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Lille, 1-2 September 2016
http://l2ep.univ-lille1.fr/hil2016/

FPGA based RTMiL analysis of variable reluctance machines for EV applications

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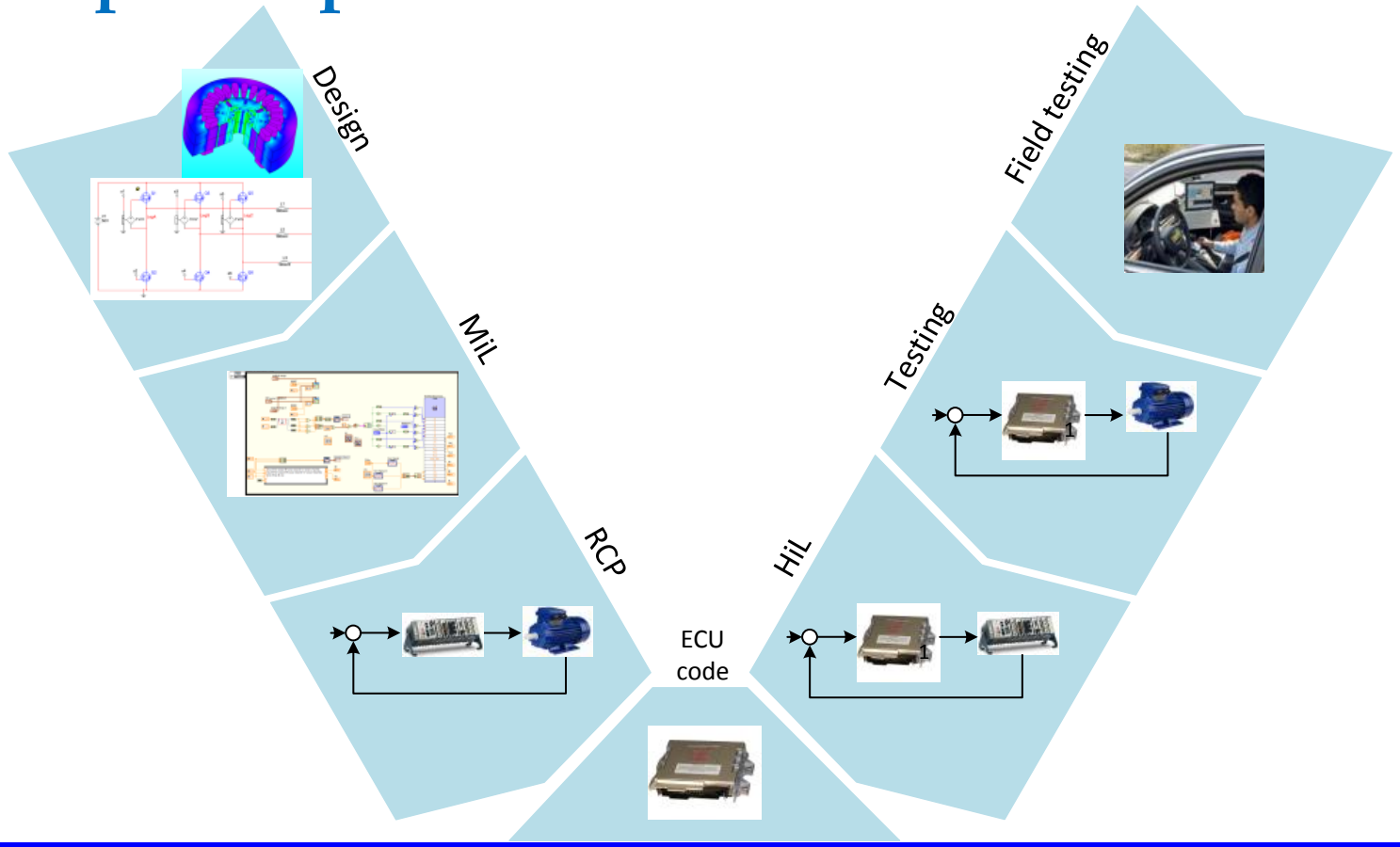
Electromechanical Systems and Power Electronics for Sustainable Applications

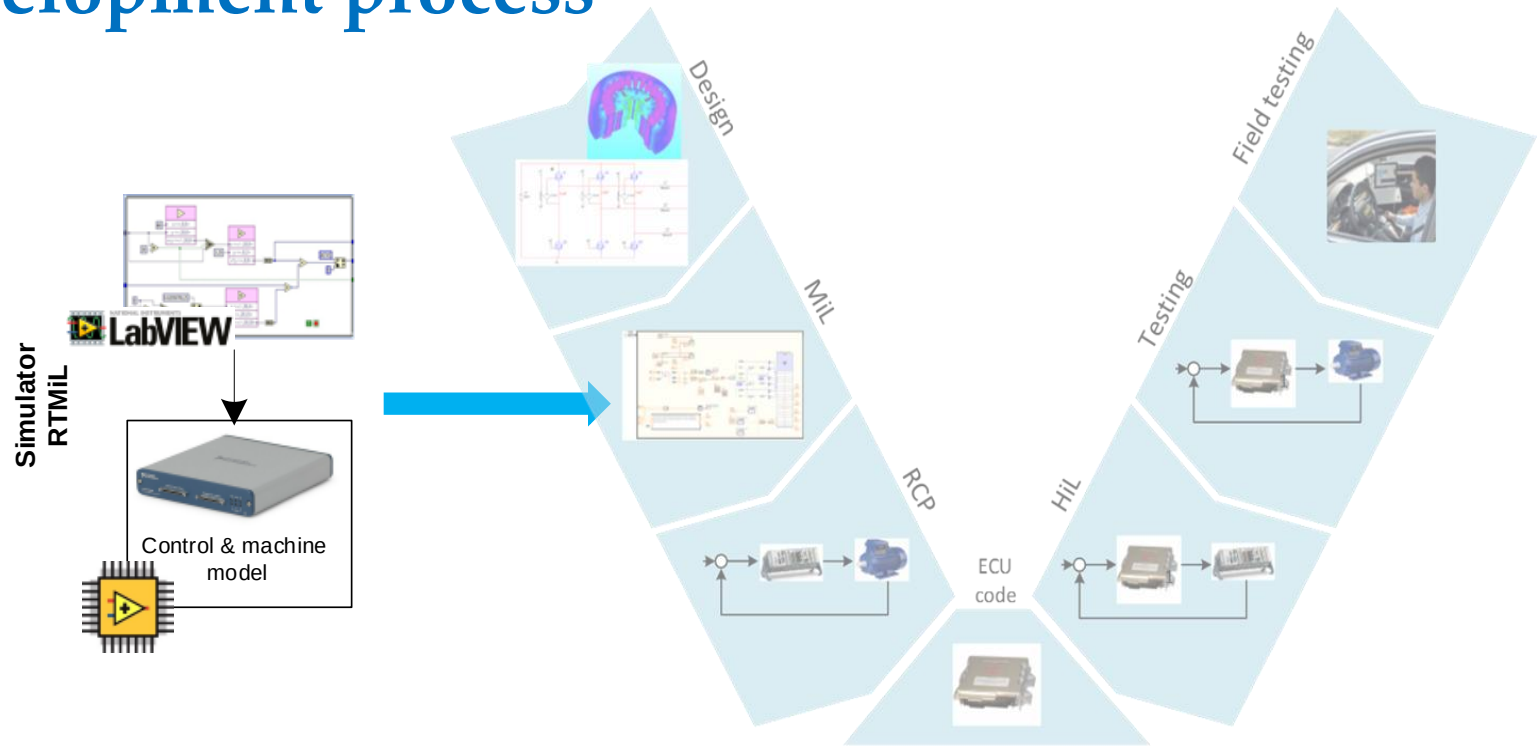
Introduction

- **Motivation:**
  - Using wise tools for aided design, testing and control
  - Necessity to pass from PC simulations to Real-Time simulations
  - Take advantage of the NI-FPGA platforms
  - Construction of RTMiL simulators for realistic analysis

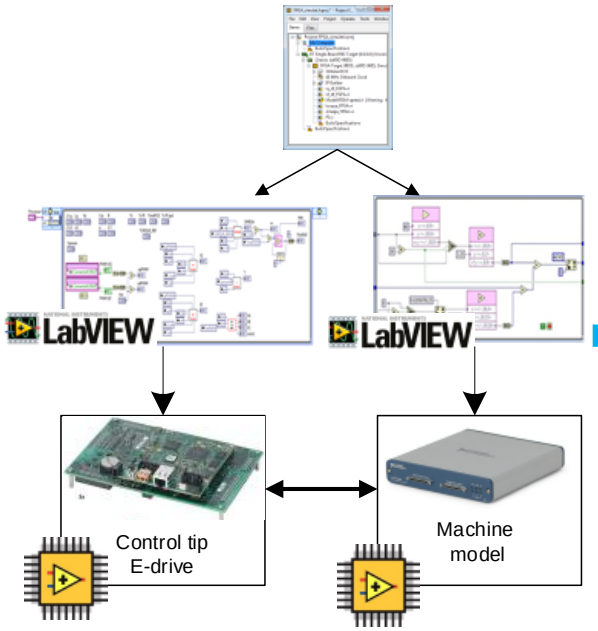
Development process

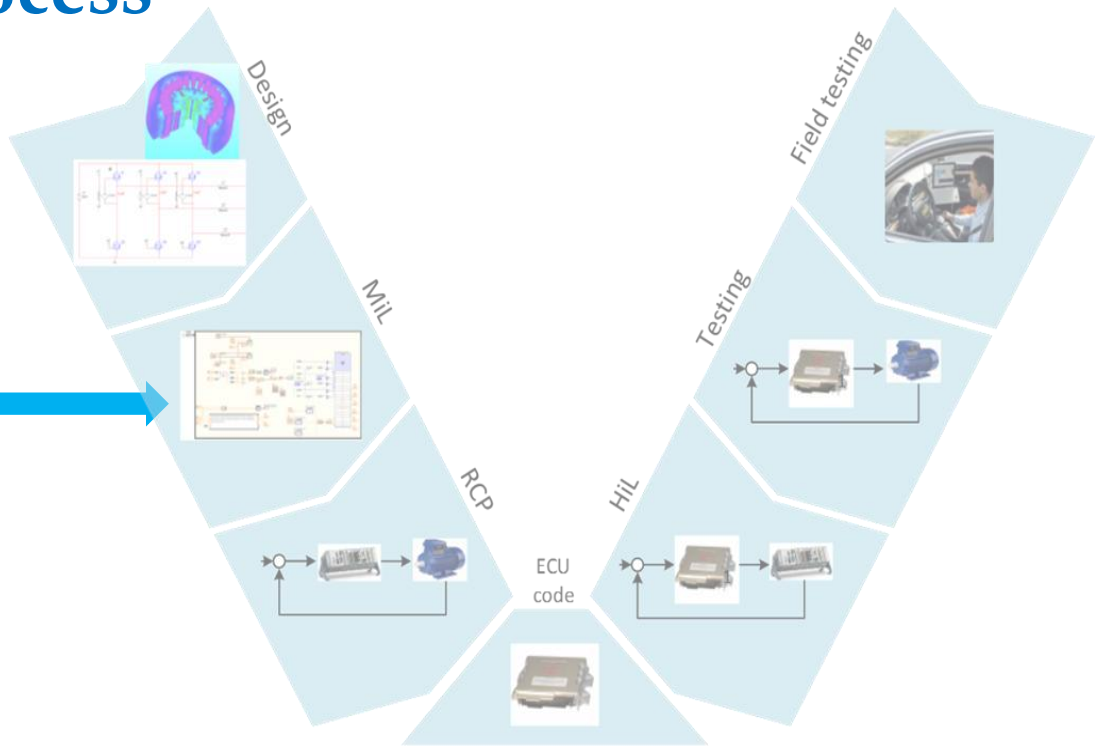


Development process



Development process



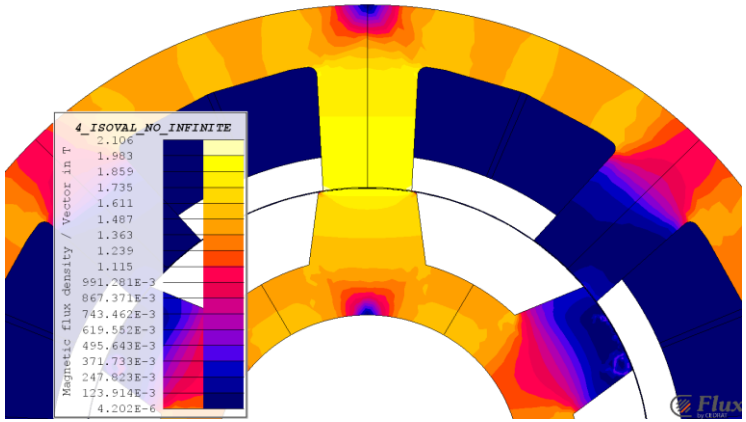


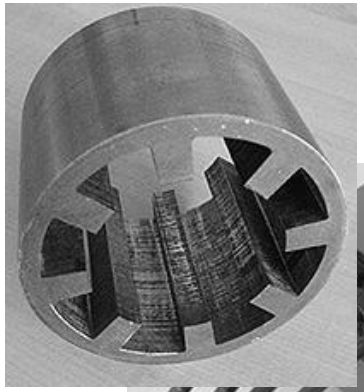
The SRM in study

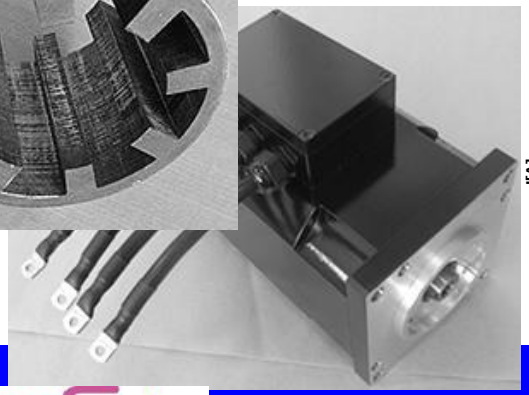
Rs=0.01Ω

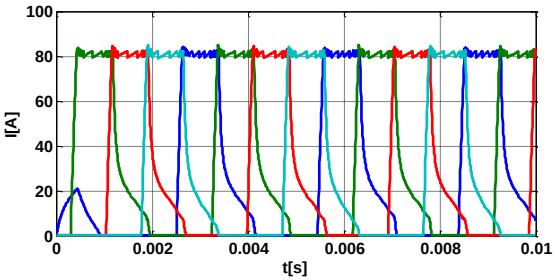
J=0.006kg·m^2 B=0.003N·m·s

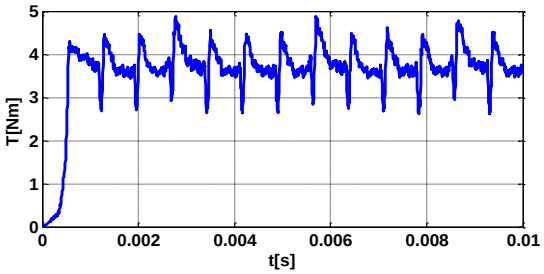
DC link voltage	U_{DC}=24 V
RMS current	I=80 A
Output power	P_{2N}=1.2k W
Rated torque	T=3.4Nm
Rated speed	n_N=3400 rpm
Number of stator poles	8
Number of rotor poles	6









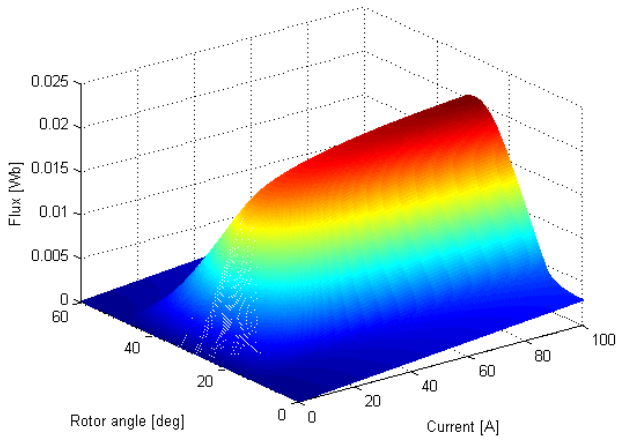


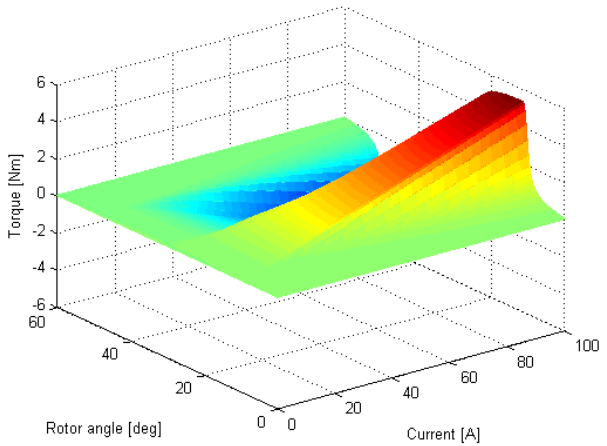
The SRM's simulation model

- Hybrid model:
  - Voltage and mechanical equation

$$\Psi = \int \left(u - R_f \cdot i\right) \cdot dt \qquad T_e = J\frac{d\omega_m}{dt} + B\omega + T_L$$

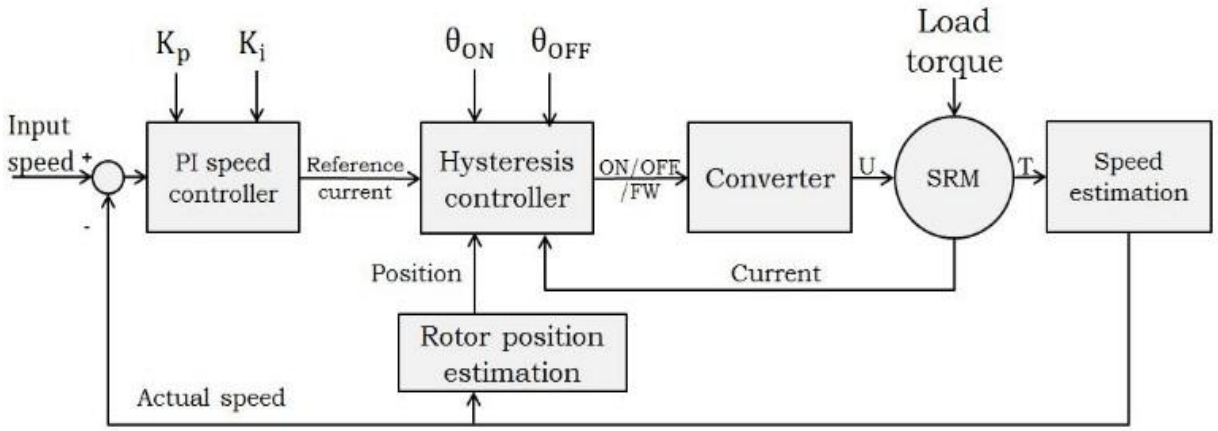
  - Flux and torque versus current and rotor position look-up-tables (LUT)





SRM Drive modelling in LV FPGA

- The general scheme of the drive (machine, converter and controller)



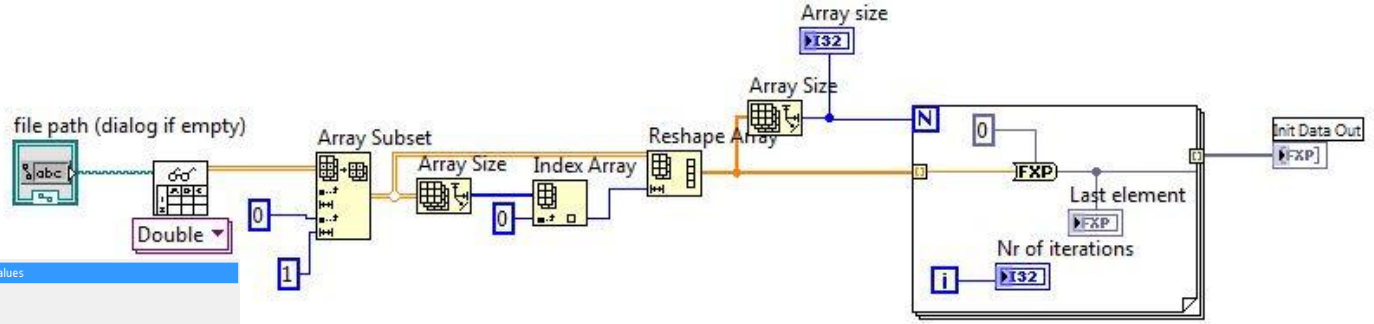
SRM Drive modelling in LV FPGA

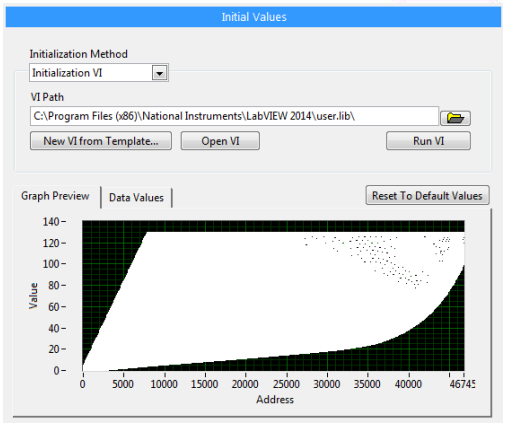
- LUT data management

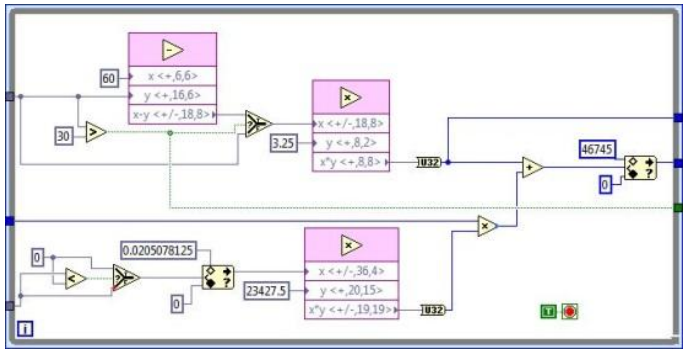
	ψ_1	ψ_2	ψ_3
θ_1	I_{11}	I_{12}	I_{13}
θ_2	I_{21}	I_{22}	I_{23}
θ_3	I_{31}	I_{32}	I_{33}

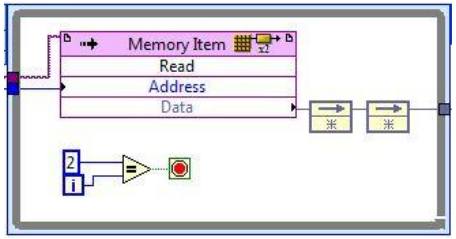
→

θ_1	θ_2	θ_3	θ_1	θ_2	θ_3	θ_1	θ_2	θ_3
I_{11}	I_{21}	I_{31}	I_{12}	I_{22}	I_{32}	I_{13}	I_{23}	I_{33}
ψ_1			ψ_2			ψ_3		



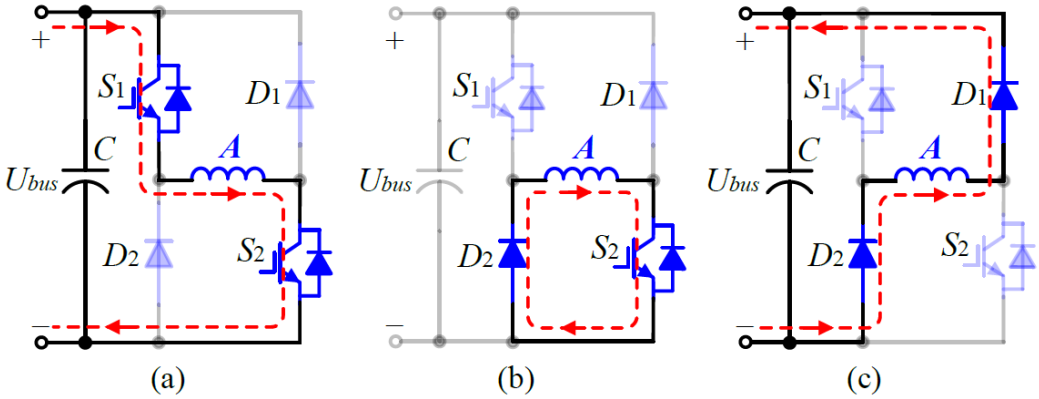


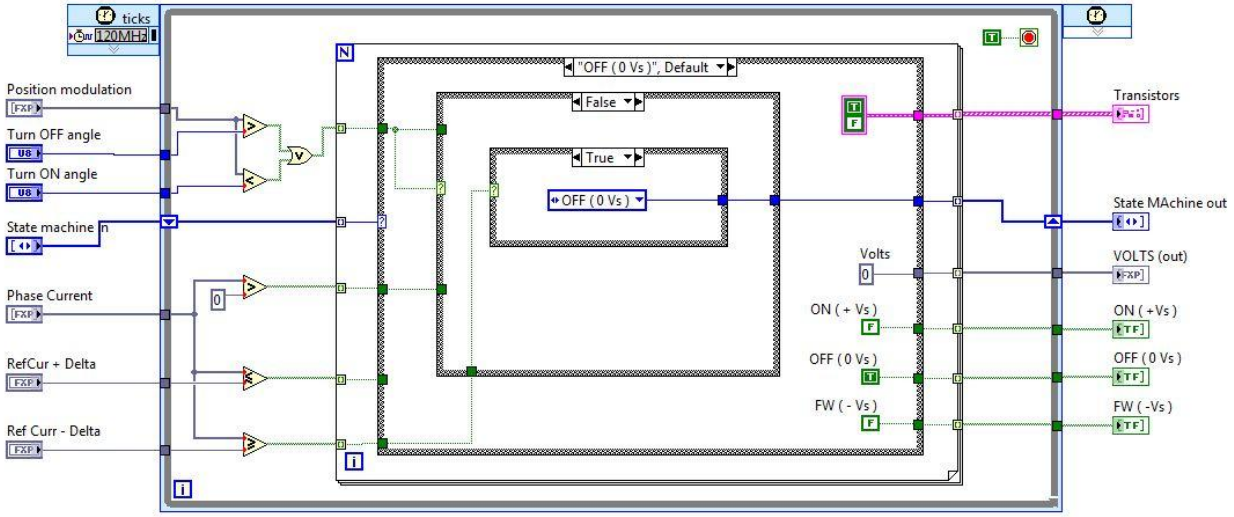




SRM Drive modelling in LV FPGA

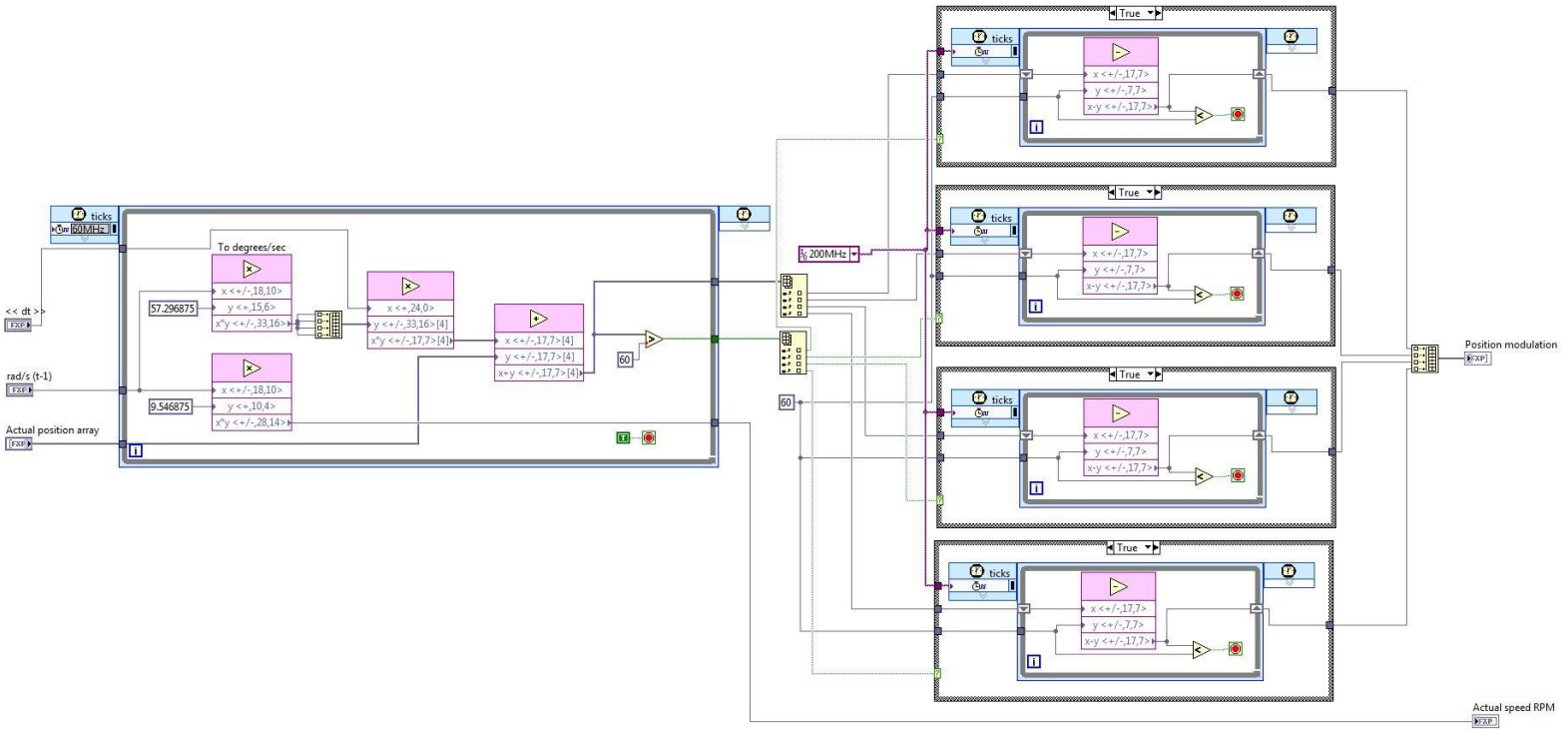
- Hysteresis current controller
  - ON condition (Vph=Vdc)
  - 0 condition (Vph=0)
  - OFF condition (Vph=-Vdc)





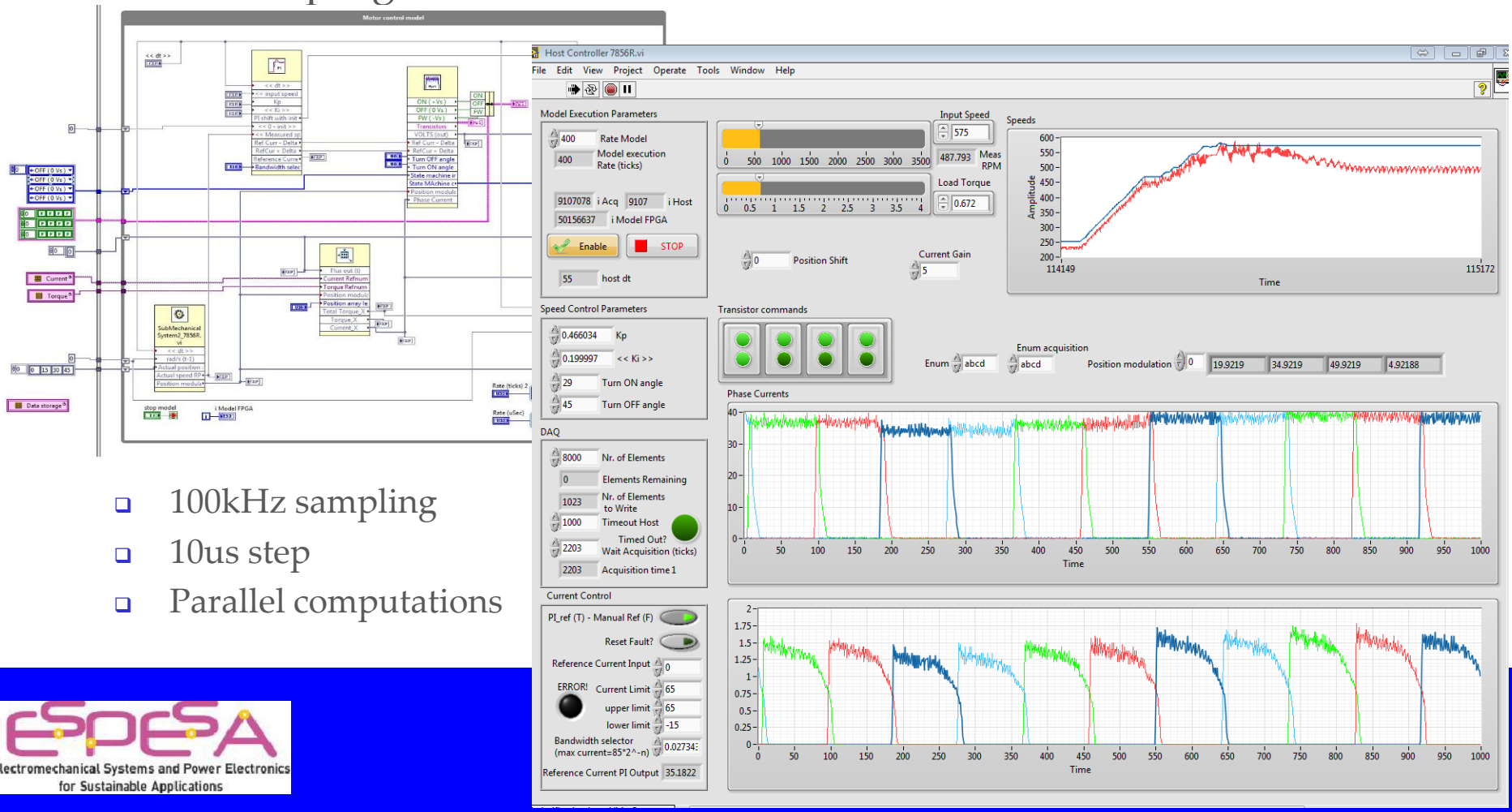
SRM Drive modelling in LV FPGA

- Treating velocity and position



SRM Drive modelling in LV FPGA

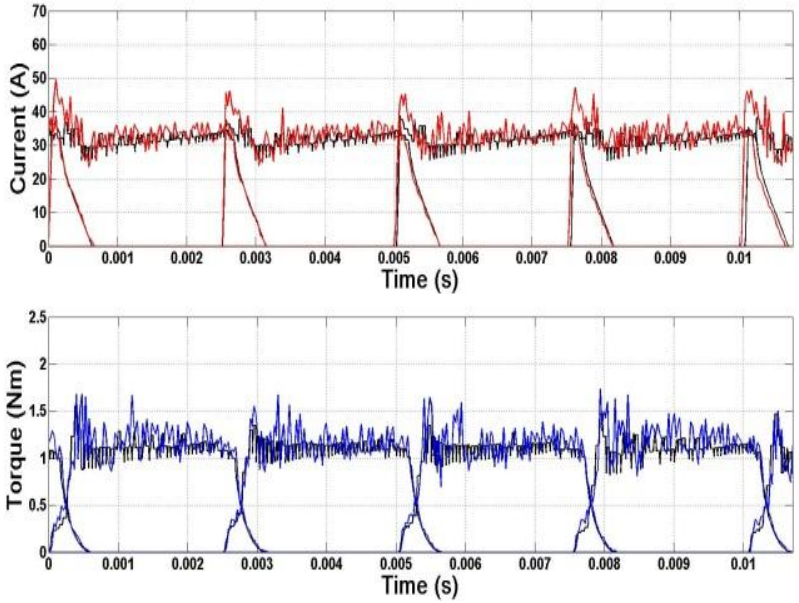
- The main program in LV FPGA



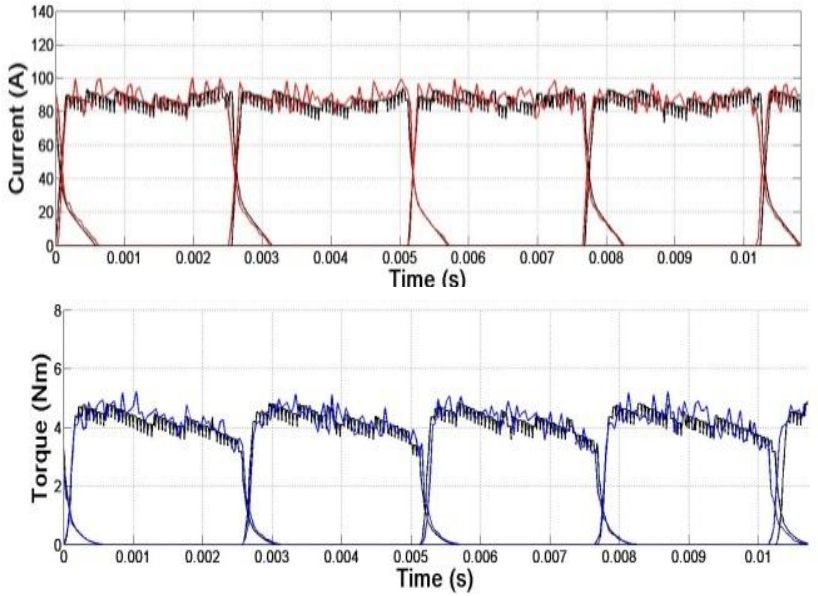
- 100kHz sampling
- 10us step
- Parallel computations

SRM Drive modelling in LV FPGA

- Results of FPGA analysis



- 1000rpm 1Nm



1000rpm 4Nm

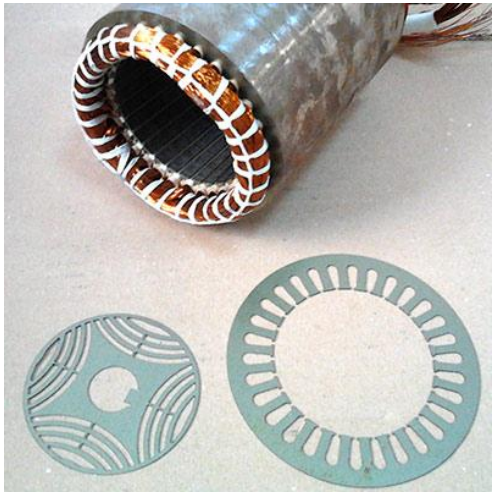
The SyncREL in study

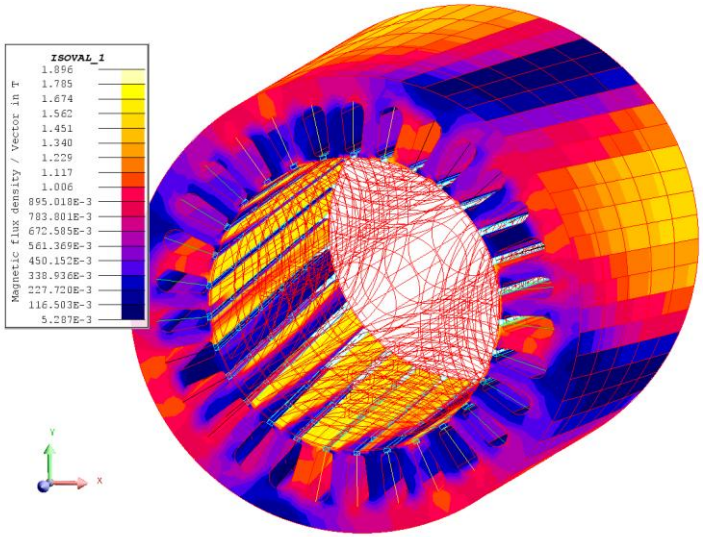
Variable Reluctance Synchronous Machine

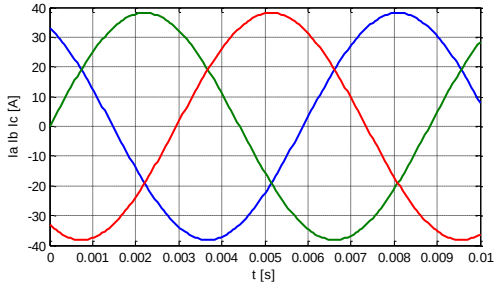
Ld=0.00244H Lq=0.0006H Rs=0.21Ω

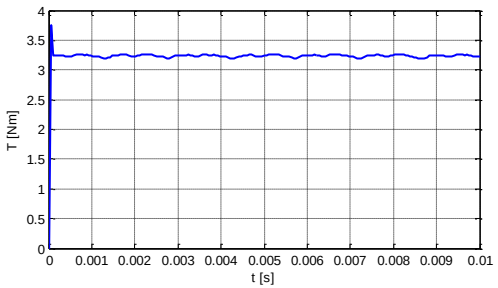
J=0.00332kg·m^2 B=0.00122N·m·s

DC link voltage	U_{DC}=60 V
RMS current	I=27 A
Output power	P_{2N}=1.2k W
Rated torque	T=3.4Nm
Rated speed	n_N=2600 rpm
Number of stator slots	30
Number of rotor barriers per pole	4









The SyncREL mathematical model with control

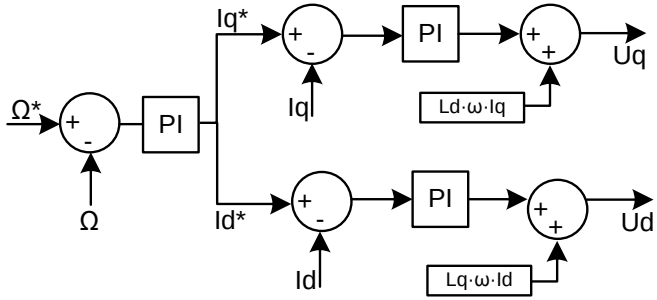
The 3 phase machine is converter to 2 phase machine (Park transf.)

The mathematical model in DQ coordinates

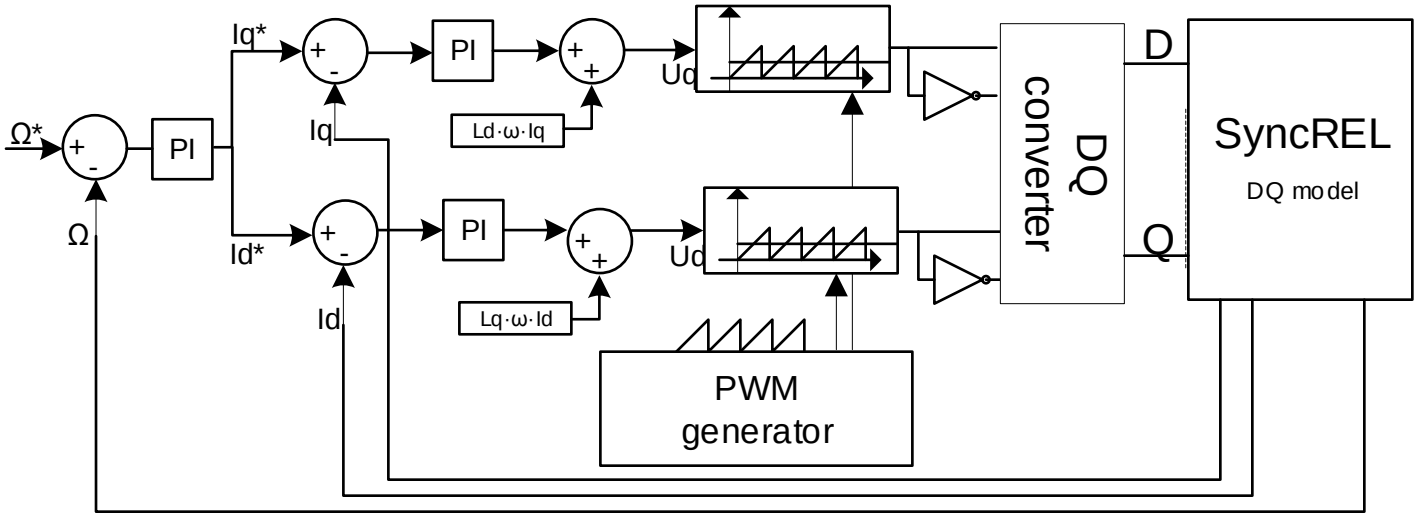
$$\frac{di_d}{dt} = \frac{u_d - R_s i_d + \omega L_q i_q}{L_d} \qquad \frac{di_q}{dt} = \frac{u_q - R_s i_q - \omega L_d i_d}{L_q} \qquad T = p i_d i_q (L_d - L_q) \qquad T = J\frac{d\Omega}{dt} + B\Omega + T_{rst}$$

The control strategy with Field Oriented Control (FOC) - Maximum Torque Per Ampere control (MTPAC)

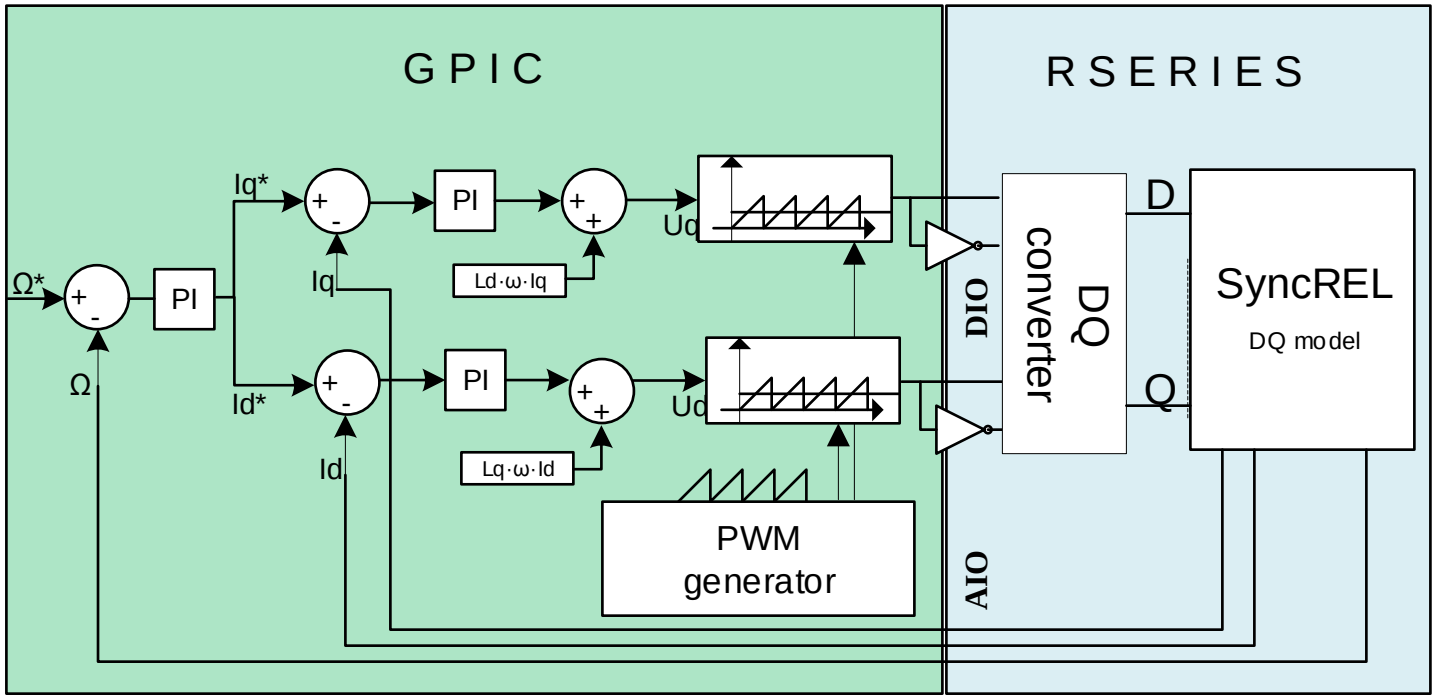
$$i_d = i_q = \sqrt{\frac{T_{ref}}{p(L_d - L_q)}}$$



The RTMiL model in LabView FPGA

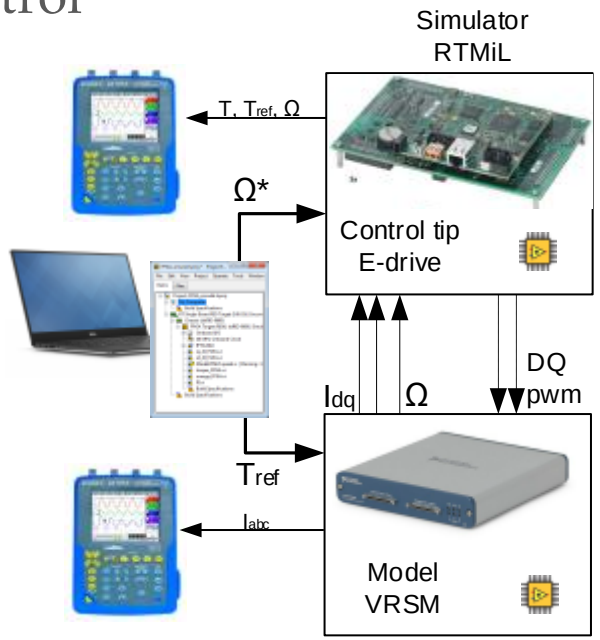


The RTMiL model in LabView FPGA



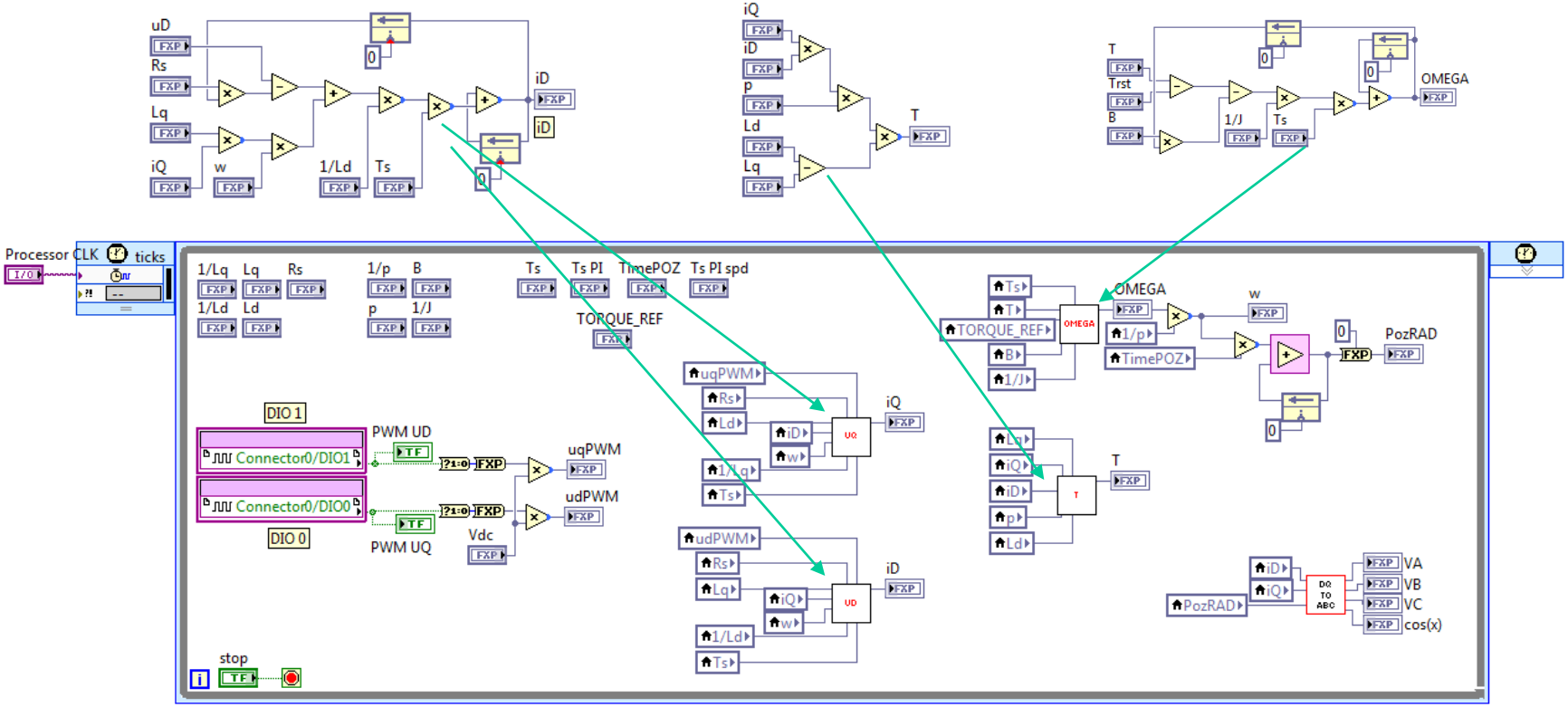
The RTMiL model in LabView FPGA

- Two FPGAs are engaged NI-GPIC and Rseries
- The PC is used just as GUI via the RT of GPIC
- GPIC runs the FOC+MTPAC control
- Rseries runs the SyncREL model
- DIO and AIO communication



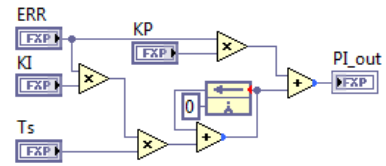
The FPGA model of the SyncREL

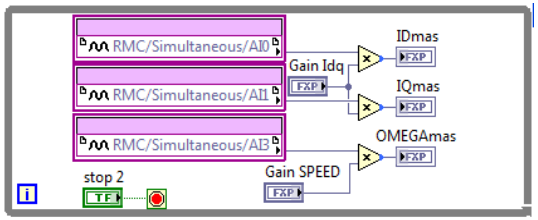
Fixed Point (FXP) models are created

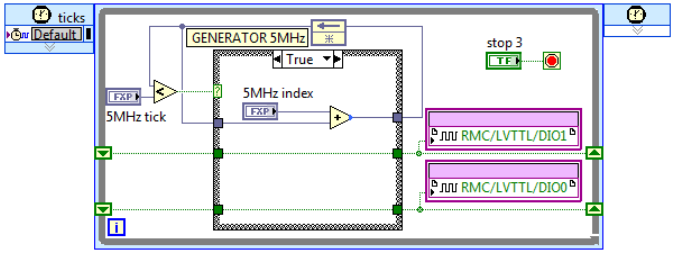


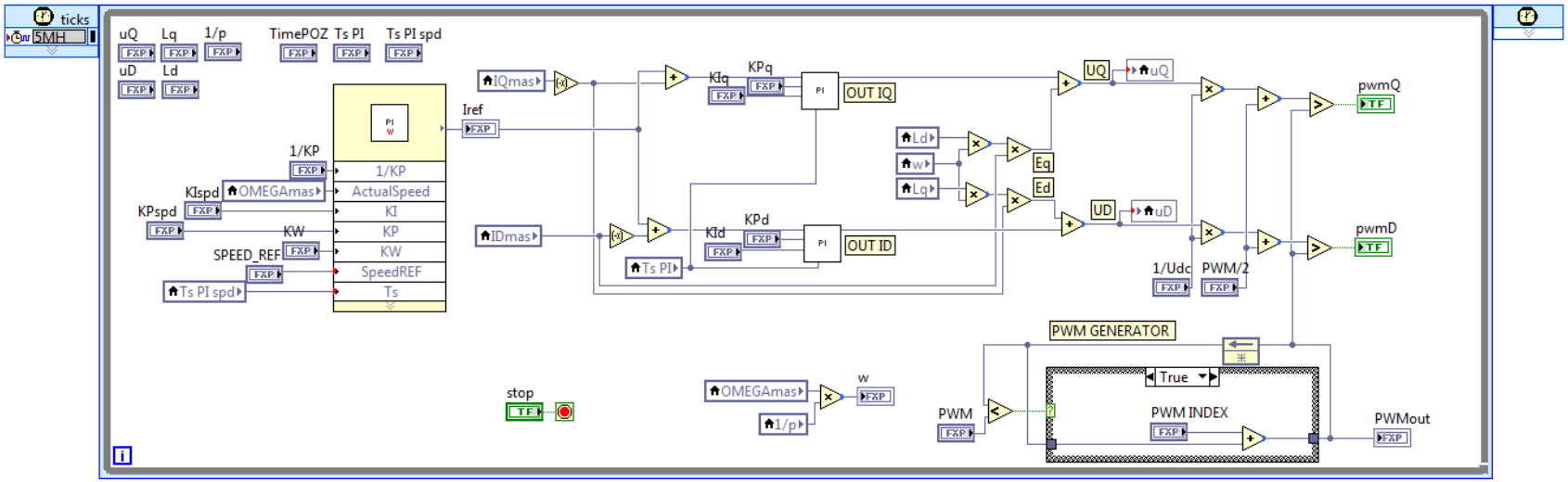
The FPGA model of the FOC control

Fixed Point (FXP) models are created



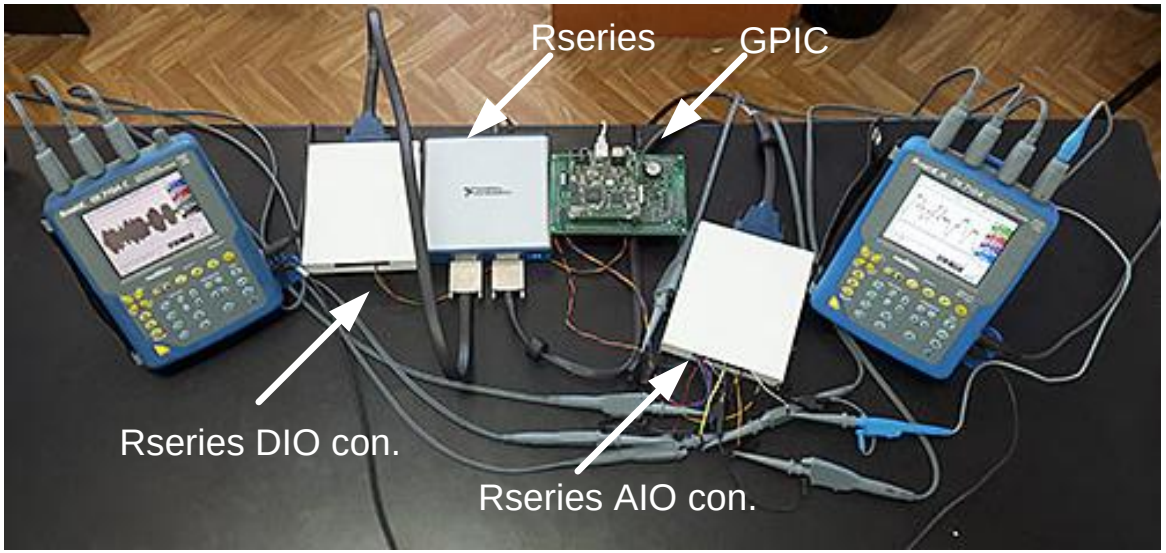






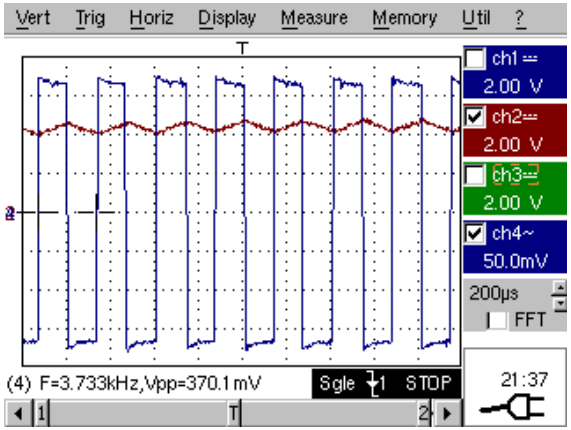
Experimental results of RTMiL platforms

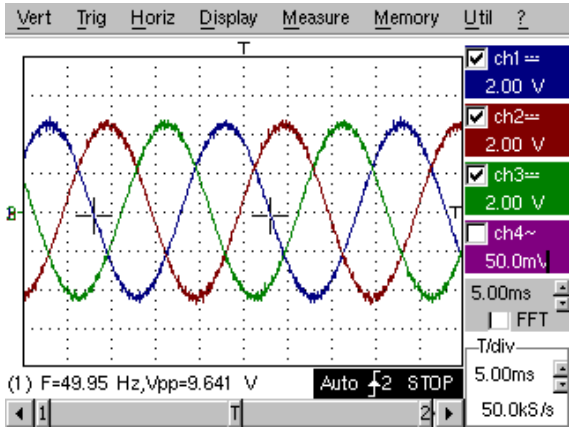
- Rseries + GPIC for the main models
- Connection boxes for communication
- Two oscilloscopes for data acquisition and plotting

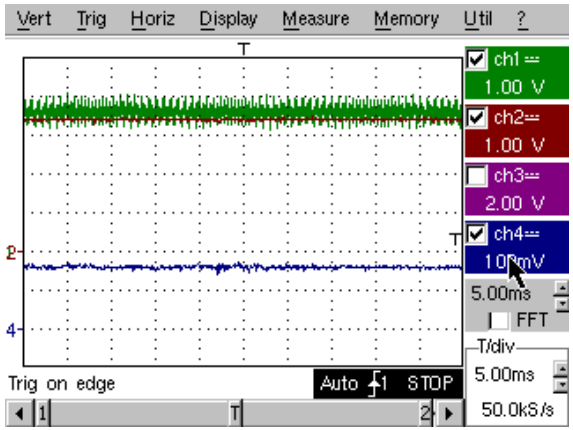


Experimental results of RTMiL platforms

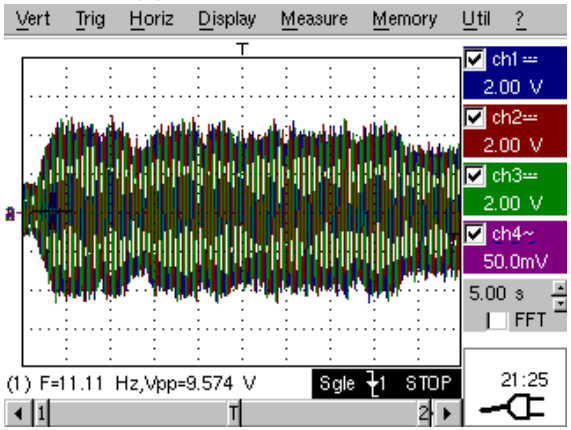
Testing PWM frequency , abc and DQ currents

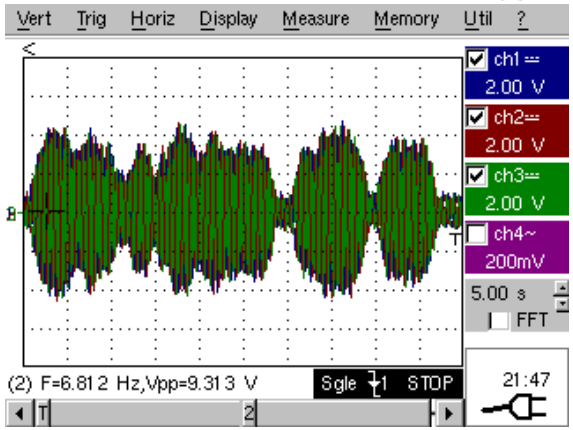


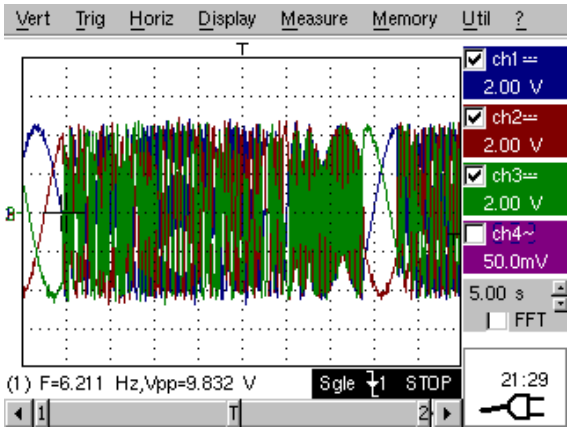


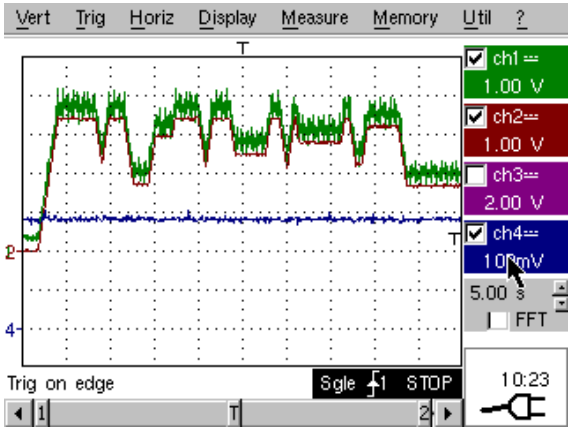


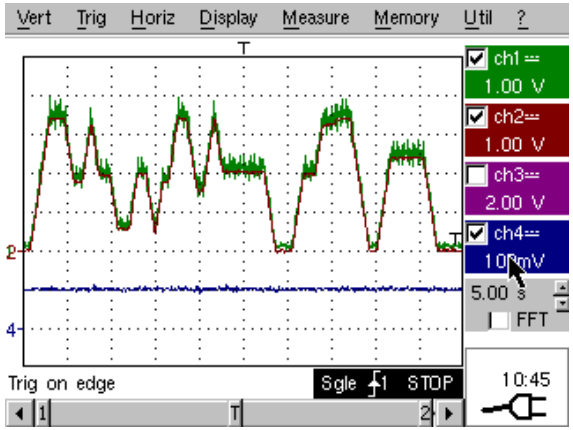
Experimental results of RTMiL platforms

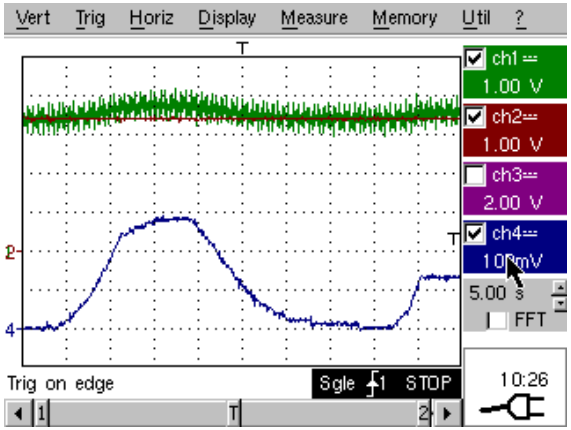












load

100rad/s variable load

3.4Nm and varia e

Conclusions

Complete RTMiL models of a SyncREL and SRM used for LEV designed and validated in FEA

-good accuracy

-deterministic calculations

-fast development speed

-safety

Acknowledgement

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Thank you for your attention!