syreDrive: A New Add-on to the Motor Design Framework for Automated Sensorless Control Simulation

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***Abstract*—This digest summarizes the M.Sc. thesis work thoroughly described in the full version text. The aim of the work is to provide a general approach for the automatic generation of the dynamic model and the control C-code for simulation of Synchronous Reluctance (SyR) motor drives, starting from the Finite Element Analysis (FEA) model of the motor. Multiple control methods are analyzed, both encoder-relying and sensorless techniques. A systematic comparison of various sensorless methods is presented, and the automatic control code generation is validated simulating three SyR machines of different sizes. The work is implemented in the electric motor design platform *SyR-e*, in the form of the new feature *syreDrive*, capable of generating the dynamic model of the electric drive, the control files and simulating a default speed and torque sequence for evaluation of the dynamic response of any selected control scheme and any given SyR motor.**

I. Introduction

This work aims at developing an automated procedure to evaluate the performance of synchronous reluctance motors through auto-generated control simulations, provided the parameters and the flux maps of the machine.
The main motivations are:

1) To build a general control algorithm that is independent of the machine specifications.
2) To provide a quick control performance evaluation for machine design prototypes.

A. Description of the Work

This thesis work contributes to the open-source motor design platform *SyR-e*, in the form of the new add-on, *syreDrive*. Given a motor designed in *SyR-e*, the new *syreDrive* feature will automatically build a Simulink model comprising the electric motor, the inverter and the current vector control blocks for control development purposes. A template of C control files that is general in nature and a Simulink model, which is suitable for any synchronous reluctance motors, are generated and automatically customized according to the data of the motor under consideration. Then, the simulation is run. This will enable the fast and seamless transition from the motor design environment to the digital control environment. The user inetrface of *syreDrive* provides options for torque or speed control modes and can be encoder-relying or position sensorless. Multiple sensorless control methods are integrated and available to the user in a simple GUI. The user will be able to run and further develop the motor control simulation. The C code generated is portable to any floating-point 32-bit microcontroller with minor modifications.

II. Comparison of Sensorless Control Techniques

The position estimation techniques employed for sensorless control in this work are:

- *fundamental model-based*: they rely on the back-emf from voltage integration for position estimation at medium to high speeds region. To this end, a hybrid flux observer is implemented in the stationary reference. Among the numerous techniques available in literature, two schemes are implemented: *(i)* active flux position observer; *(ii)* adaptive projection vector for position error estimation (APP);
- *saliency-based*: they rely on the anisotropic machine response to high-frequency excitation. They are employed at zero to low speeds.

A speed-dependent linear fusion scheme is used to achieve a smooth transition from the low-speed to the high-speed sensorless methods and viceversa. The block diagram of the full-speed sensorless control scheme is showns in Fig. 1.

III. Control Implementation and Results

After assessing the torque and speed control relying on the encoder for the rotor position and speed feedback, the sensorless control implemented is tested and the multiple position estimation techniques presented in Section II are compared to each other.

A. Tuning and Calibration of the Control Parameters

syreDrive is meant to provide an automatically generated initial model for SyR motor control to be furhther developed. Hence, the tuning of the control parameters aims at giving good performances for any SyR motor, without reaching the outermost limit, to ensure acceptable dynamic responses for a broad range of machines of different sizes. A thorough calibration is left to the end user, after obtaining the first approach tuning from *syreDrive*.
Three motors of different sizes are simulated to assess the general valididty of the control calibration methodology. Their

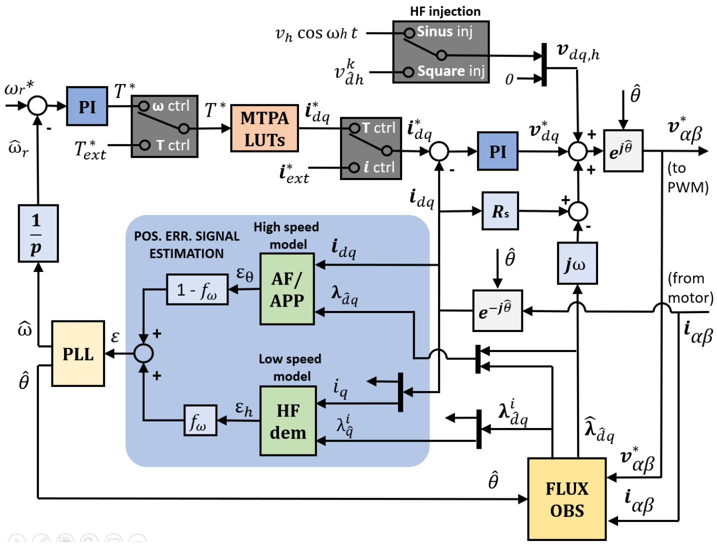
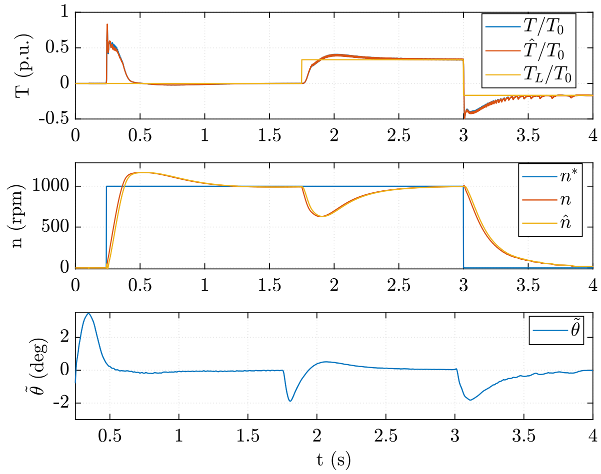


Fig. 1: The block diagram of the full-speed sensorless control scheme implemented.

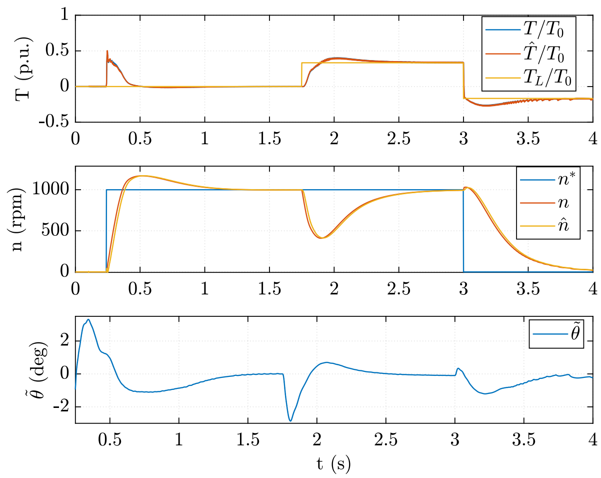
power ratings are 1.1, 2.2 and 4.4 kW. The current and speed loop regulators are adjusted according to the machine parameters. The bandwidth of the PLL, the frequency and amplitude of the high-frequency voltage injection are defined separetely for different low-speed position estimation methods. The parameters suitably calibrated automatically by the control algorithm for each machine resulted in good performances for all of the tested motors. Moreover, an example of optimization of the automatically generated control parameters is provided.

B. Simulation Results

A comparison of the three tested motors is carried out to determine the limitations of the automated generation of the control and simulation model. In particular, a saliency analysis is performed to assess the no-load and high-load operations, which are critical for the saliency-based sensorless algorithms, entrusted with the start-up of the motor.
In Fig. 2, an example of the output results of an automated simulation performed with *syreDrive* in speed control mode of two of the motors under test is reported. The control files of these simulations, which employ the full-speed sensorless control scheme, have been automatically generated, as well as the Simulink model. The first plot shows the motor torque T, the torque computed with the observed quantities $\hat{T}$ and the load torque T_L, all in $p.u.$ relative to the rated torque of the simulated motor T_0. The second plot depicts the reference speed n^*, the speed n and the observed speed $\hat{n}$ in rpm. The last plot shows the position error $\tilde{\theta}$, which is mostly zero, except for the speed transients, during which it remains below four degrees in either cases. The control dynamic response to torque load is rather relaxed, to avoid harsh torque peaks and to allow any motor to be controlled with the automatatically generated parameters, even the ones that exhibit poor saliency at high loads, for which the saliency-based position estimation methods would struggle to sustain the control.



(a) 1.1 kW motor under test.



(b) 2.2 kW motor under test.

Fig. 2: Two examples of simulation in speed control mode from *syreDrive*. The simulation in (a) was performed using the 1.1 kW SyR motor tested, while the one in (b) using the 2.2 kW motor.

IV. Conclusion

In this thesis work, a method for fast and easy automated generation of control files and the Simulink model for any given SyR motor is introduced and implemented in the software *SyR-e* in the form of the new add-on, *syreDrive*. The automated system for control file generation is validated on three motors of different size, proving the effectinveness of the automatic control calibration, and its general validity. This tool provides a shortcut towards the implementation of the control strategy of a freshly designed motor or any SyR machine for which the control is to be evaluated, especially for consideraing position sensorless control implementation. The control files generated are easily portable to any floating-point microcontroller and can be utilized for practical tests or for further dedicated tuning of the control.