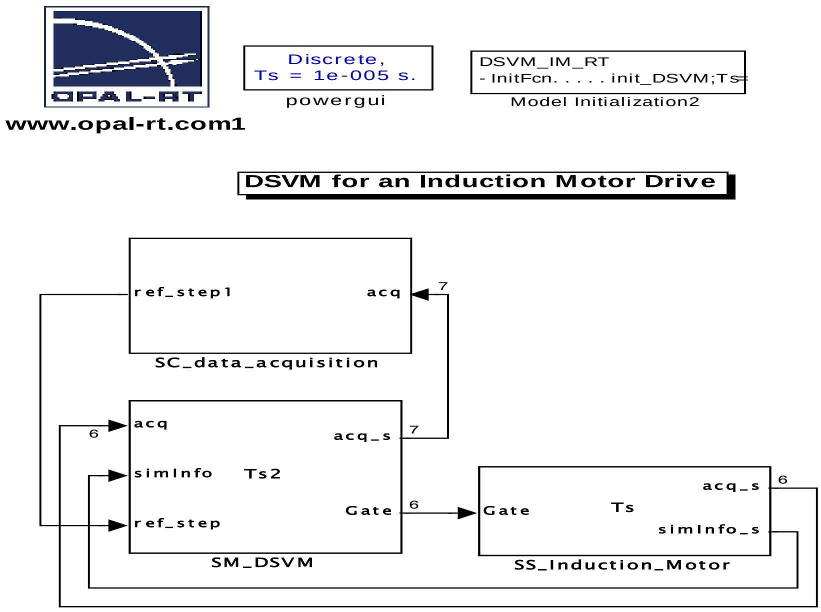

Fig. 3 – RT-Lab real time simulation graphic model of DSVM for an IM.

The subsystem named "SS_induction_motor" contains the simulink model of the induction motor and the inverter RT-Events model. Another subsystem named "SM_DSVM" contains the discrete space vector modulation generator control model, while subsystem named "SC_data_acquisition" represents the model for online data acquisition.

The following steps are required to implement the control system in real time RT-Lab:

– Opening the model already created in Matlab/Simulink (.mdl).

– Editing the open model for its adaptation and calculation in real time.

– Preparing original model for code separation and generation.

– Subsystems assignation to physical nodes and activation of eXtreme high performance (XHP) mode.

– Loading model by transferring the code by file transfer protocol (FTP) towards the selected nodes.

– Executing the model by launching the real time simulation on all the nodes (parallel execution).

3.3. REAL TIME RT-LAB SIMULATION RESULTS

The control algorithm has been implemented using RT-Lab software package. The characteristics of the induction motor are: rated power = 900 W, rated speed= 1420 rpm, stator resistance R_s = 21 Ω, rotor resistance R_r = 22.63Ω, stator inductance $L_s = 1.052$ H, rotor inductance $L_r = 1.081$ H, mutual inductance $L_m = 0.996$ H, current = 2.6 A, frequency $f = 50$Hz and pair of pole $p = 2$.

Figures 4 and 5 show respectively the real time simulationof stator currents and flux response.

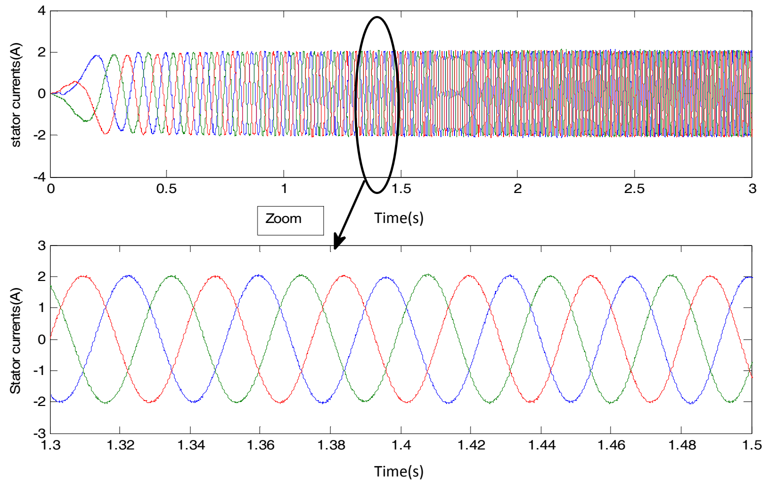

Fig. 4 – Real time simulation of stator currents: i_{sa}, i_{sb}, i_{sc} [A].

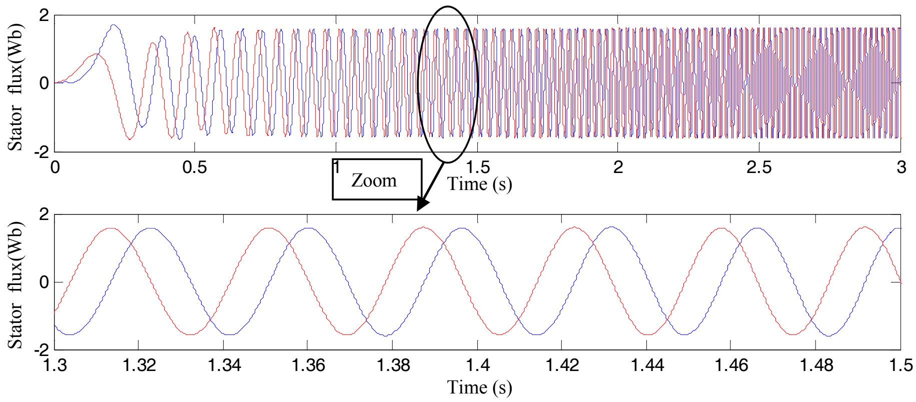

Fig. 5 – Real time simulation of *dq* stator flux components [Wb].

A good response of current and flux has been observed through the results obtained from the real time simulation. Thus prove the effectiveness of the powerful tool, which is actualy widely used for rapid control prototyping and hardware in the loop applications.

The advantages of Real-Time RT-Lab simulator are: i) online modification possibility of the executed model; ii) model parameters can be read and updated online; iii) and model quantity is accessible during all the execution time.

4. DIRECT TORQUE CONTROL

The amplitudes of stator flux and motor torque are controlled using two independent hysteresis controllers. The feedback signals, T_e and ϕ_r, are computed from stator voltages and currents [14–16].

The stator flux space vector $\overline{\phi_s}$, is obtained by integrating the motor electromotive force (emf) space vector:

$$\overline{\phi_s} = \int \left(\overline{V_s} - R_s \overline{I_s} \right) \mathrm{d}t \,. \tag{3}$$

The stator voltage space vector $\overline{V_s}$ is calculated using the dc link voltage V_{dc} and the gating signals S_a, S_b, S_c:

$$\overline{V_s} = \frac{2V_{dc}}{3} \left[S_a + \mathrm{e}^{\mathrm{j}\pi 2/3} S_b + \mathrm{e}^{\mathrm{j}4\pi/3} S_c \right]. \tag{4}$$

The stator current space vector $\overline{I_s}$ is calculated from measured currents (i_a, i_b, i_c)

$$\overline{I_s} = \frac{2}{3}\left[i_a + \mathrm{e}^{\mathrm{j}2\pi/3}\, i_b + \mathrm{e}^{\mathrm{j}4\pi/3}\, i_c \right]. \tag{5}$$

The electromagnetic torque T_e is computed as the product of $\overline{I_s}$ and $\overline{\phi_s}$:

$$T_e = \frac{3}{4}\, p(\overline{I_s}\, \mathrm{j}\overline{\phi_s}). \tag{6}$$

The inverter switching states are determined by the torque and flux errors according to the sector settled.

As shown in Fig. 6, a switching table is used to control the inverter, whereas the torque and flux errors are kept within the specified bands.

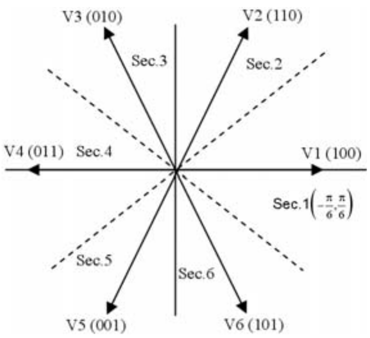

Fig. 6 – Output voltage vectors.

Table 1

Classical DTC switching table

		Sector 6	Sector 5	Sector 4	Sector 3	Sector 2	Sector 1
		$\left(-\frac{\pi}{2},-\frac{\pi}{6}\right)$	$\left(-\frac{\pi}{6},\frac{\pi}{6}\right)$	$\left(\frac{\pi}{6},\frac{\pi}{2}\right)$	$\left(\frac{\pi}{2},\frac{5\pi}{6}\right)$	$\left(\frac{5\pi}{6},\frac{7\pi}{6}\right)$	$\left(\frac{7\pi}{6},\frac{9\pi}{6}\right)$
Decrease Flux	Increase Torque	100	110	010	011	001	101
	Decrease Torque	011	001	101	100	110	010
Increase Flux	Increase Torque	110	010	011	001	101	100
	Decrease Torque	001	101	100	110	010	011

It should be noted that a three level torque and flux hysteresis controller were applied according to the outputs of the torque controller and the sector information. Appropriate voltage vectors for both inverters are selected from a switching table shown in Table 1.

5. REAL-TIME DSPACE PLATFORM

The experimental tests has been carried out to verify the effectiveness of the proposed control algorithm. The block diagram of the developed test bench is shown in Fig. 7. The proposed control scheme has been implemented in the Matlab/Simulink environment combined with the real time interface (RTI) and associated to the dSPACE DS1104 control board. An experimental platform using three phase squirrel cage induction motor fed by a three phase SEMIKRON IGBT PWM VSI. The load torque is controlled by a magnetic powder brake (FP3).The switching frequency was set at 9 kHz, while the sampling frequency was fixed to 1 kHz.

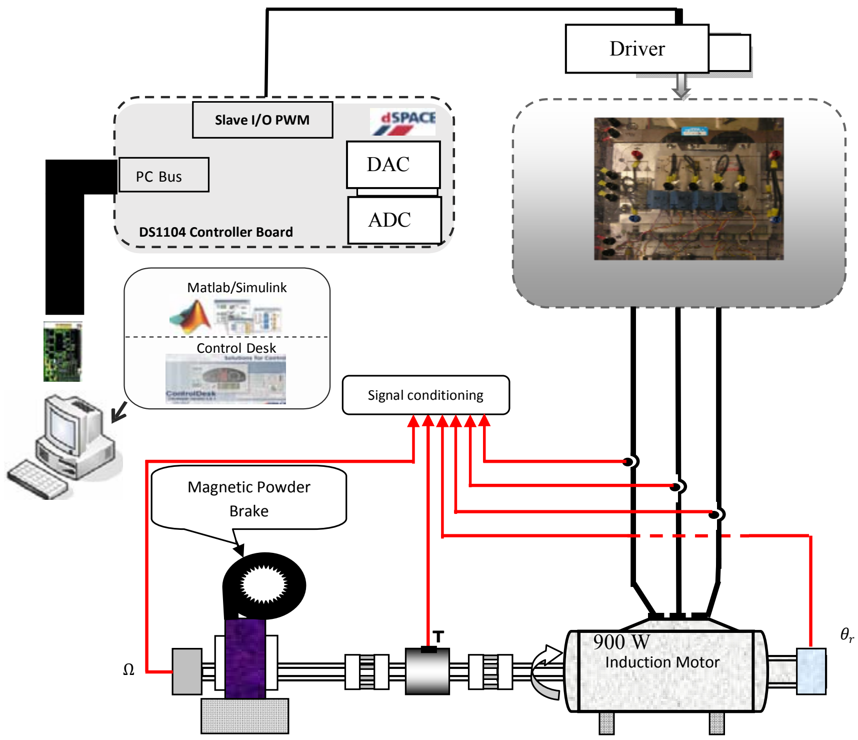

Fig. 7 –Synoptic scheme of the experimental platform

The different steps required to implement the control system using DS1104 Controller Board are described below [8]:

– Control system modeling based on Matlab/Simulink.

– Configuration of the I/O connections of the connector panel.

– Generation of the C-code using RTI.

– C-code execution which has been generated by real-time workshop (RTW) toolbox, using RTI.

– Data acquisition and simulation monitoring.

6. EXPERIMENTAL RESULTS

Figure 8 shows the experimental results of the estimated flux components when the rotor speed reaches its nominal value, and Fig. 9 shows the experimental results of flux amplitude and angle.

It can be view that the stator flux waveforms are almost sinusoidal and stator flux module is kept constant.

dSPACE tool is useful for faster testing and development of digital controllers for high performance of electrical machines, but does not offer the online modification possibility during the execution of the model.

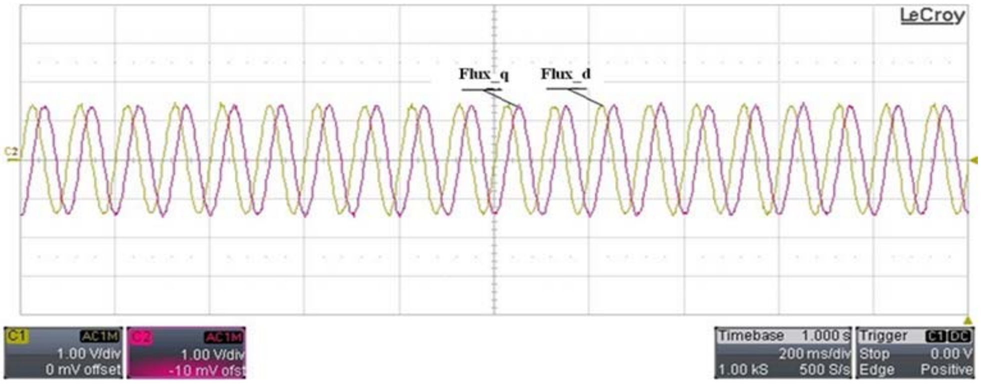

Fig. 8 – Estimated dq stator flux components [Wb].

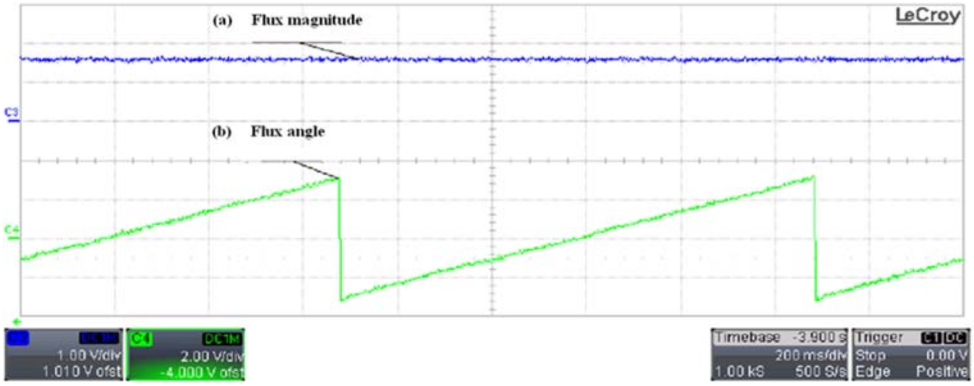

Fig. 9 – a) Stator flux magnitude [Wb]; b) stator flux angle [rad].

7. CONCLUSION

Two powerful tools have been presented through this paper, real time RT-Lab and dSPACE DS1104 platforms. RT-Lab platform is proposed for real time simulation of DSVM and dSPACE hardware/software is used for the implementation of DTC for the induction motor drive. Real time simulations are required by hardware in the loop applications and their use allows fast prototyping and minimizes the design process cost. The RT-Lab simulator remains advantageous comparing to the dSPACE, because RT-Lab offers the accessibility to the model for online modification during the execution.

Received on, 6 January 2014

REFERENCES

1. M. Mihalache, *Equivalent circuit parameters and operating performances of the three-phase asynchronous motor*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **55**, *1*, pp. 32–41, Bucarest, 2010.
2. P. M. Menghal, A Jaya laxmi,*Real Time Simulation: Recent Progress & Challenges*, IEEE 2nd International conference on Power, Signals, Control &Computation (EPSCICON), 2012.
3. C. Gencer, M. Gedikpinar, *A Computer-Aided Educational Tool for Induction Motors,* Computer Applications in Engineering Education, 2010.
4. ****RT-LAB*, Opal-RT Technologies, Inc., 1751 Richardson Suite 2525 Montréal Qu´ebec H3K 1H6 Canada, 2003.
5. N.V. Truong and D.L. Vu, *Hardware-in-the-Loop approach to the development and validation of precision induction motor servo drive using xPC Target*, International Joint Conference on Computer Science and Software Engineering (JCSSE), 2012, pp. 159–163.
6. C. Vasiliu, N. Vasile, *Hardware-in-the-loop simulation for electric powertrains*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **57**, *2*, pp. 212–221, 2012.
7. J. Sawant& D. Ginoya, *dSPACE DSP DS-1104 based State Observer Design for Position Control of DC Servo Motor*, on dSPACE User Conference, India, Sept 24th, 2010.
8. C. Versèle, O. Deblecker, J. Lobry, *Implementation of advanced control schemes using dSPACE material for teaching induction motor drive*, International Journal of Electrical Engineering Education, **47**, *2*, pp. 151–167, 2010.
9. G. Wang, R. Yang, D. Xu, *DSP-Based Control of Sensorless IPMSM Drives for Wide-Speed-Range Operation*, IEEE Trans. Ind. Electron, **60**, *2*, pp. 720–727, 2013.
10. R. Maharjan, S. Kamalasadan, *Real-time simulation for active and reactive power control of doubly fed induction generator,* North American Power Symposium, IEEE. Conf. 2013, pp. 1–6.
11. A. Idir, M. Kidouche, *Real-Time Simulation of V/F Scalar Controlled Induction Motor using RT-Lab Platform for Educational purpose,* Proceedings of the International Conference on Systems, Control and Informatics, 2013, pp.189–192.
12. S. Abourida, *real-time platform for the control prototyping and simulation of power electronics and motor drives*, Proceedings of the Third International Conference on Modeling, Simulation and Applied Optimization Sharjah,U.A.E, January 20–22, 2009.
13. P. M. Menghal, A. Jaya laxmi,*Real Time Control of Electrical Machine Drives: A Review*, IEEE International Conference on Power Electronics, Control and Embedded Systems (ICPCES), 2010.
14. H. Le-Huy, *Comparison of field-oriented control and direct torque control for induction motor drives*, **2**, 1999, pp. 1245–1252.
15. D. Casadei, *Implementation of a Direct Torque Control Algorithm for Induction Motors Based on Discrete Space Vector Modulation*, IEEE transactions on power electronics, **15**, *4*, 2000.
16. L. Youb & A. Crãciunescu, *Commande directe de couple et commande vectorielle de la machine asynchrone*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **53**, *1*, pp. 87–98, 2008.