

Comparison Between Field and Circuit Models of Induction Machine Direct Vector Control.

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The two requirements of the active torque and rotor flux generation induction machine can be performed by the vector control method using flux, speed and currents regulators. This paper analyses direct vector control using two induction machine models. In the first, the induction machine is represented in the control scheme by its circuit model i.e. the equivalent design with constant resistance and inductance values. The simulations using this circuit model of the machine are performed using the Matlab/Simulink platform. The second analysis, based on the field model of the induction machine, is a coupling between the regulation system and the finite element model of the machine. This connection is possible due to the Flux software-Matlab/Simulink coupling

Control Scheme

The main components of the direct vector control scheme in the figure below are: the PWM inverter ("PWM2"), the current-angular velocity estimator for the rotor flux ("Rotor flux estimator"), two blocks for the axis transformations ("ABC-DQ" and "DQ-ABC"), regulators for the flux, angular velocity and stator current components i_{sd} and i_{sq} ("PI_flux", "PI_speed", "PI_isd", "PI_isq"). The principle of the direct vector control is to estimate the amplitude and the position of the rotor flux vector with respect to the fixed reference system (α, β). The amplitude and the position of the rotor flux are estimated using a current-angular velocity estimator.

Field model of the induction machine

The numerical analysis refers to a 2 pole, 3-phase induction machine characterized by a rated power of 7.5 kW, rated voltage 380 V and rated frequency 50 Hz. The electromagnetic field computation domain in figure 2 represents half of the induction machine cross section. In the figure below, the corresponding Simulink block that reflects the finite element field model of the induction machine is called "Coupling with Flux2d V8 VS".

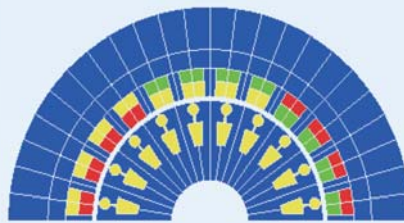


Figure 2: Electro-magnetic field computation domain and the corresponding Simulink block.

Circuit model of the induction machine

For the circuit model of the induction machine, the block "Coupling with Flux2d V8 VS" in figure 1 is replaced with the electric equivalent circuit in figure 3, from the SymPowerSystems Toolbox of Simulink. The parameters of the equivalent scheme have constant values, irrespective of time, current and voltage and relative rotor-stator position.

Results of numerical simulations

The results of the motor start-up with and without load corresponding to the two models of the induction machine are presented comparatively below. Firstly, the parameters of the four regulators in Table 1 are presented.

The flux and angular velocity reference values are set to 1.6 Wb, respectively 100 rad/s. Time step is set to 1e-4 s.

Application 1: Direct vector control of transient no-load start-up

The figures below present the results of the no-load start-up regime of the induction machine for the field and circuit models. The rotor flux module shows almost the same variation in both models. The i_{sd} component of the stator current in the mobile coordinate system (d, q), has approximately the same variation in both models, because the rotor flux module controls this component.

The steady state values of the angular velocity, 110 rad/s in the field model, figure 4, and 103 rad/s in the circuit model, figure 5, are similar, but the steady state is reached 3 times faster in the circuit model.

	Flux regulator	Angular velocity regulator	i_{sd} regulator	i_{sq} regulator
K_p	2000	8	10^5	10^5
K_i	2500	3	10^5	10^5

Table 1: The parameters of the regulators.

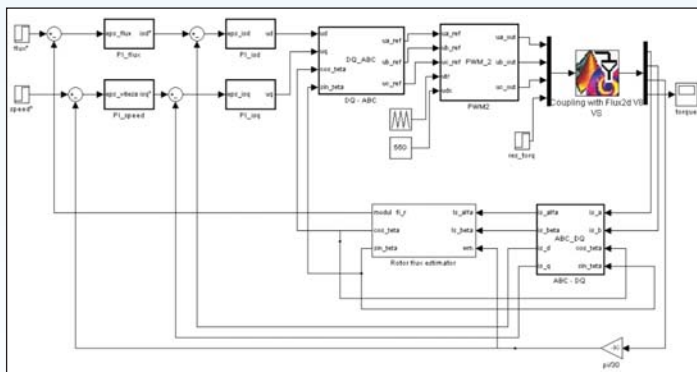


Figure 1: Control scheme of the induction machine.

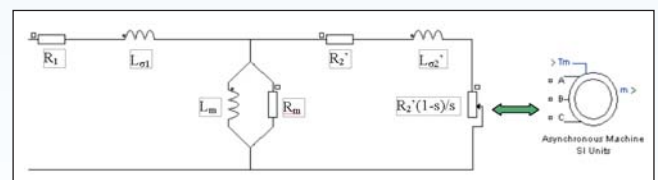


Figure 3: Equivalent electric scheme of the induction machine and the corresponding Simulink block.

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In the field model, saturation is taken into account and the rotor flux follows the non-linear magnetic curve of the materials. Since the direct vector control method requires a constant rotor flux, the operation of the flux regulator is slowed down, and, thus the dynamic regime of the angular velocity is slower compared to the circuit model.

In the circuit model, the computation of rotor flux uses the equivalent scheme with constant values of parameters and the saturation is not taken into account.

The angular velocity controls the variation of the torque and of the i_{sq} component of the stator current. Thus, the i_{sq} component falls to zero when angular velocity reaches the reference value.

The magnetic torque increases until the rotor flux reaches the reference value; then, the magnetic torque stabilises, (17 Nm in the field model, figure 6, and 22 Nm, in the circuit model, figure 7) until the angular velocity reaches the reference value. The difference between the mean values of the magnetic torque obtained by the two models is explained by the variation in the magnetic state of the induction machine.

Application 2: Direct vector control of transient start-up with load

The second direct vector control application refers to the start-up of the motor with load. The load torque is applied at $t = 0$ s having a value of 10 Nm. The results of the start-up with load regime of the induction machine for the field and circuit model are presented in the figures below.

Again, there are insignificant differences between the time variation of the i_{sd} component in the models.

By studying the numerical results in figures 8 and 4 we note that the dynamic regime with load is 2.5 times slower than the no-load regime.

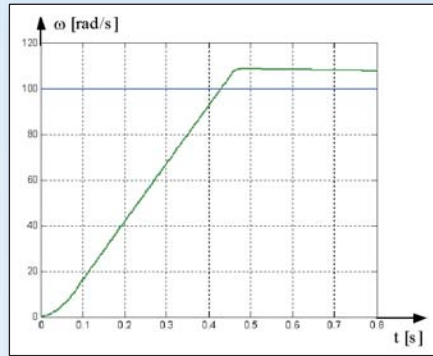


Figure 4: Time variation of angular velocity (field model).

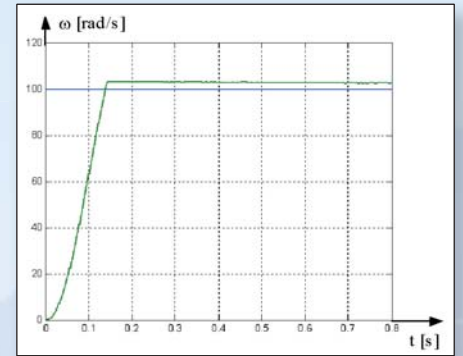


Figure 5: Time variation of angular velocity (circuit model).

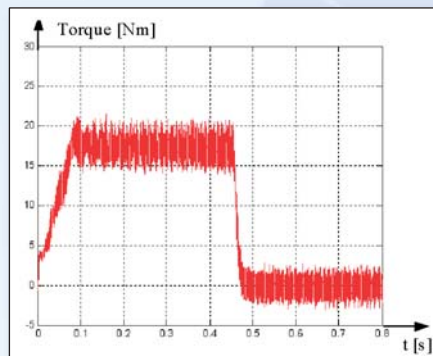


Figure 6: Electromagnetic torque variation (field model).

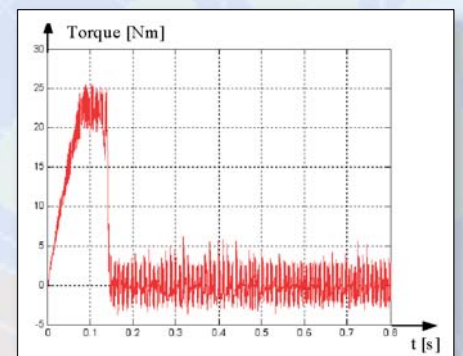


Figure 7: Electromagnetic torque variation (circuit model).

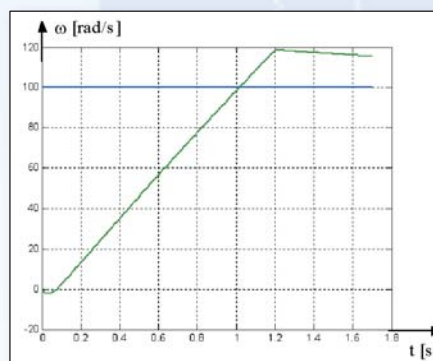


Figure 8: Time variation of angular velocity (field model).

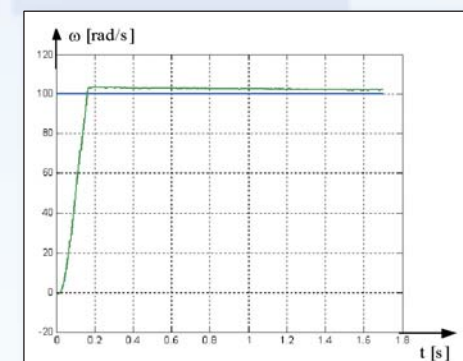


Figure 9: Time variation of angular velocity (circuit model).

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The steady state mean value of the i_{sq} component, figures 10 and 11, after the angular velocity reaches the reference value, is higher in the field model than in the circuit model.

Conclusions

This paper brings new contributions to the study of the direct vector control scheme of the induction machine by using a Flux - Matlab/ Simulink coupling.

The field model takes into account the specific electromagnetic phenomena of the induction machine such as armature slotting, magnetic nonlinearity of laminations and slip dependent equivalent rotor circuit parameters. Thus this model is much more realistic for the study of dynamic behaviour of the squirrel cage induction machine than the circuit model in which the equivalent parameters of the electric scheme, resistances and inductances are constant, irrespective of the machine's operating conditions.

Vector control algorithm performance depends on the magnetic state of the induction machine.

A variation of the magnetic state leads to fluctuations and deviations in all mechanical and electrical quantities. As a result, we observe that the dynamic regime of angular velocity, torque and stator currents is slower in the field model compared to the circuit model and their numerical values are different. The dynamic regime of motor start-up with load is slower than in the case of no-load start-up.

In variable-speed AC drives that use voltage fed inverters, controlling the voltage amplitude and frequency output of the inverter feeding the

AC motor is essential for torque and speed control of the machine. Using the direct vector control scheme, the stator currents can be controlled and kept constant to a reference value without producing substantial Joule losses. The chosen reference value of the angular velocity is two times smaller than the rated angular velocity in order to verify the capacity of the control scheme to function at different angular velocities.

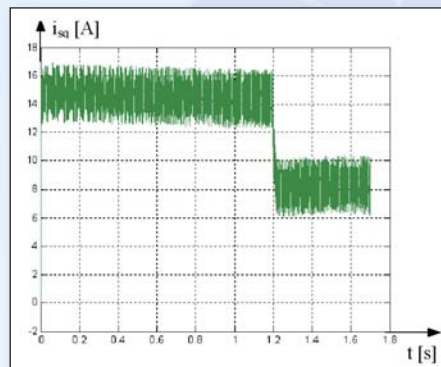


Figure 10: Component i_{sq} of the stator current (field model).

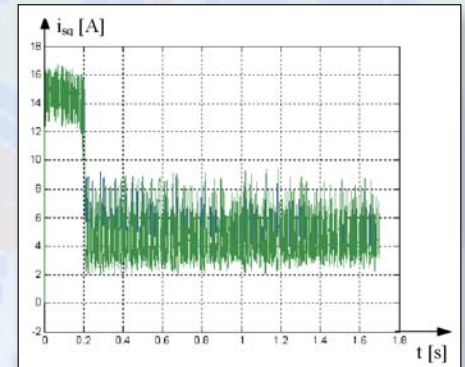


Figure 11: Component i_{sq} of the stator current (circuit model).

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