POLITECNICO DI TORINO
Master Thesis in Electrical Engineering

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

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Presentation outline

1. Introduction and motivation

2. *syreDrive* description

3. Focus on position sensorless techniques
    1. Active fluxe or APP – high-speed region.
    2. Sinusoidal or square wave injection } low-speed region.
    3. Current or flux demodulation } low-speed region.

4. Selected results

5. Conclusion

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Aim of the work

GOAL

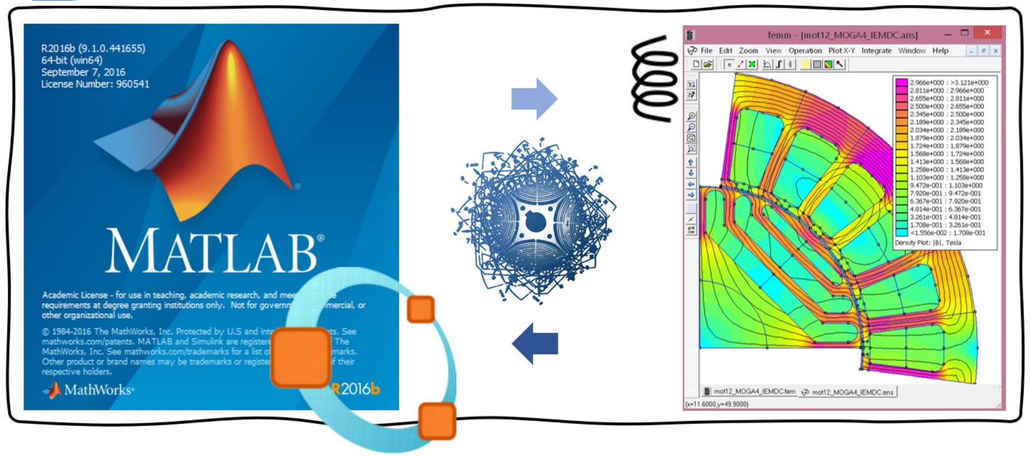
To develop an **automated procedure** to evaluate the performance of SyR motors through **auto-generated control simulations**, provided the parameters and the flux maps of the motor.

CONTRIBUTE

This work contributes to the open-source motor design platform ***SyR-e***, in the form of the new add-on:

syreDrive.

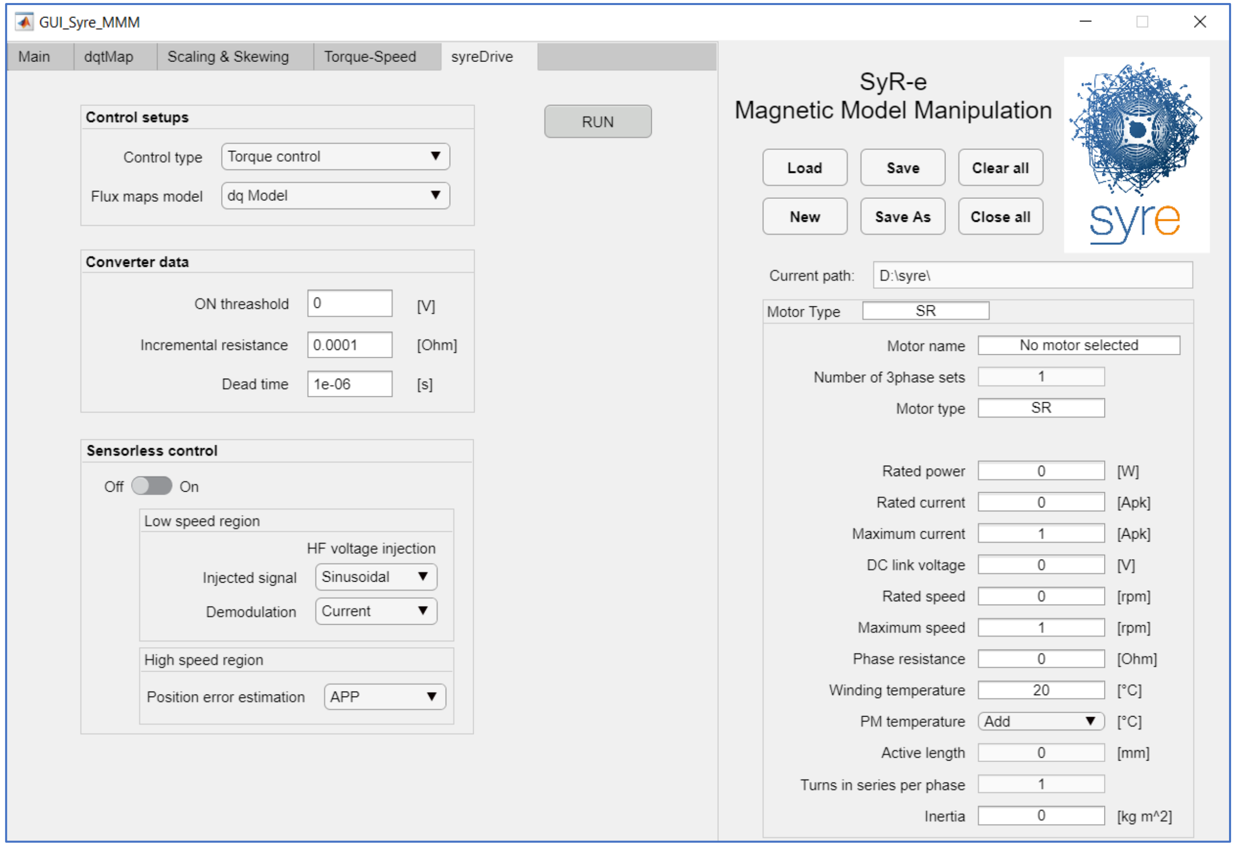
syre https://github.com/SyR-e

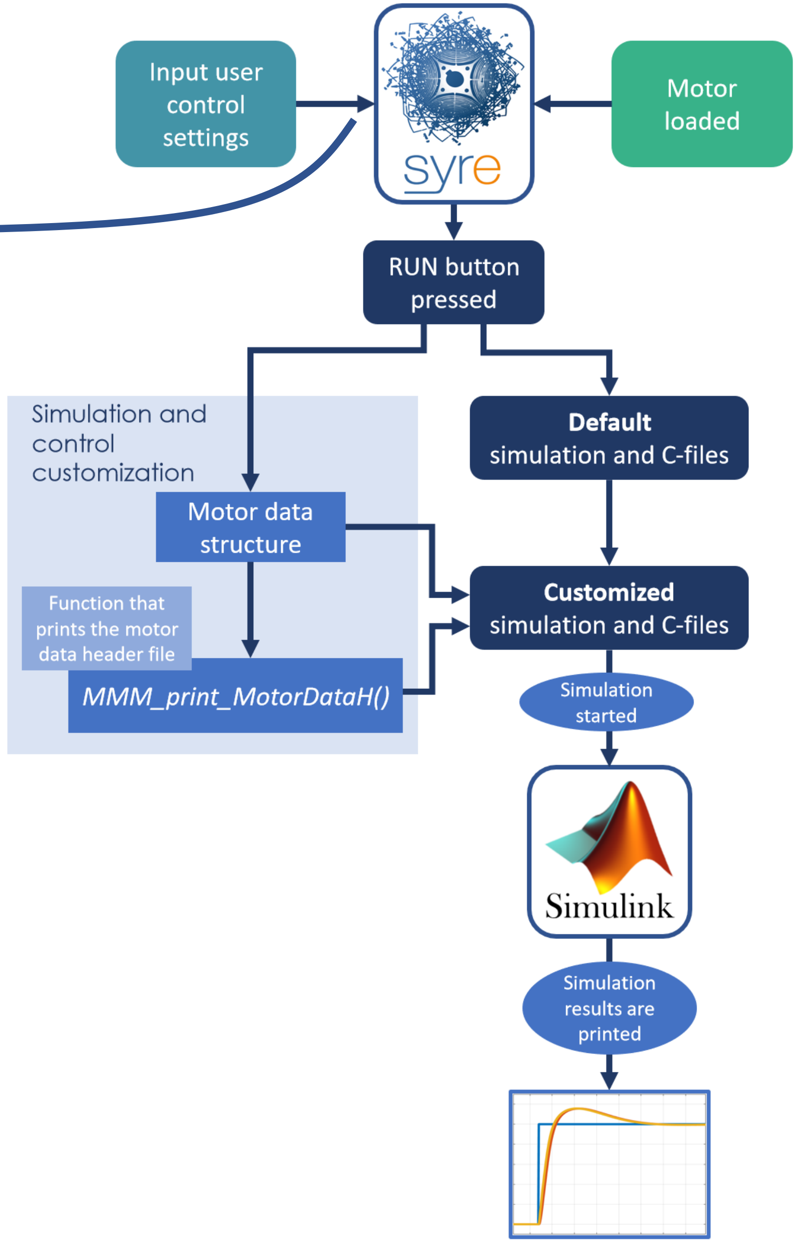


syreDrive flow chart

syreDrive GUI

The work is integrated in a simple **GUI**





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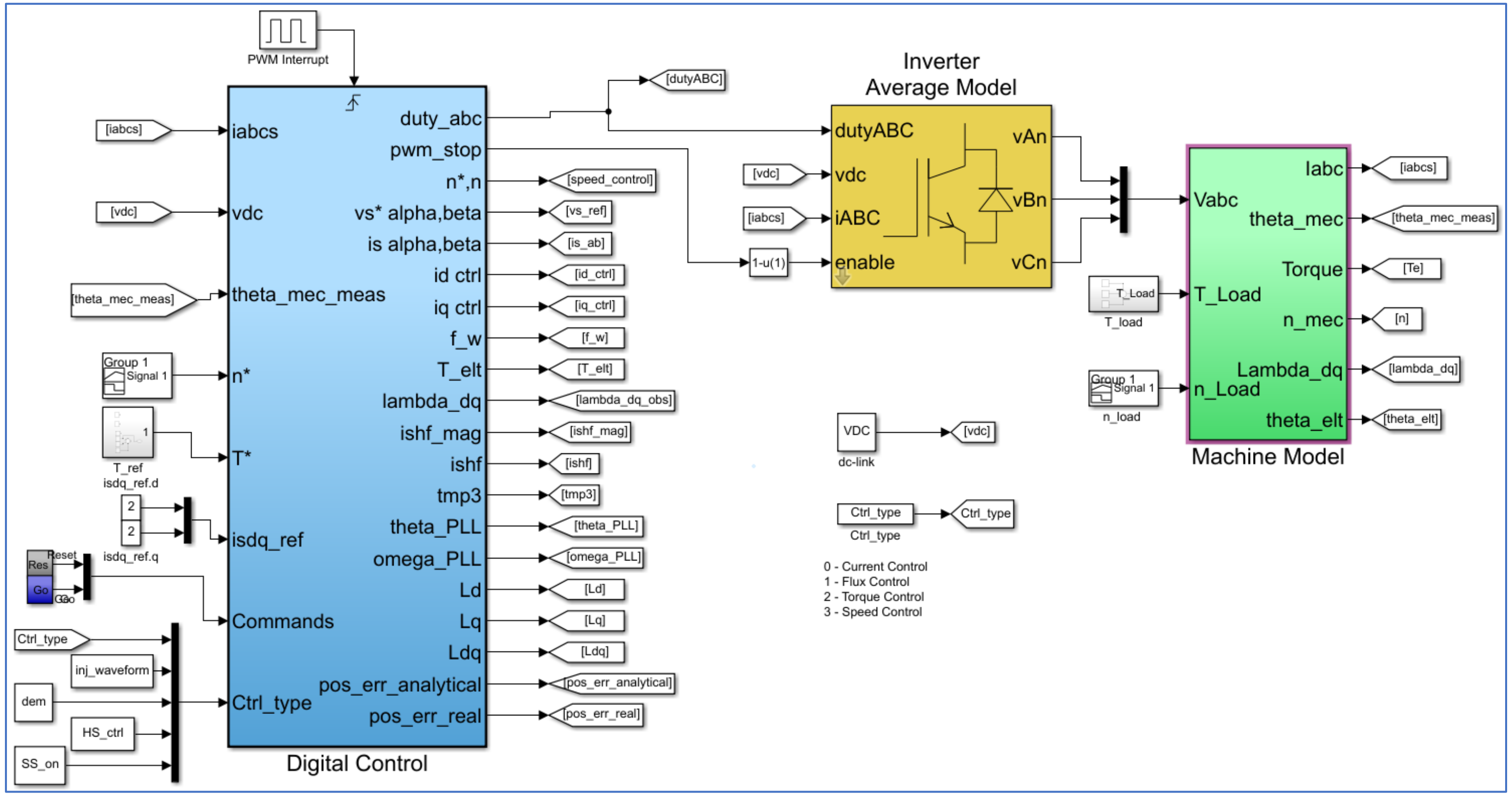
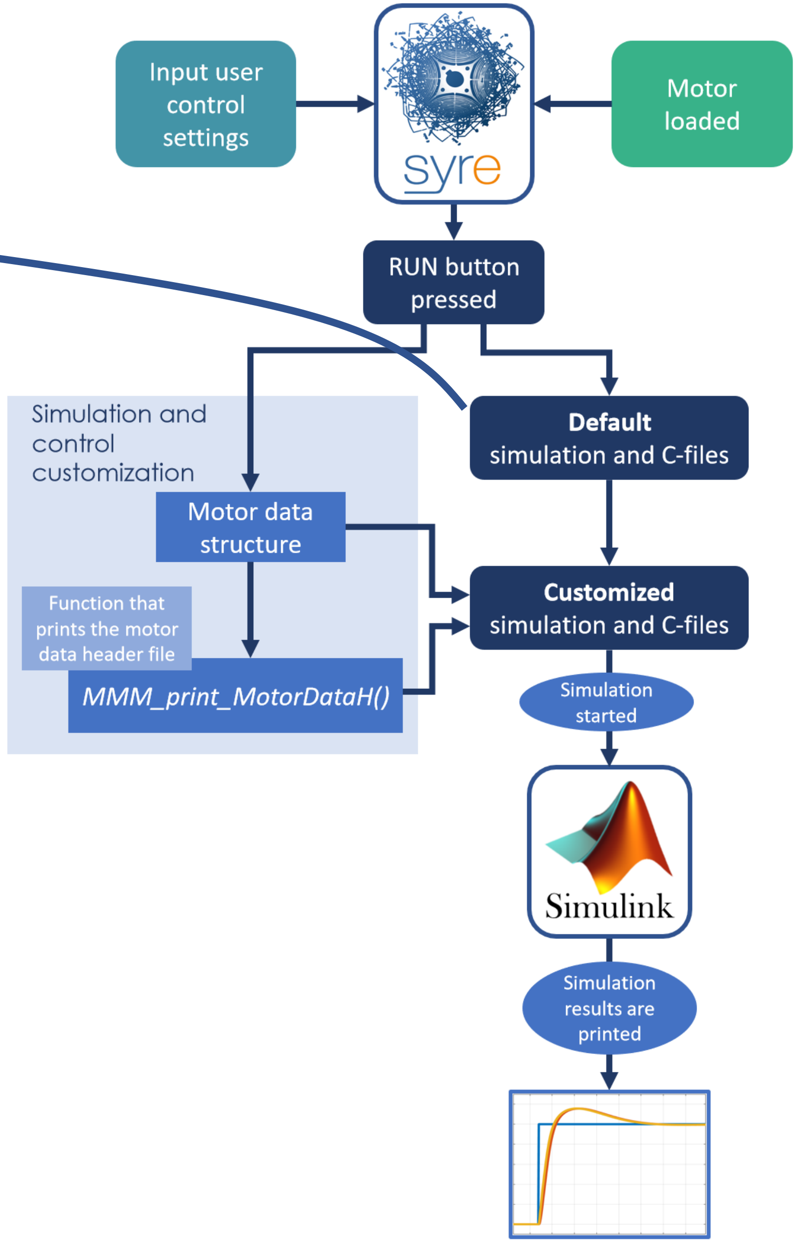
syreDrive flow chart

Simulink model

A default Simulink model is customized with the motor data



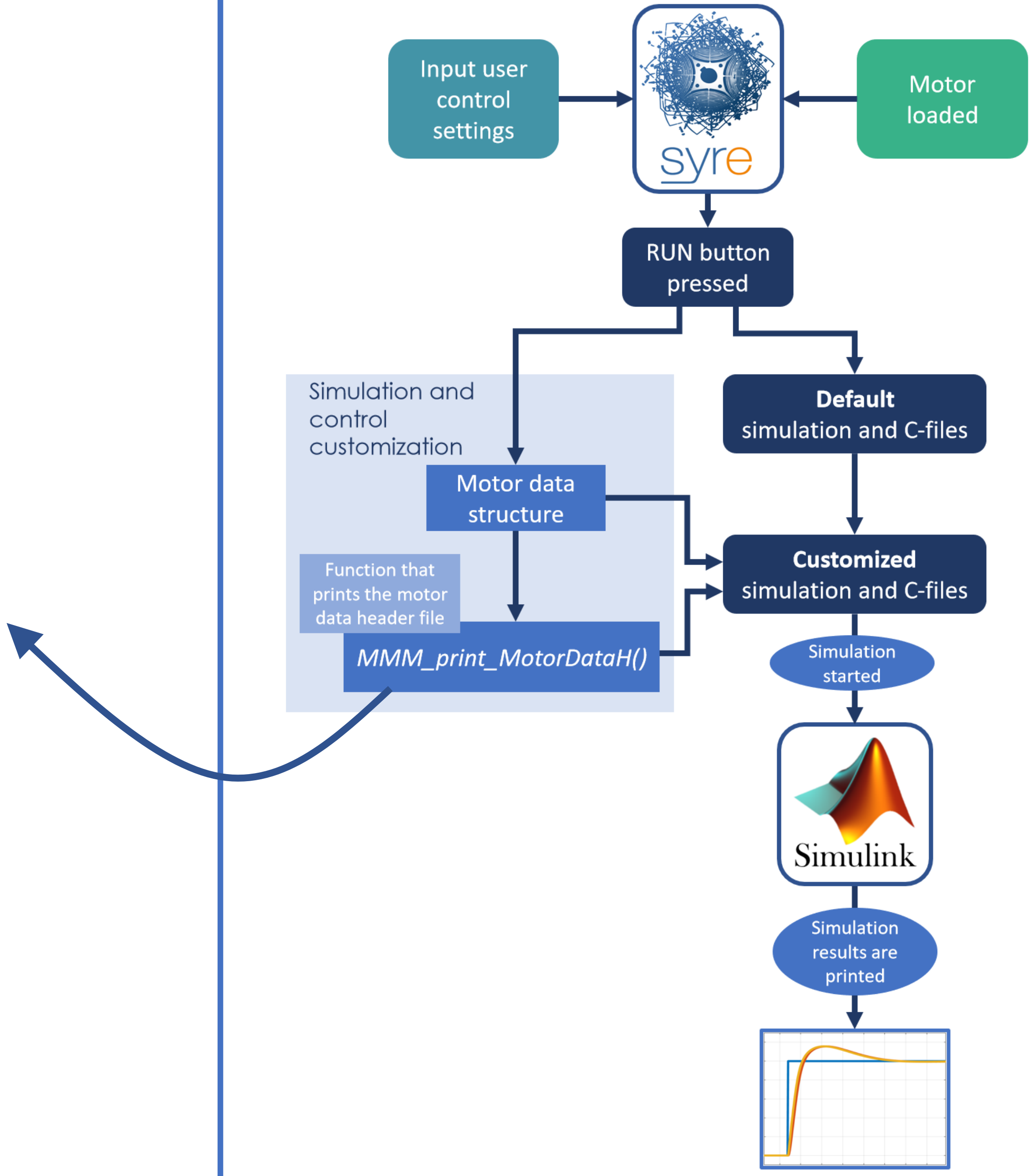


syreDrive flow chart

Control files customization

MotorData.h

```c
#define I_rated             3.00
#define T_rated             7.10
#define Tmax_mot            14.20
#define Imax_mot            8.00
#define nmax_mot            3000
#define RS                  4.5000
#define PP                  2 // pole pairs
#define ONE_P               1/PP
#define J                   0.00400
#define ENCODER_RESOLUTION 2048 //1024 //512

#define deadtime 1e-6

#define Ld_inic 0.452
#define Lq_inic 0.050
#define ld_inic 0.452
#define lq_inic 0.050
#define ldq_inic -0.015

//21-Oct-2020
float TMIN    = 0;
float TMAX    = 31.474; //Nm
float DT      = 1.5737; //Nm
float INV_DT  = 0.6355; //Nm^-1

//MTPA - id
float  ID_REF[21] =
{ 0.000, 1.177, 1.628, 1.955, 2.230, 2.424, 2.589, 2.723, 2.852, 2.967, 3.084, 3.237, 3.355, 3.510, 3.630,

//MTPA - iq
float  IQ_REF[21] =
{ 0.600, 1.263, 1.711, 2.094, 2.439, 2.822, 3.214, 3.627, 4.042, 4.467, 4.892, 5.295, 5.720, 6.125, 6.552,

//MTPA - fd
float  FD_REF[21] =
{ 0.000, 0.579, 0.799, 0.951, 1.069, 1.139, 1.190, 1.222, 1.247, 1.266, 1.281, 1.302, 1.314, 1.330, 1.340,

//MTPA - fq
float  FQ_REF[21] =
{ 0.000, 0.167, 0.184, 0.200, 0.213, 0.228, 0.244, 0.261, 0.278, 0.296, 0.313, 0.328, 0.345, 0.360, 0.376,
```



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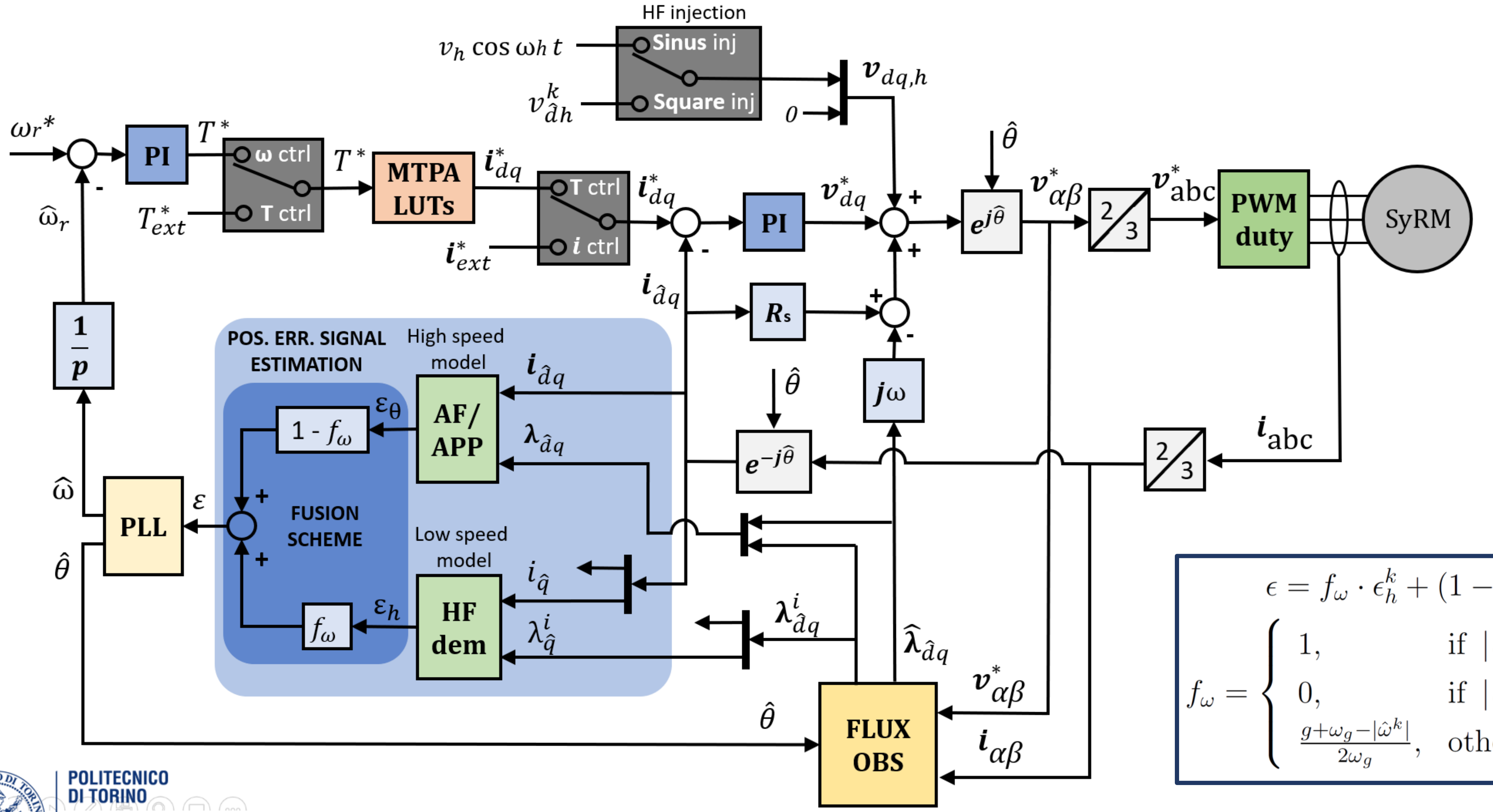
Position sensorless control implemented



$$\epsilon = f_\omega \cdot \epsilon_h^k + (1 - f_\omega) \cdot \epsilon_\theta^k$$

$$f_\omega = \begin{cases} 1, & \text{if } |\hat{\omega}^k| < g - \omega_g \\ 0, & \text{if } |\hat{\omega}^k| > g + \omega_g \\ \frac{g+\omega_g-|\hat{\omega}^k|}{2\omega_g}, & \text{otherwise} \end{cases}$$

SyR motors under test

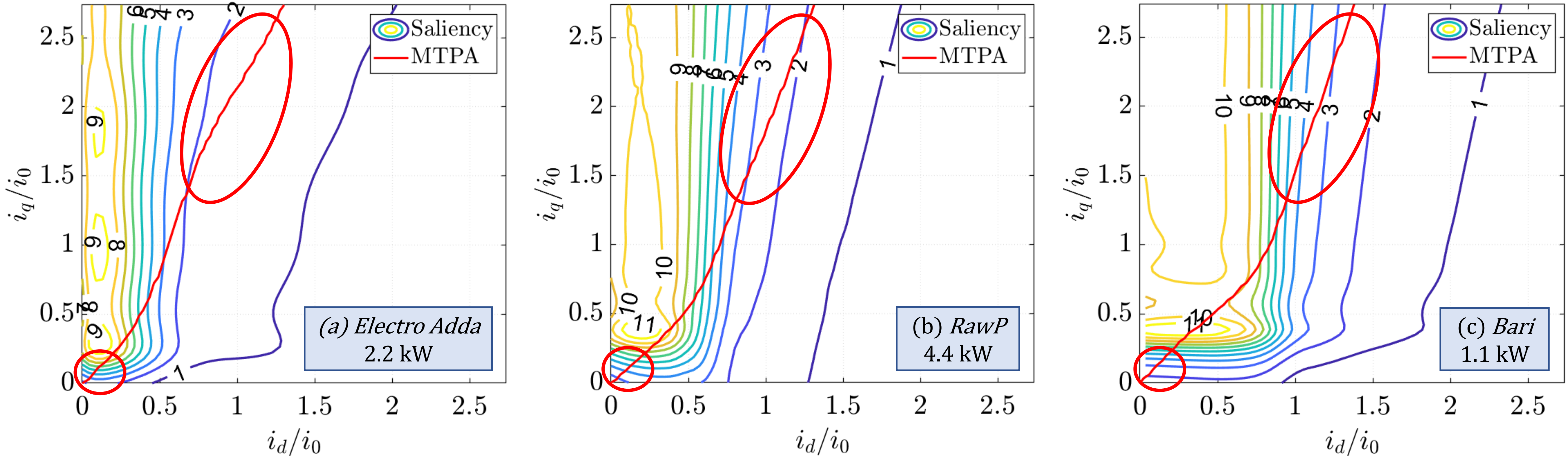
			Bari	Raw-P	Electro Adda
Rated power	P_0	(kW)	1.1	4.4	2.2
Rated torque	T_0	(N)	7.3	17	14
Rated speed	n_0	(rpm)	1500	2500	1500
Maximum speed	n_{max}	(rpm)	3000	6000	3000
Rated current	i_0	(A)	3.0	15	7.0
Maximum current	i_{max}	(A)	8.0	30	20
Phase resistance	R_s	(Ω)	4.5	0.46	3.5
DC-link voltage	V_{DC}	(V)	565	565	520
Pole pairs	p	(-)	2	3	2
Inertia	J	$kg{\cdot}m^2$	0.004	0.008	0.005

Saliency analysis

Since the sensorless position estimation methods for the low-speed range are **incremental saliency-based**,
a saliency analysis of the motors under test is carried out.

The incremental saliency is defined as:

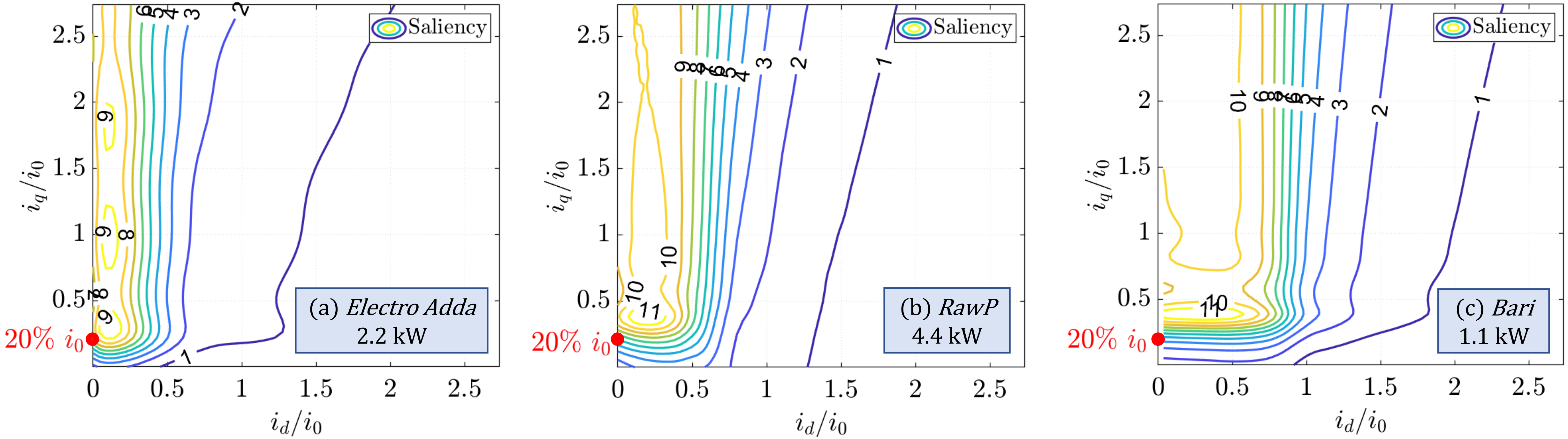
$$\frac{l_d}{l_q}$$



No-load operation

From the incremental saliency maps it is evident the convenience of imposing a minimum *q*-current at no-load, rather than a *d*-current.
This makes the automatic selection of the minimum current easier.

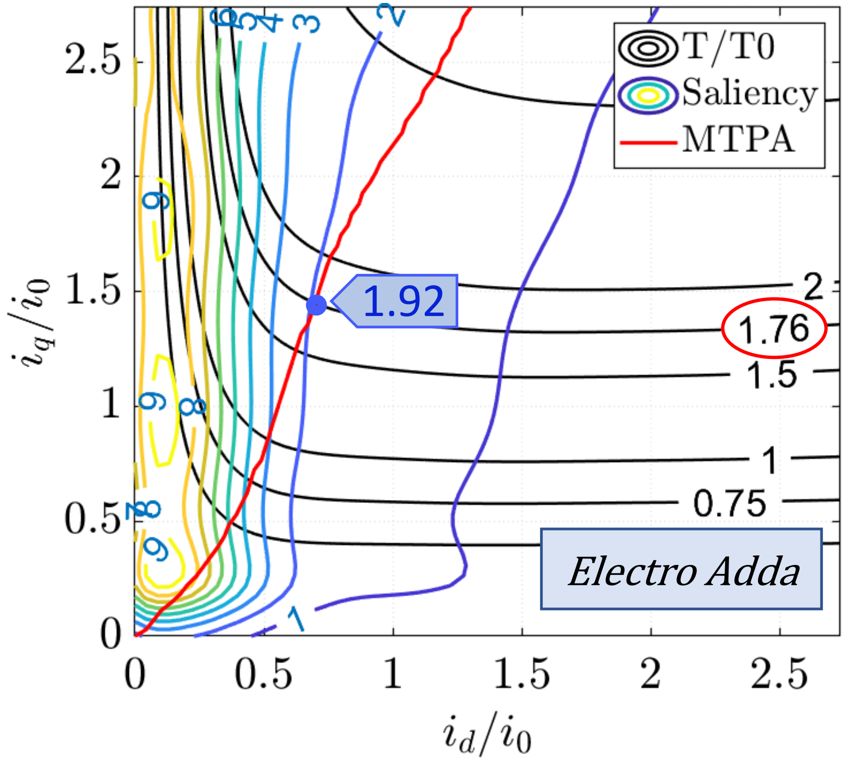
A value equal to the 20% of the rated current is selected.
By doing so, a sufficient value of saliency ratio is achieved in all three cases employing the lowest value of current possible.



High-load operation

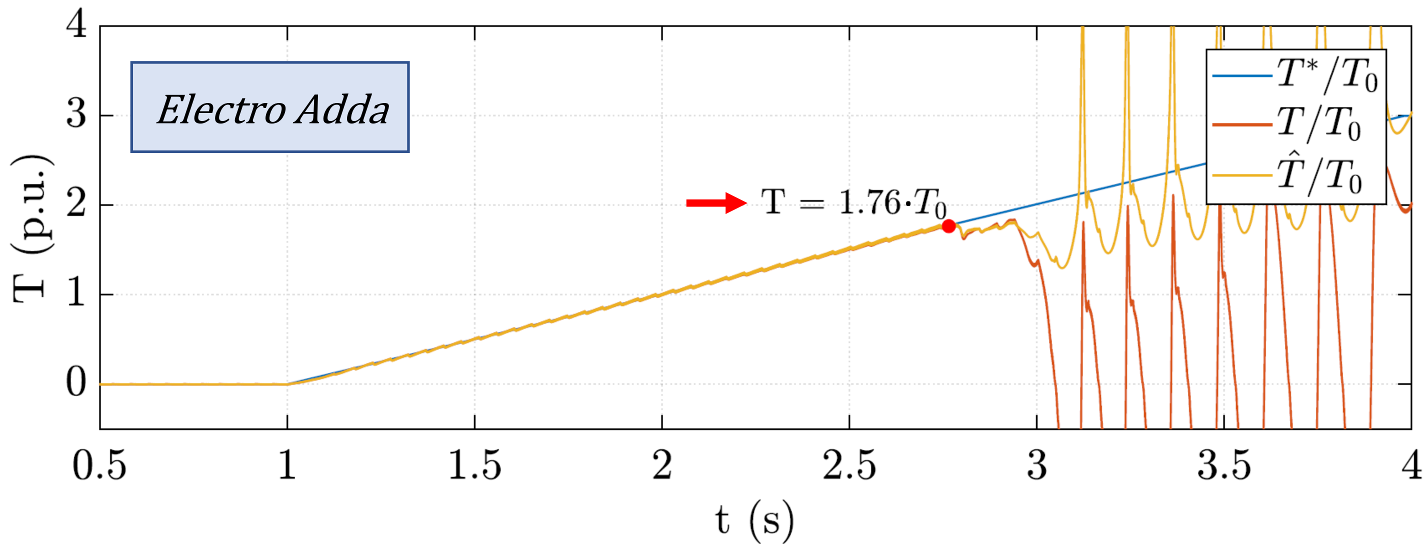
- Saliency map
- Torque map
- MTPA trajectory

→ Saliency at each operating point.



- The reference torque is ramped up from zero to $3T_0$.
- The speed is kept constant at $100\ rpm$ to be certain to operate with the low-speed **saliency-based position estimation method**.

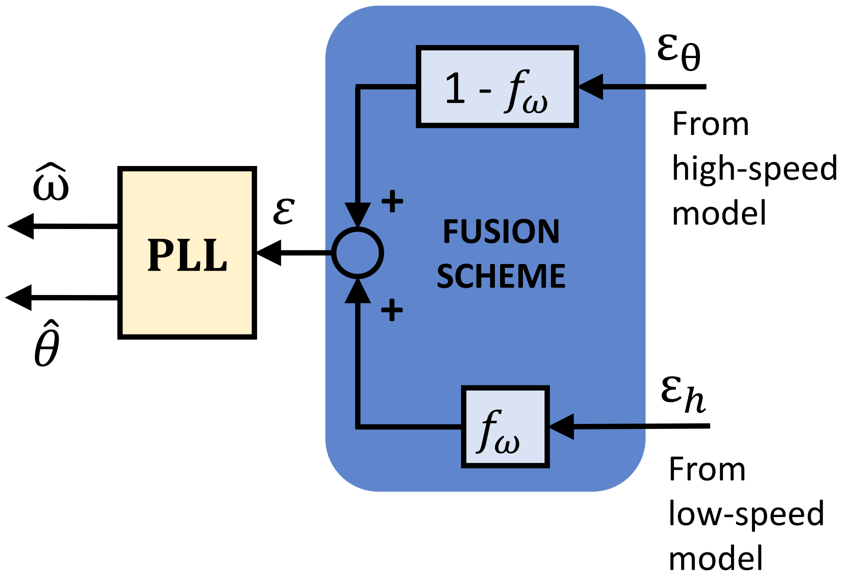
Electro Adda case:
The control loses the reference torque at $T = 1.76 \cdot T_0$.
It corresponds to an incremental saliency ratio of 1.92.
This value cannot be endured by the low-speed sensorless methods.

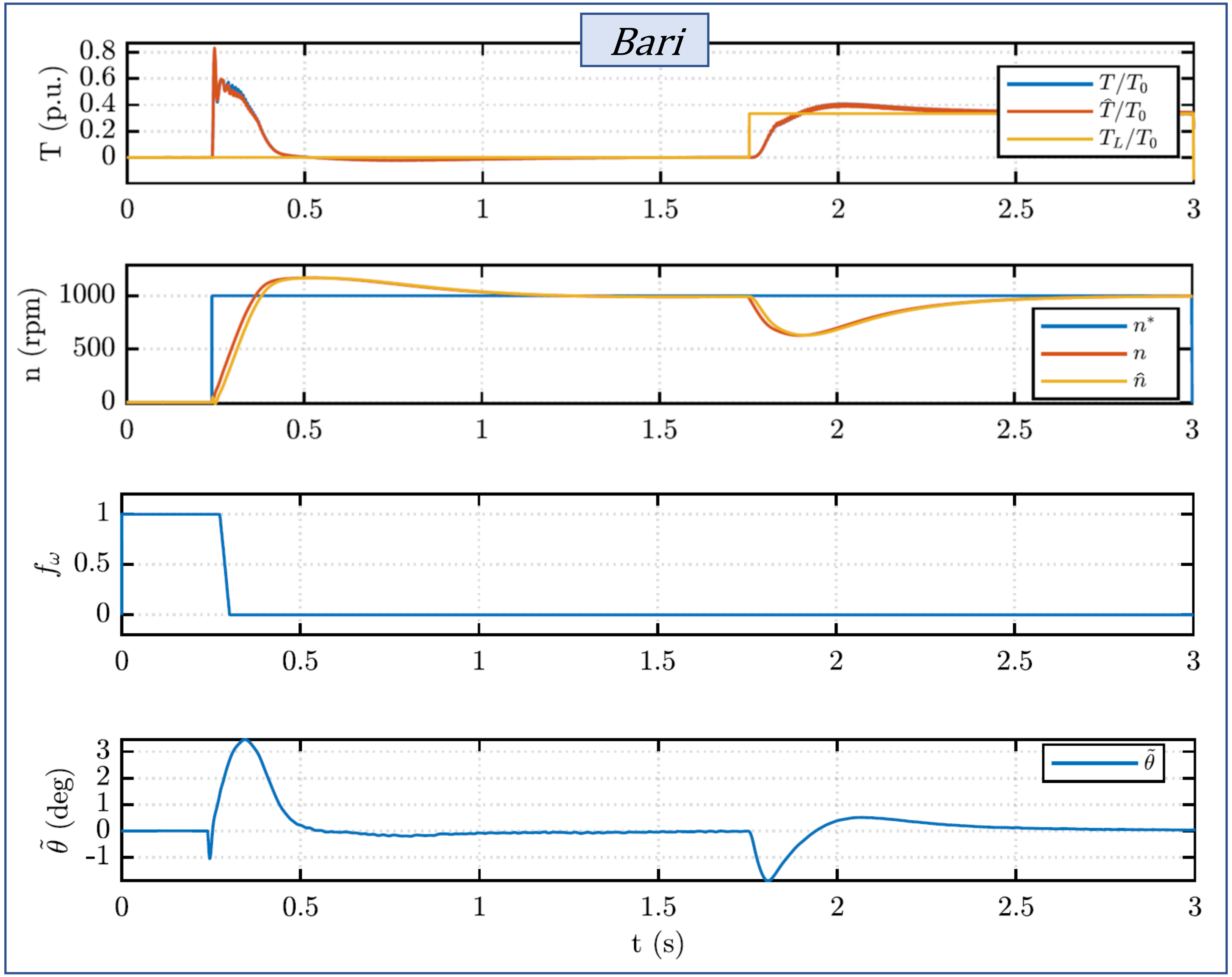


Selected results for the full-speed sensorles response

High-speed position error estimation method:

- Adaptive Projection vector for Position error estimation (**APP**)





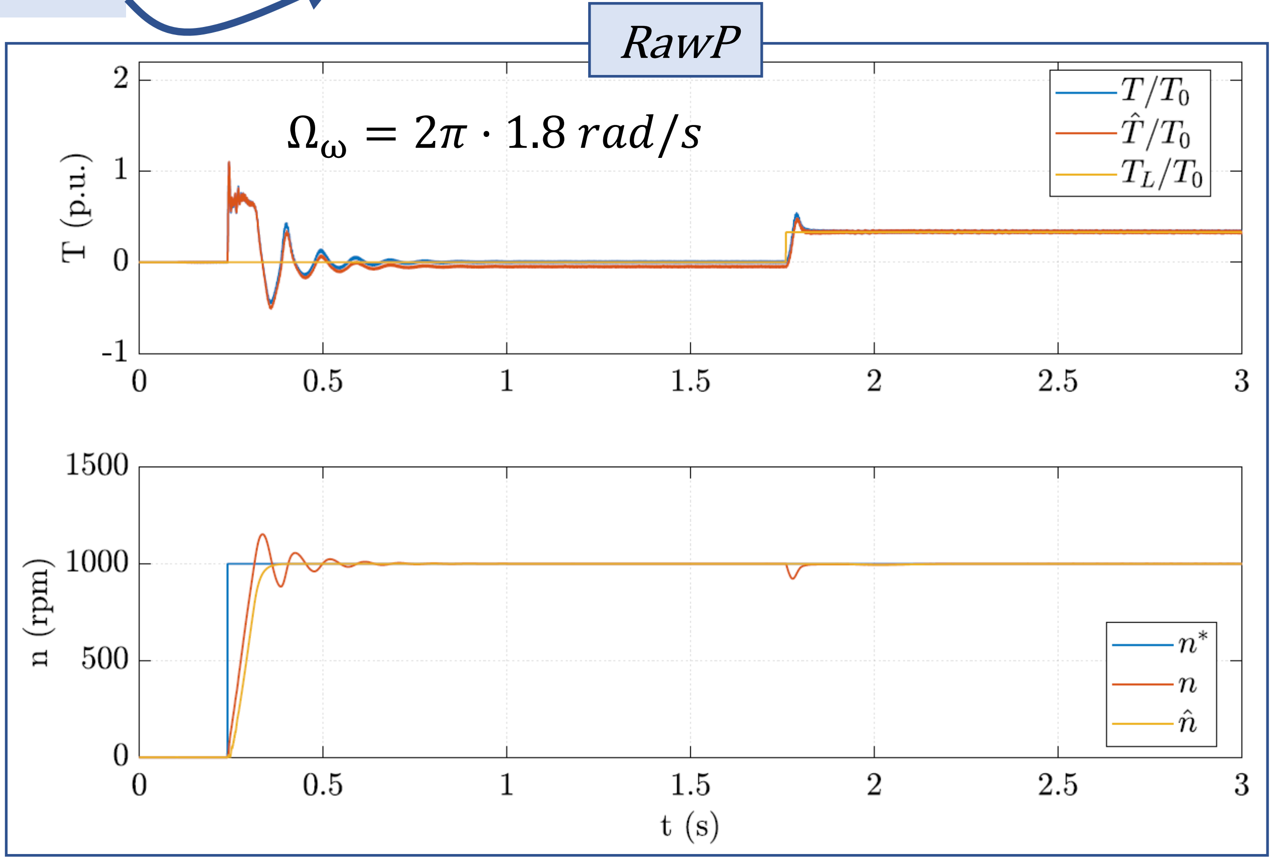
Calibration optimization

syreDrive is meant to provide a first-approach calibration of the control. A further tuning of the parameters is left to the end user and can be easily achieved by changing the values in the *User_Constants.h* header file.

```
// Flux Observer
#define KOBS            TWOPI*10.0f

// PI Reg
#define OMEGA_BW        TWOPI*1.0f
#define OMEGA_BI        TWOPI*75.0f
#define OMEGA_0_INJ     TWOPI*50.0f
#define WB_PLL_SIN      TWOPI*10.0f
#define WB_PLL_SQUARE   TWOPI*25.0f

// Control fusion
#define OMEGA_G         TWOPI*4.0f
```



Example

- The default speed loop bandwidth is $2\pi \cdot 1\ rad/s$.
- By increasing it to $2\pi \cdot 1.8\ rad/s$ the performance of the *RawP* motor improves.

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Conclusion

- The **automatic generation** of the control delivered reliable results for all the three different-sized motors simulated
- Attention must be paid when operating at **no-load** and in **overload** with the full-speed sensorless control scheme.
- An **ad-hoc optimization** of the control performances is easily obtainable.

Future work perspectives:

- Examination of more SyR motors.
- Experimental tests for validation of the results obtained at simulation stage
- Insert additional control strategies selectable in the GUI

Thank you for your attention!

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