

THE INFLUENCE OF THE SAMPLING PERIOD ON THE PERFORMANCE OF THE REGULATION BY DTC OF THE INDUCTION MOTOR

Sergiu Ivanov
 Faculty of Electromechanical Engineering
 University of Craiova
 107 Decebal Blv, 200440 Craiova, Romania
 E-mail: sivanov@em.ucv.ro

KEYWORDS

Induction motor, DTC, sampling period.

ABSTRACT

The regulation by DTC of the induction motor is a quite “natural” method, being much lighter, as mathematical support, than the vector control, regardless the type of field considered for orientation. Despite its simplicity, the practical implementation of the method rise serious problems, mainly due to the fact that the sampling period for regulation purposes is right the minimum PWM period of the inverter which supplies the motor. This why, without involving powerful command systems, the results can be far for the expectances. The paper deals with the simulation of such regulation system and highlights the importance on the performances of the sampling period.

INTRODUCTION

The direct torque control (DTC) of the induction motor represents an alternative to the well known vector control. This control strategy was developed due to the necessity, for certain applications, of avoiding the precise position or speed transducer, or currents loops, required by the vector control schemes. Basically, the DTC of the induction motor controls the speed and the amplitude of the estimated stator flux, by the mean of the stator voltage applied to the motor by a voltage source inverter. The two magnitudes (amplitude and speed of the stator flux) are controlled in order to maintain constant the flux amplitude and to obtain the desired electromagnetic torque.

It is necessary to have an estimation of the stator flux and this could be obtained based on the applied stator voltage and measured stator currents:

$$\underline{\Psi}_s = \int (\underline{u}_s - R_s \cdot \underline{i}_s) dt \quad (1)$$

where \underline{u}_s and \underline{i}_s are the space vectors of the stator voltage and stator current respectively:

$$\begin{aligned} \underline{u}_s &= u_{s\alpha} + j u_{s\beta} , \\ \underline{i}_s &= i_{s\alpha} + j i_{s\beta} , \end{aligned} \quad (2)$$

both referred to the stationary reference frame α - β fixed to the stator.

Also, the electromagnetic torque developed by the induction motor must to be estimated. This can be obtained based on the α - β components of the stator flux resulted from (1) and the measured stator currents components from (2):

$$T_e = \frac{3}{2} p (\Psi_{s\alpha} \cdot i_{s\beta} - \Psi_{s\beta} \cdot i_{s\alpha}) \quad (3)$$

where p is the number of pairs of poles of the machine. As the inverter states are discrete and consequently the supplied voltages are not sinusoidal waves, the circle of the ideal locus of the stator flux space vector must be reconstituted as precise is possible, in order to avoid high currents and torque ripples. However, this could be done by using the only six non-zero space vectors and the two “zero” space vectors available as output of the inverter (Vas 1998), as are depicted in Figure 1. Figure 2 depicts as example the topology of the inverter that determines the position \underline{u}_2 of the stator voltage space vector.

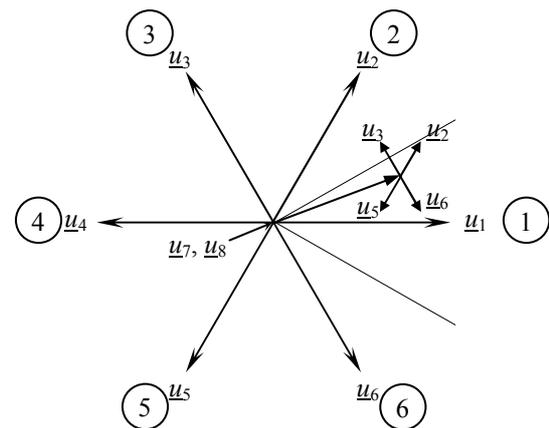


Figure 1 The Stator Voltage Space Vectors

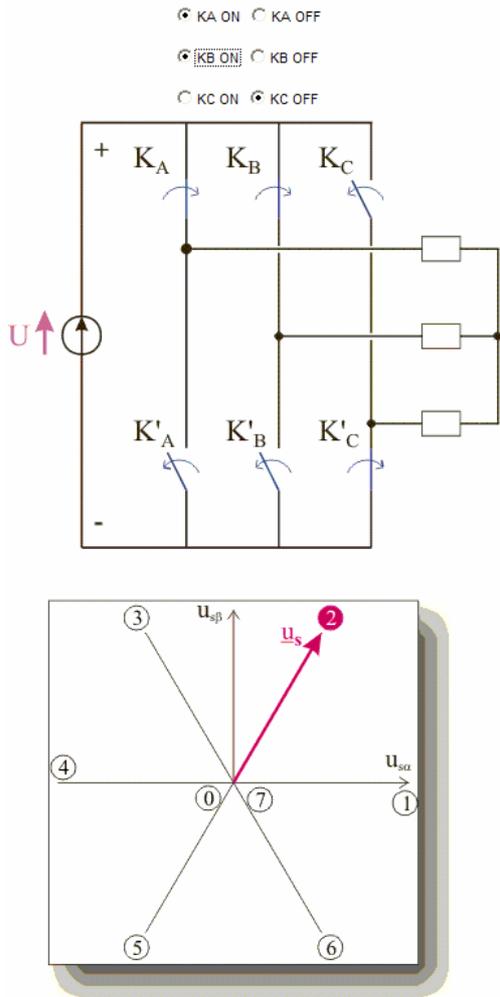


Figure 2 The Inverter's Topology for Obtaining the Voltage Space Vector \underline{u}_2

Depending on the sector (Figure 3) where the stator flux space vector is and on the requested action, the next topology of the inverter is chosen in accordance with the commutation table (Table 1).

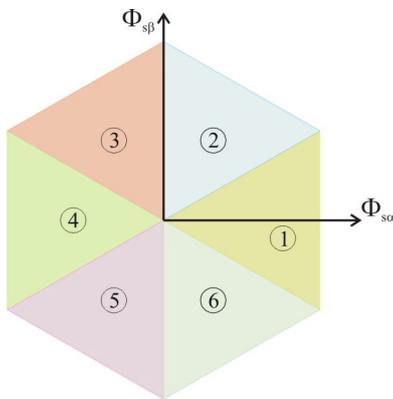


Figure 3 The Six Sectors of the Plane ($\Psi_{\alpha}, \Psi_{\beta}$)

The requested action refers to the necessary evolution of the stator flux as amplitude and speed.

Table 1 The Commutation Table for DTC Control

$ \Psi_s $	T_e	Sector					
		1	2	3	4	5	6
↑	↑	\underline{u}_2	\underline{u}_3	\underline{u}_4	\underline{u}_5	\underline{u}_6	\underline{u}_1
↑	0	\underline{u}_7	\underline{u}_8	\underline{u}_4	\underline{u}_8	\underline{u}_7	\underline{u}_8
↑	↓	\underline{u}_6	\underline{u}_1	\underline{u}_2	\underline{u}_3	\underline{u}_4	\underline{u}_5
↓	↑	\underline{u}_3	\underline{u}_4	\underline{u}_5	\underline{u}_6	\underline{u}_1	\underline{u}_2
↓	0	\underline{u}_8	\underline{u}_7	\underline{u}_8	\underline{u}_7	\underline{u}_8	\underline{u}_7
↓	↓	\underline{u}_5	\underline{u}_6	\underline{u}_1	\underline{u}_2	\underline{u}_3	\underline{u}_4

The choice of one of the null vectors \underline{u}_7 or \underline{u}_8 is done having in mind the reduction of simultaneous commutations and consequently, the switching losses in the inverter's legs.

As the necessary supplying voltage and therefore the inverter's topology is determined at each sampling period, it is obviously that this one is desired to be as small as possible. If for simulation it is possible "everything", for the real time control, the limitations of the control system must be considered, even it is a DSP based one.

THE SIMULATION OF THE SYSTEM

By using the Simulink libraries previously developed (Ivanov 1998), the model of the driving system, Figure 4, was relatively simply developed.

The most accurate results could be obtained, as can be easily previewed, by choosing a small simulation step. The Figure 5 depicts the results of the simulation with a fixed simulation step of $100\mu s$. The locus of the flux space vector (a) and the phase currents (b) were detailed for about one period during a step start, in order to highlight the successive commutations determined by the Commutations Table.

The results are quite acceptable due to the fact that the two hysteresis controllers (flux and torque) switch with periods larger than the sampling one, as can be seen in Figure 6. Consequently, the phase voltage plotted in Figure 7 is rich in pulses and the current waveform (Figure 4b) is acceptable.

However, this step is too small for the possibilities of the control board DS1102 that will be used to experimentally test the control. This why, the simulation step size was increased to $500\mu s$, as has been estimated that could be a feasible value for the real time control. The results of these simulations are depicted in Figure 8, for a similar regime as in Figure 5. It could be easily noticed the quite disturbed shape of the phase current, due to the reduction to about 2 kHz of the switching frequency of the inverter, as can be seen from the Figure 9, where the phase voltage is plotted.

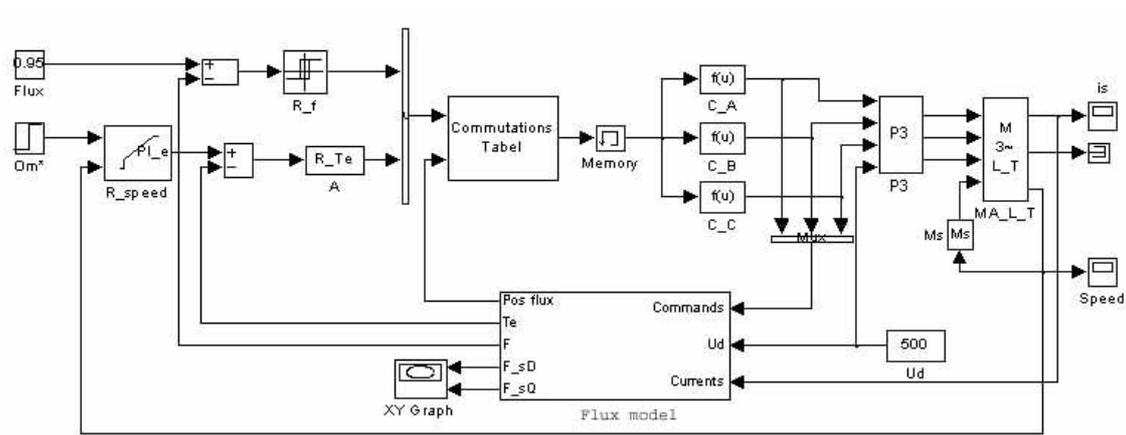
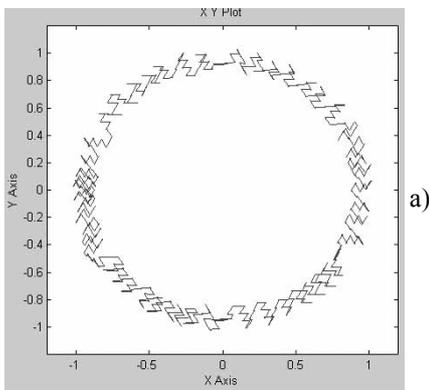


Figure 4 The Simulink Model of the Driving System with Induction Motor and DTC



a)

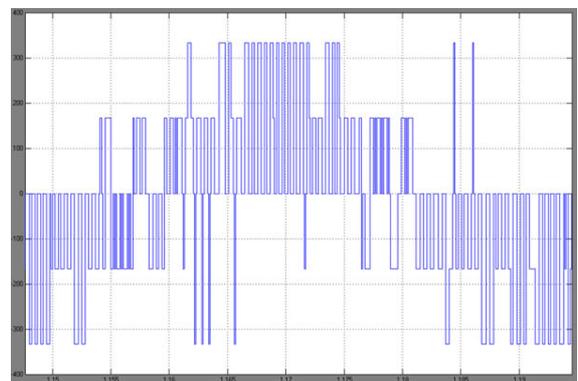
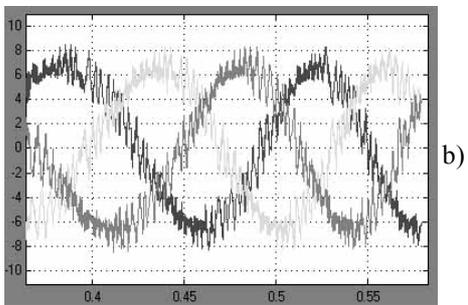
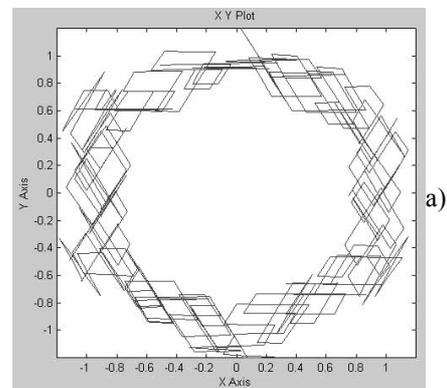


Figure 7 The Phase Voltage for Fixed 100 μ s Simulation Step

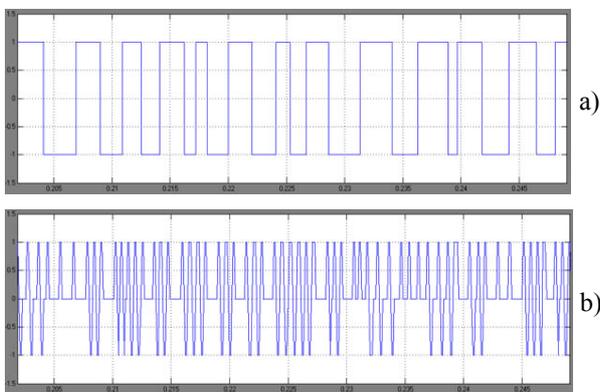


b)

Figure 5 Simulation Results for fixed 100 μ s Simulation Step of: a – the Locus of the Stator Flux Space Vector; b – Phase Currents



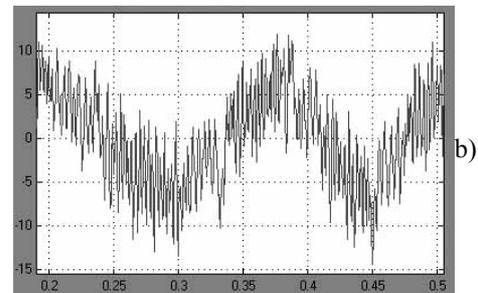
a)



a)

b)

Figure 6 Outputs of the Flux Controller (a) and Torque Controller (b)



b)

Figure 8 Simulation Results for Fixed 500 μ s Simulation Step of: a – the Locus of the Stator Flux Space Vector; b – Phase Current

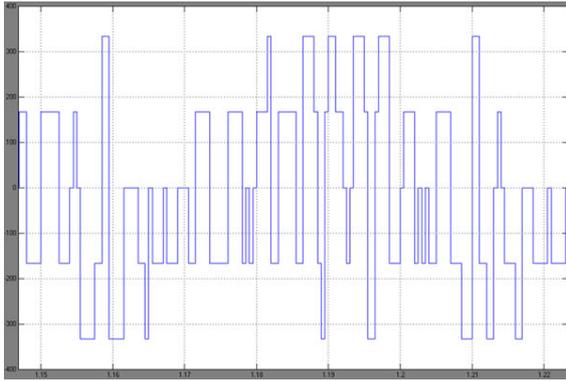


Figure 9 The Phase Voltage for Fixed 500 μ s Simulation Step

EXPERIMENTAL RESULTS

The hard of the testing stand is a DSP based control all-in-one board dSPACE GmbH, DS1102. Mainly, the DSP board is equipped with a six channels PWM generator, an interface dedicated to incremental encoders, four A/D channels and four D/A channels. As can be foreseen, these main hardware facilities are quite enough for the development of a simple testing stand. Additionally, thanks to the advantages of the friendly interface supplied by dSPACE GmbH between his DS1102 DSP board and the Matlab-Simulink[®] environment, it is possible the quick implementation of the control algorithms and the interfacing of the sensors.

Using this friendly interface supplied by dSPACE, making only slight changes in the simulation diagrams, the experimentation of different control schemes requires less effort than any other experimentation platform (Ivanov 1997; Ivanov 2003). Basically, the structure of the Simulink control diagram rests as in simulations, only the blocks specific to the interfacing with the power system having to be added. These blocks substitute the models of the inverter and of the motor, as can be seen in Figure 10.

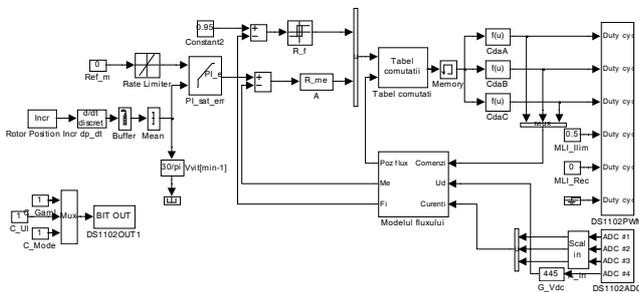


Figure 10 The Simulink Diagram for the Real Time Control of the Driving System with Induction Motor and DTC

The experimental results were, as could be easily anticipated, not very satisfactory, an example being

depicted in Figure 11, where a period of the phase current is plotted.

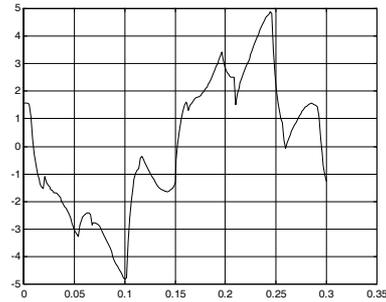


Figure 11 Phase Current with 500 μ s Sampling Time

In order to increase the switching frequency of the inverter without decreasing the sampling period, on one hand, the switching table and on the other hand, the bi-positional flux controller and tri-positional torque controller, were replaced by continuous controllers, as can be seen in Figure 12.

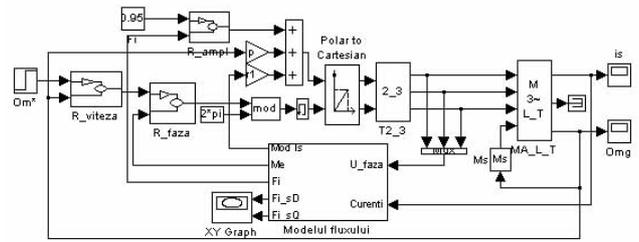


Figure 12 The Simulink Model of the Driving System with Induction Motor and DTC without Commutation Table

This allows the generation of the instantaneous values of the preset phase voltages, thus being possible to use a higher switching frequency, even with a sampling period of 500 μ s, due to the advantage of the DS1102PVM unit which uses its own frequency to generate the PWM pulses. As the power part of the inverter consists in MOS transistors, capable to switch at tens of kHz, in simulation it is no more necessary to consider a model for the inverter and the load will act depending on the instantaneous mean value on switching period (about 30 μ s). Experimental tests will be developed in order to test the proposed control diagram.

CONCLUSIONS

Due to the very basic principles of the classical DTC for induction motor, the switching frequency of the supplying inverter is at most the sampling frequency of the signals necessary for control. Because of this, the performances highly depend on the sampling period which must be as small as possible.

When moderate powerful real time control systems are used, the classic DSP control, based on commutation

table leads to insatisfactory results. The control has to be ameliorated in order to allow greater switching frequency, nondependent by the sampling frequency.

REFERENCES

- Vas P., 1998. *Sensorless Vector and Direct Torque Control*. Clarendon Press, Oxford.
- Ivanov S.; Câmpeanu A.; Bitoleanu A. 1998. "MATLAB-SIMULINK Library for AC Drives Simulation". In *IEE Conference on Simulation*, University of York, UK, 195-200.
- Ivanov S.; Sente P.; Labrique F. 1997. "Vector Control: Building the Missing Link between a DSP Controller board and the VSI fed AC Motor". In *Proceedings of the Symposium on Power Electronics, Electrical Drives, Advanced Machines, Power Quality*. Sorrento, Italy, P2.39-P2.44
- Ivanov S.; Sente P. 2003. "Library for AC Drives Simulation and Real Time Control". In *Proceedings of the 7th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2003)* (Orlando, FL, July 27-30). <http://www.e-lee.net>

AUTHOR BIOGRAPHIE



SERGIU IVANOV was born in Hunedoara, Romania and went to the University of Craiova, where he studied electrical engineering and obtained his degree in 1986. He worked for the Institute for Research in Motors, Transformers and Electrical Equipment Craiova before moving in 1991 to the University of Craiova. He obtained his PhD in 1998 with a topic in the field of the control of the electric drives systems. He is involved in modelling of the electromechanical systems.