Switched reluctance motor (SRM) drive modelling using Flux to Simulink technology.

Frederik D'hulster – Hogeschool West-Vlaanderen dept. PIH, Kortrijk, Belgium.

1 - Introduction

Switched reluctance machines are relatively simple electric machines but with a high degree of nonlinearity. This yields a drive with complicated algorithms to control its nonlinear behaviour. SRM-drives can be optimized for different customer demands (maximum efficiency, maximum torque, minimum noise and vibration ...). To optimize its control parameters, an accurate nonlinear model of the SRM is required. The model, presented in this article, uses the Flux to Simulink technology. The advantage of this coupled method is the integration of a simple 2D FE-model of the motor geometry into a complex Matlab/Simulink® model of the drive with different control optimizations.

2 - Basic principles of SRM's

The concept of a switched reluctance machine is very simple. It consists of stator and rotor poles, made of laminated steel with high magnetic permeability. Only the stator poles are excited by coils. A typical configuration is the SRM with 8 stator en 6 rotor poles, a so-called '8/6 SRM'. With 8 coils on the stator, 4 phases are created with the corresponding coils in parallel. A sequence of anti-clockwise excitations of the different phases results in a clockwise rotation of the rotor due to a positive torque generation. SRM's are characterized by a flux-linkage ψ and inductance *L*, varying with position and current. The position-dependent behaviour is due to the geometry of the overlapping stator and rotor teeth. In most SRM-applications, saturation occurs, resulting in a nonlinear inductance and flux-linkage. This nonlinear behaviour explains the difficulty in modelling and controlling SRM-drives.

3 - FE-model

A 2D FE-model of the motor geometry is built. Due to the symmetry, only half a motor is considered. The mesh is illustrated in figure 1. Attention must be paid to the uniform mesh of the airgap, which is about 0.35 mm in this particular case. This narrow airgap results in a large gradient of the number of elements, when moving away from the airgap. A dual ring in the airgap is chosen to avoid a mesh-ripple in the airgap torque calculation (figure 2). One ring is modelled as fixed air and the other as a rotating airgap. The coupled electric circuit consists of the phase coils with a programmable voltage source and a switch to obtain a unidirectional current. The model is computed through transient magnetic analysis. As can be seen in figure 3, the magnetic flux path depends on the number of excited phases, which is defined by the control angle strategy (on- , off- and freewheel-angle). The FE-model not only calculates the self-inductance but also mutual inductances and induced voltages are computed because they can affect the current and torque behaviour of the SRM. Due to the length of the rotor, which is three times the rotor diameter, end-inductances are neglected. For a shorter SRM, the end-inductance can be integrated into the electric circuit.

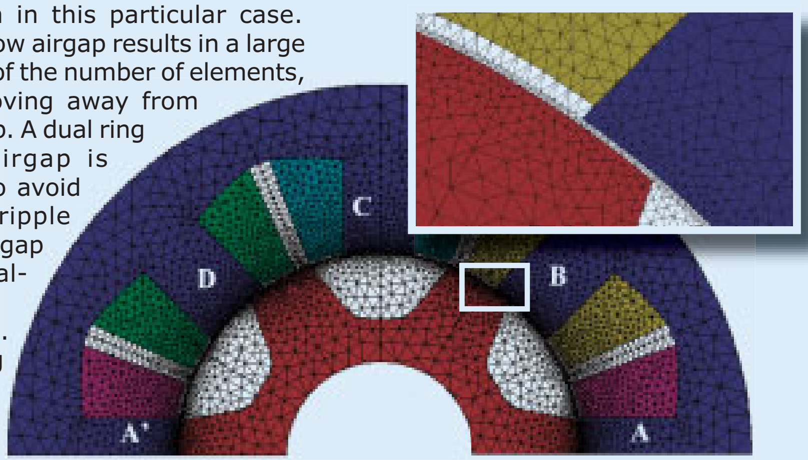

Figure 1 : 2D mesh of the motor geometry.

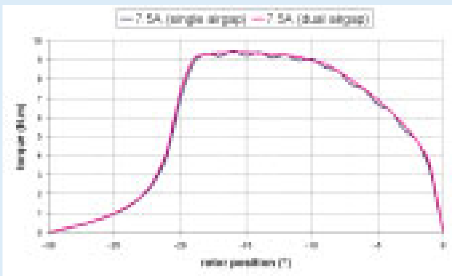

Figure 2 : Influence of airgap mesh on torque calculation (i_{ref} = 7.5A)

4 - SRM drive model

A model of the complete SRM drive (figure 4) consists of a three-level (on, off and freewheeling) current hysteresis controller with soft-chopping, a phase-activation control strategy, a speed controller and a load-model. This four-quadrant drive model calculates the different phase voltages at every time step. One switch per phase is added in the electric circuit to inhibit current flow due to induced voltages when the phase is not activated. The main variables in the control are the reference current, the rotor position and the rotor speed. Different control angle optimization strategies can be easily implemented into the model.

5 - Flux to Simulink technology

The coupling between drive model and FE-analysis is represented in figure 4. The input parameters for the FE-analysis are the applied phase voltages, the switch resistance values (R_{ON} or R_{OFF}) and the rotor speed.

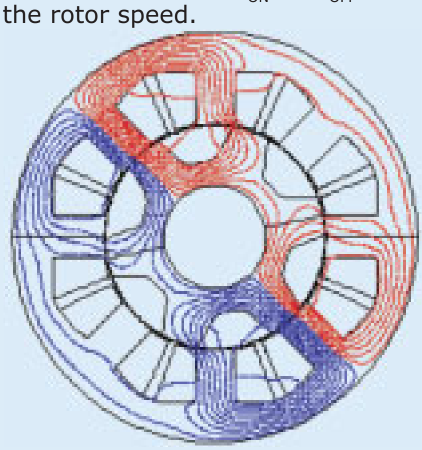

Figure 3 : Magnetic flux distribution during simultaneously excited phases C and D.

(continued on page 11)

Switched reluctance motor (SRM) drive modelling using Flux to Simulink technology. (continued from page 10)

Frederik D'hulster – Hogeschool West-Vlaanderen dept. PIH, Kortrijk, Belgium.

The output parameters of the FE-analysis are the phase currents, the coil voltages and the instantaneous electromagnetic torque in the airgap.
At every time-step ($t_s = 2.10^{-5}$ s), data is exchanged between the drive model and the FE-analysis. This method has the great advantage that a complex drive model in Matlab/Simulink® can be used in combination with accurate flux-linkage calculation, taking into account the mutual coupling between adjacent phases. The disadvantage of this method is the rather high calculation time, caused by the high amount of elements in the thin airgap. Figure 5 shows the simulation results of coil voltage, phase current and electromagnetic torque production for a reference current of 7.5 A and a rotor speed of 50 rad/s. The results clearly show that, besides the normal ON, OFF and chopping voltage of phase A, an extra induced voltage occurs, due to the excitation of adjacent phases D and B. Conform the flux distribution of figure 3, this voltage is induced in phase A when phase B or D is activated together with phase C (see figure 5).

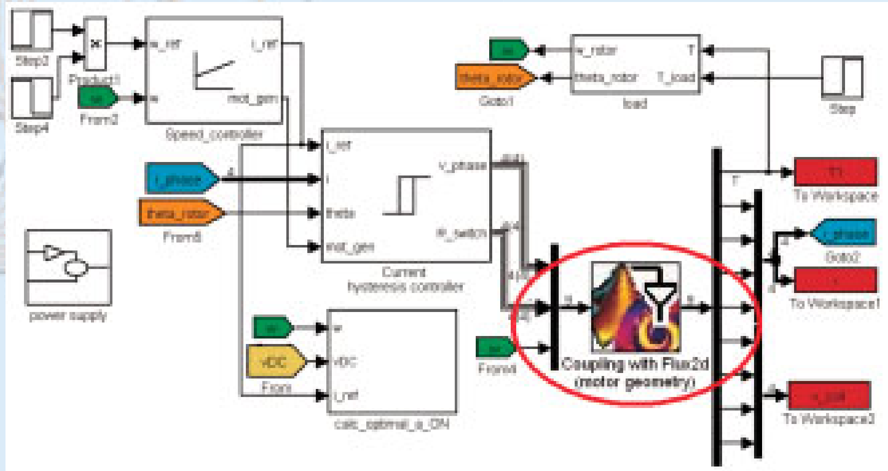

Figure 4 : SRM drive model with Flux to Simulink technology.

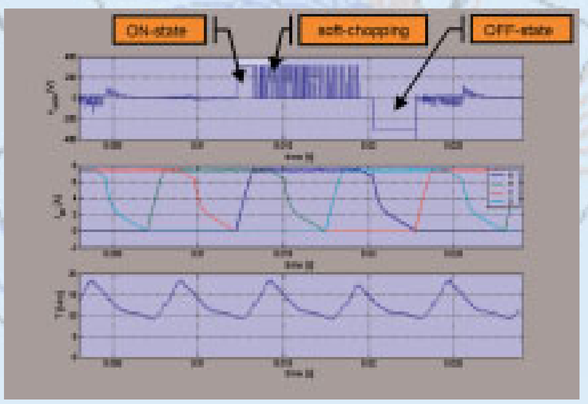

Figure 5 : Simulation results of Flux to Simulink technology.

6 - Conclusion

The Flux to Simulink technology has proven to be an efficient tool to model complex motor drives in combination with accurate flux-linkage calculation. Effects, such as mutual couplings and induced voltages, can be analysed. Attention must be paid to the sample-time in Matlab/Simulink® and the number of elements in the FE-model in order to keep the computation time acceptable...

PSCAD and transmission lines. (continued from page 7)

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placed on the line at 30% of its length from the load (figure 9). As you can see below, breaker currents from BRK22 were captured in figure 10.
With the accurate models in PSCAD, you can perform detailed transient simulations of electrical networks. The different types of PSCAD models allow the user a large degree of freedom in designing simulations. Whatever the goal of the study, users can easily and quickly realize any kind of simulation, and have discretion on the degree of accuracy.

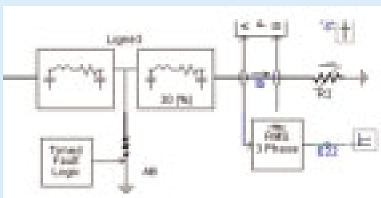

Figure 9: Fault on the line.

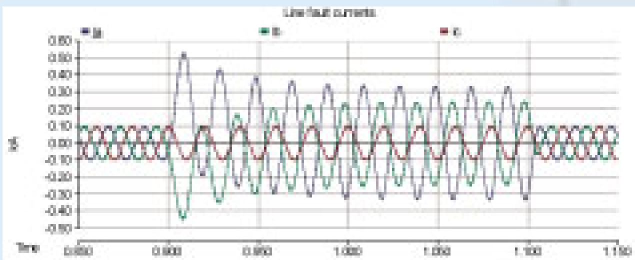

Figure 10: Instantaneous traces for a Line to Line fault on A and B phase, 30% of the line.