Politecnico di Torino

PEIC Power Electronics Innovation Center

High-performance Digital Control of Power Converters

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Outline

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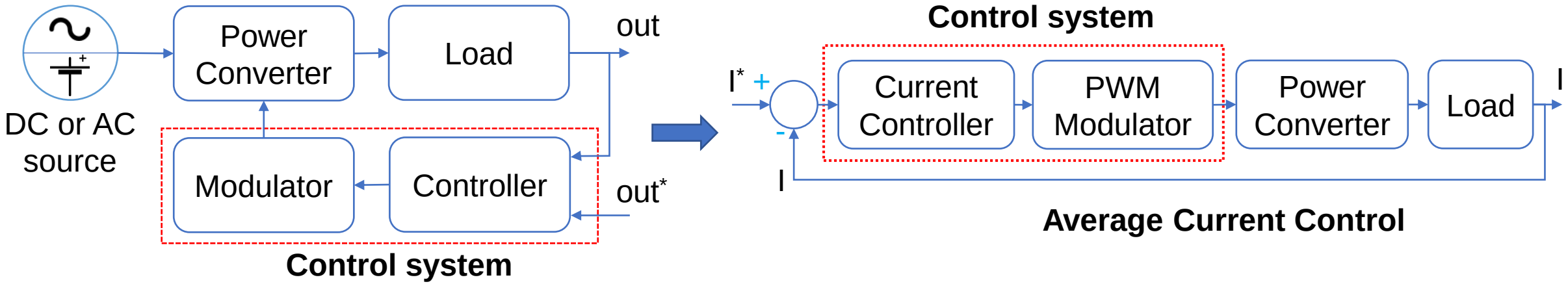
- **Digital Average Current Control**
- **FPGA components organization**
- **Setup**
- **H-bridge Converter Experimental Validation**
- **Three-phase Inverter Experimental Validation**
- **Electric Motor Torque Control**
  - Experimental Validation
- **Electric Motor Speed Control**
  - Experimental Validation
- **Conclusions**

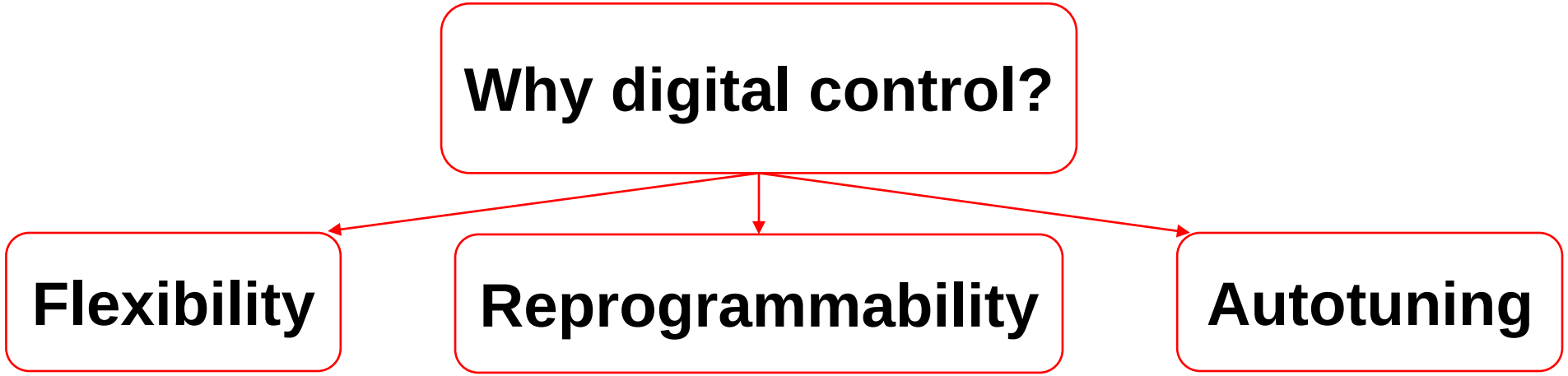
Introduction and Purpose

- **Power converter**: device which converts the electrical energy from one form to another (DC/DC, DC/AC, AC/DC, AC/AC)
- **Controller:** component which monitors the output (**current**, voltage…) and ensures it to be equal to the reference value
- **Modulator**: block which generates the signals that drive the transistors inside the power converter



Introduction and Purpose

The **control system** can be both analog and **digital**.

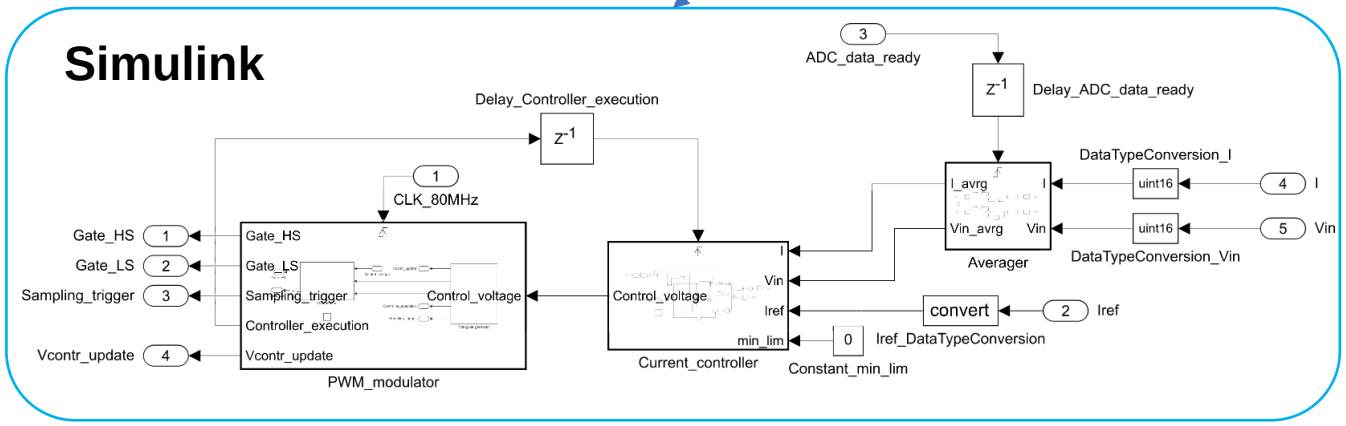


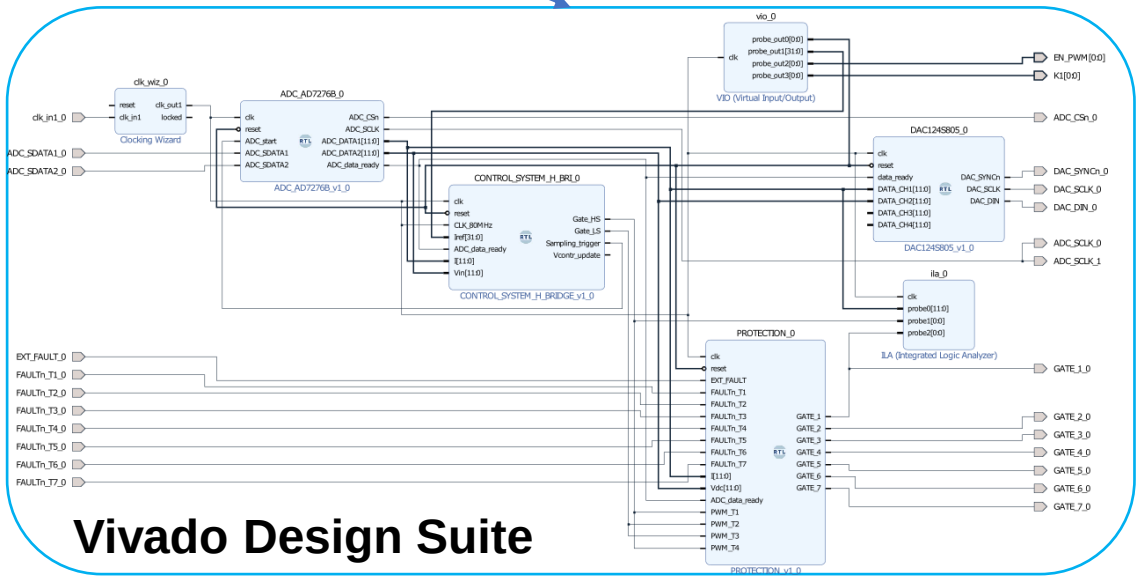
- **Problem:** the drawback of digital control systems design is the **programming effort** which is needed **from system simulation to experimental phase**
- **Purpose of the thesis**: **validation** of the **Simulink HDL Coder** tool effectiveness for the **automatic VHDL code generation** of power converters digital control systems

Introduction and Purpose

- **Workflow**:

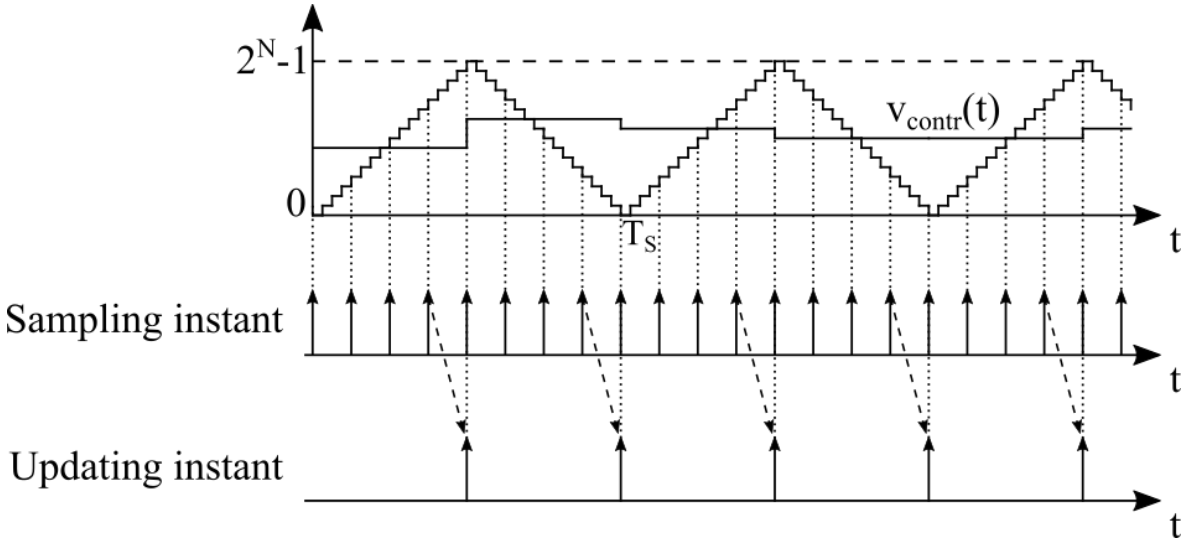
Control system design → Implementation on **Simulink** → **HDL Coder** → Implementation on **FPGA** → **Experimental validation**



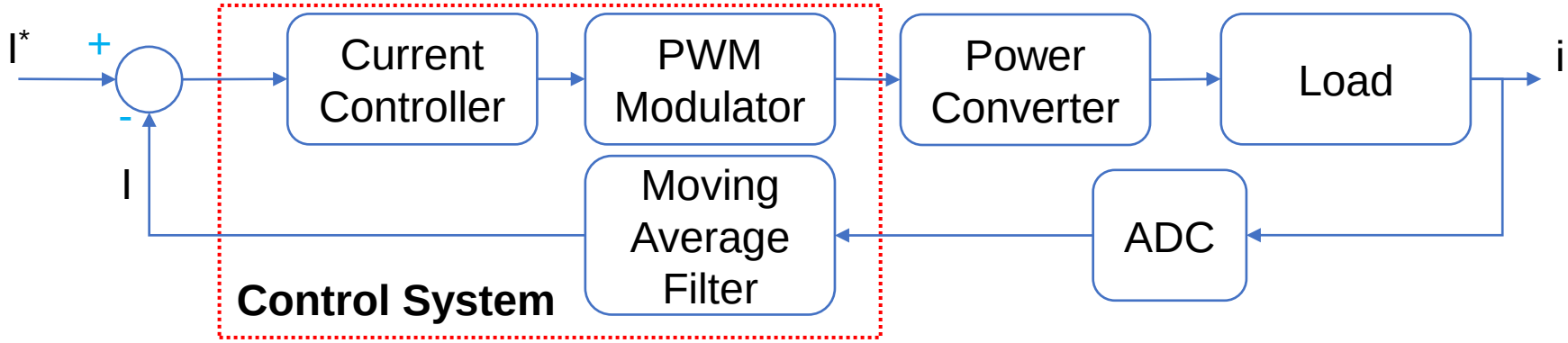


Digital Average Current Control

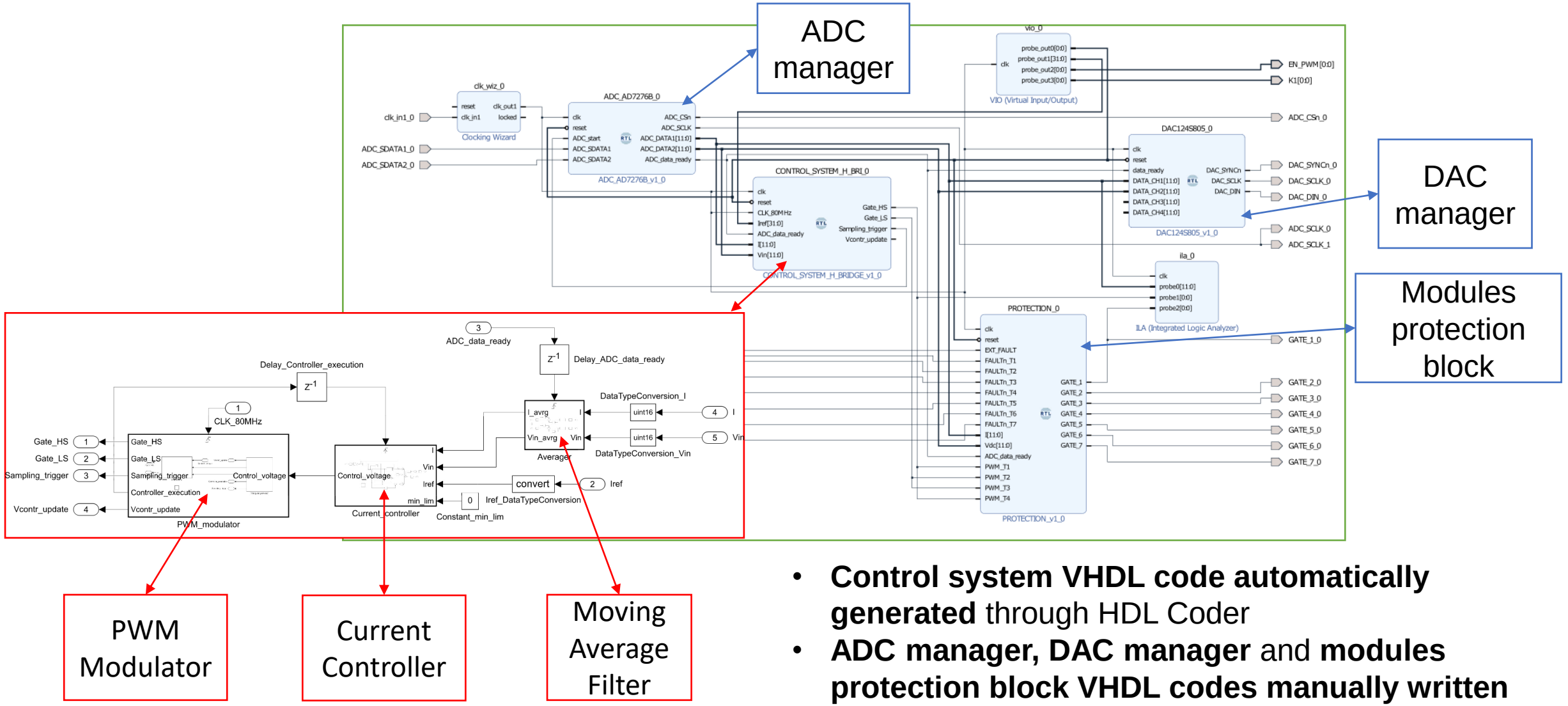
Multisampling double-update strategy



- **Load current** and input voltage **sampled several times inside a switching period**
- Average values computed by means of a **moving average filter**
- **Control voltage updated** in correspondence of **maximum** and **minimum** values of the **triangular carrier**



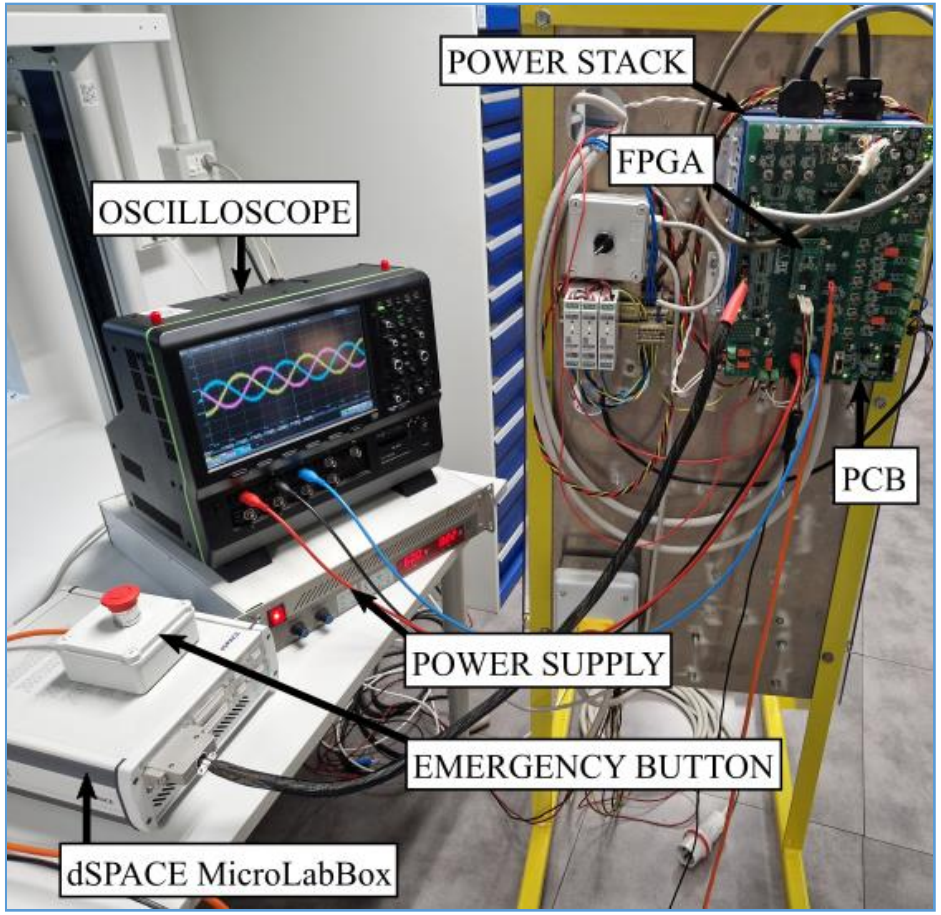
FPGA components organization



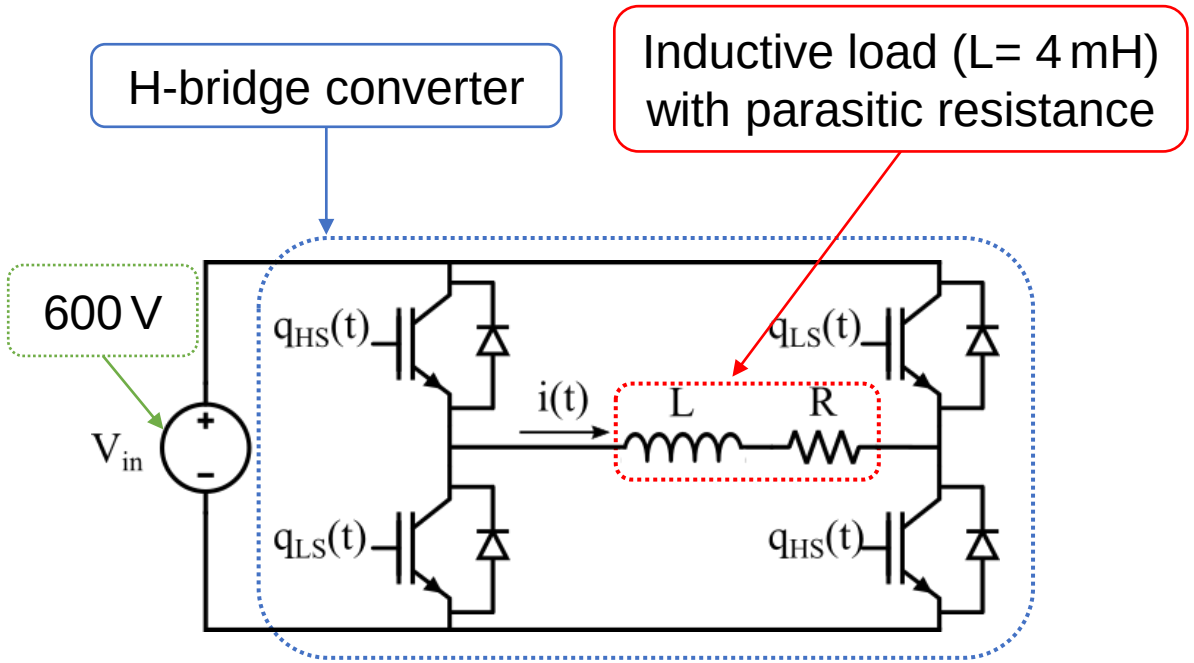
- **Control system VHDL code automatically generated** through HDL Coder
- **ADC manager, DAC manager** and **modules protection block VHDL codes manually written**

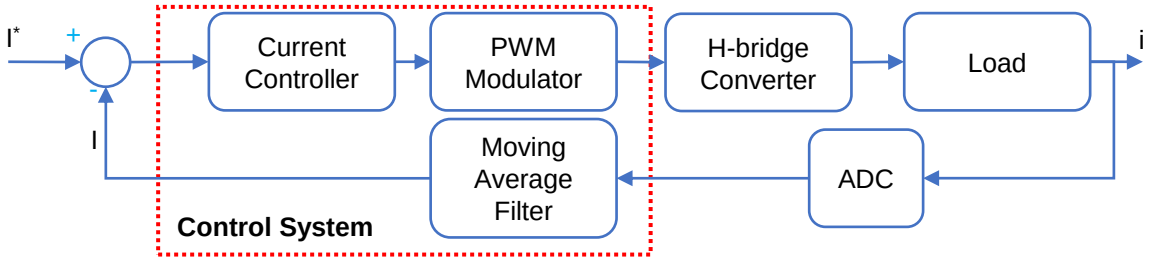
Setup

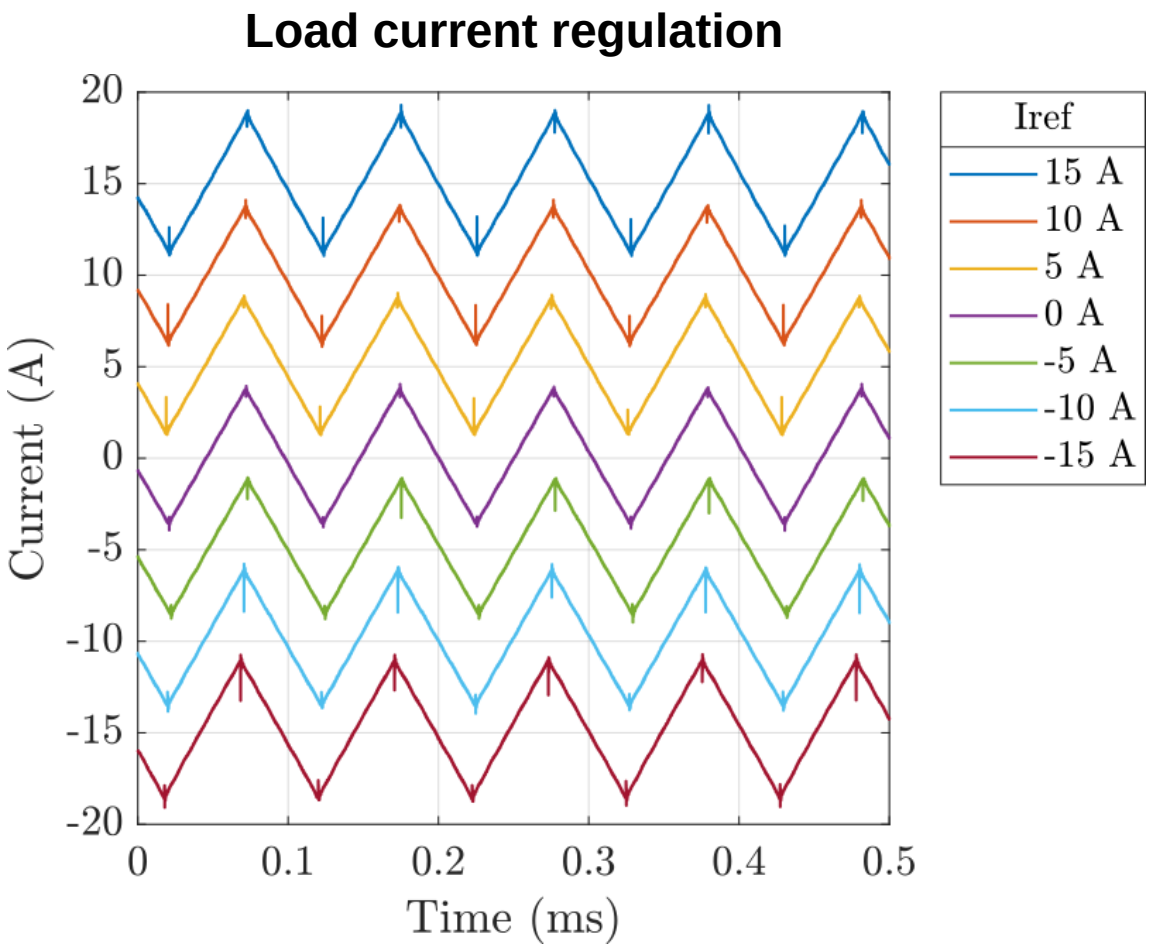
- **Power supply** up to 600 V
- **Inductive load**
- **Oscilloscope** to visualize waveforms
- **Power stack** to deploy the converter
- **dSPACE system** to provide a user interface



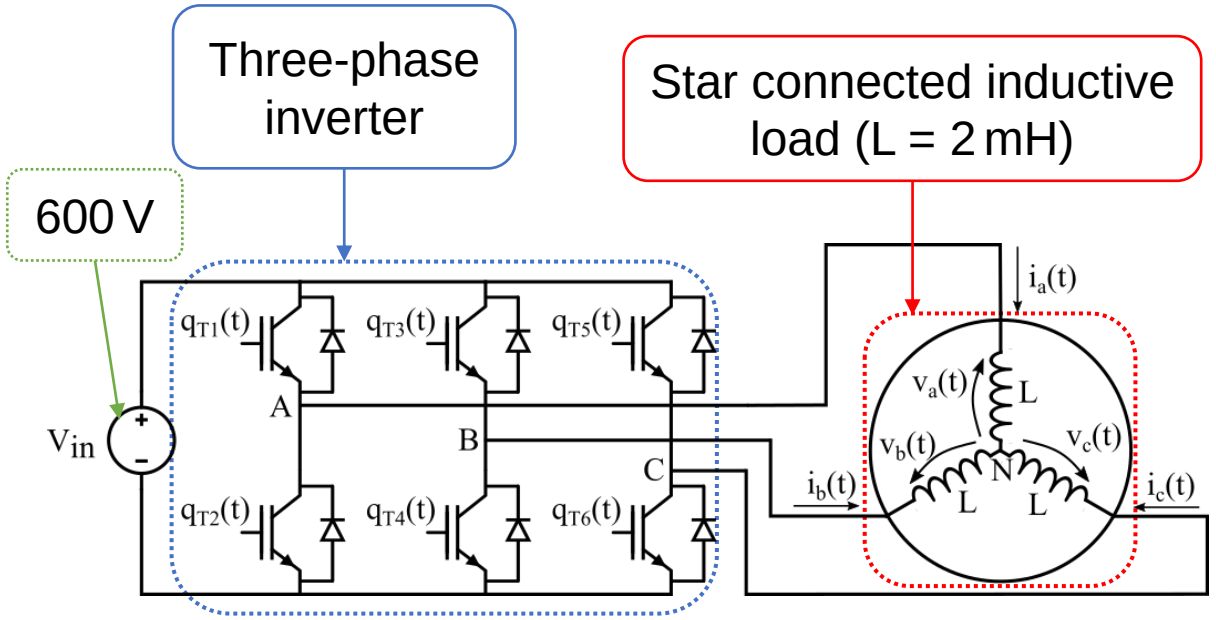
H-bridge Converter Experimental Validation

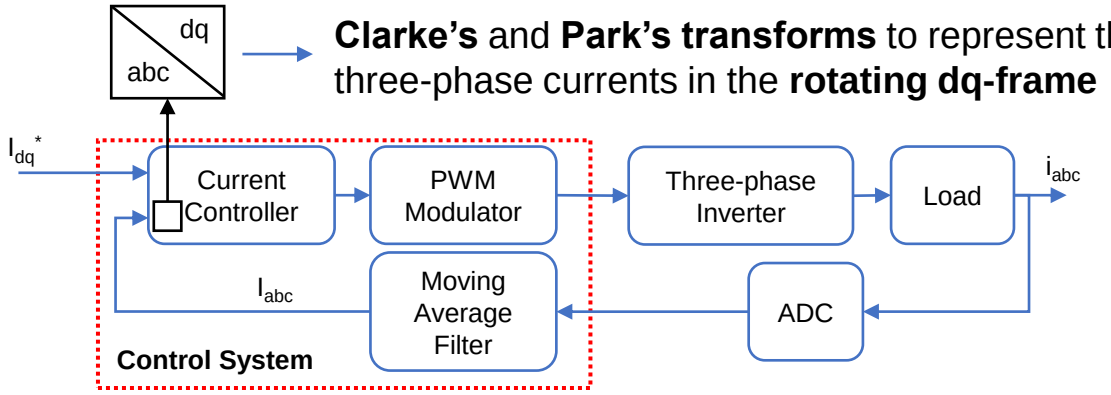






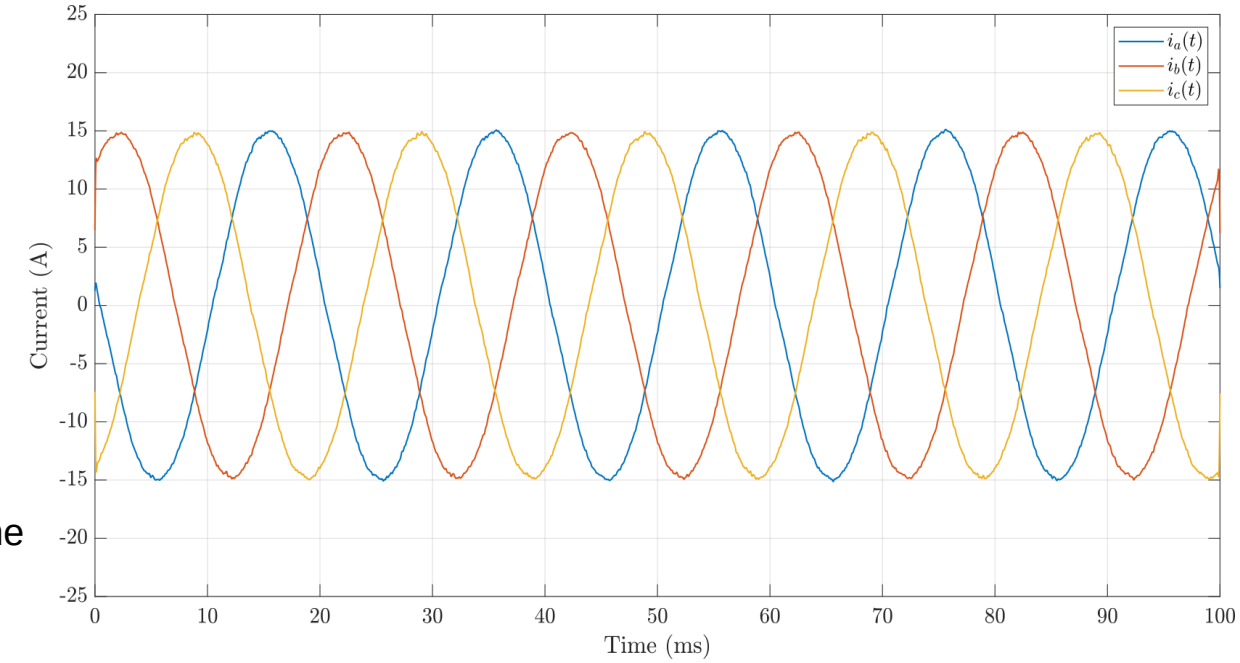
Three-phase Inverter Experimental Validation





Clarke's and **Park's transforms** to represent the three-phase currents in the **rotating dq-frame**

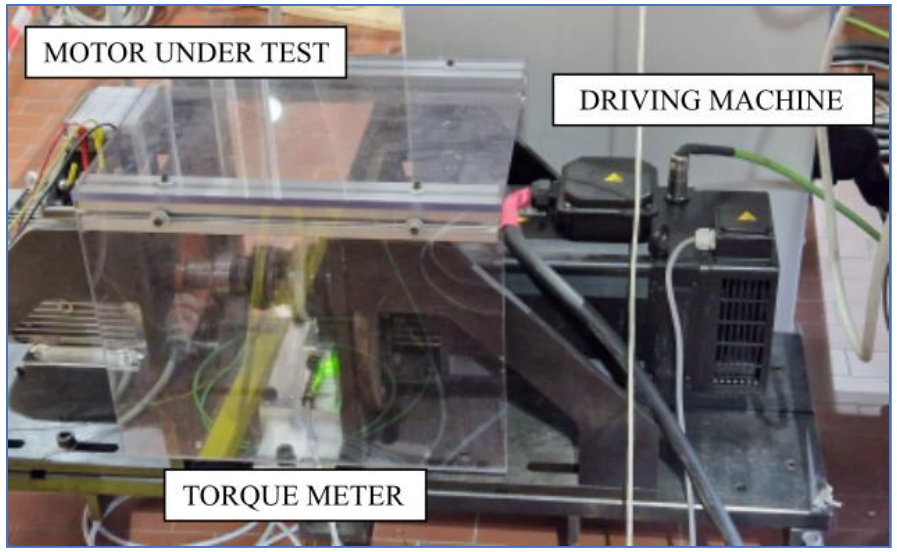
Phase currents regulation

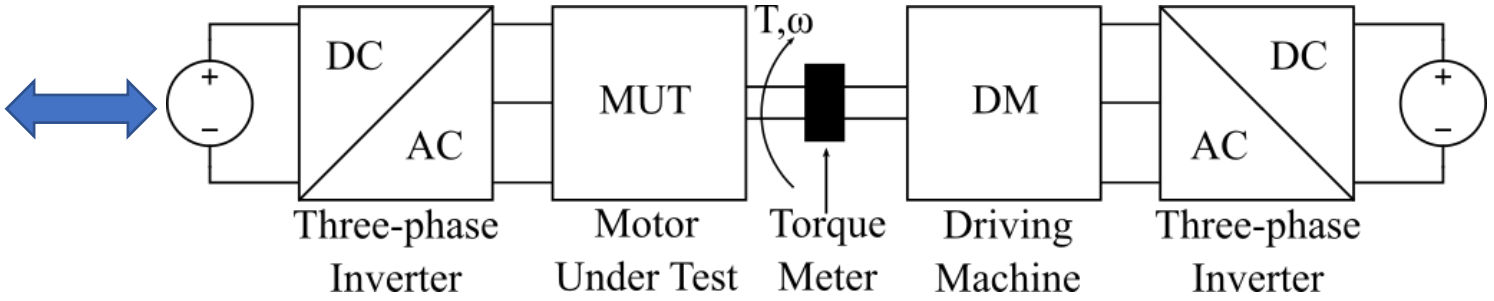


Frequency: 50 Hz
Amplitude: 15 A

Electric Motor Torque Control

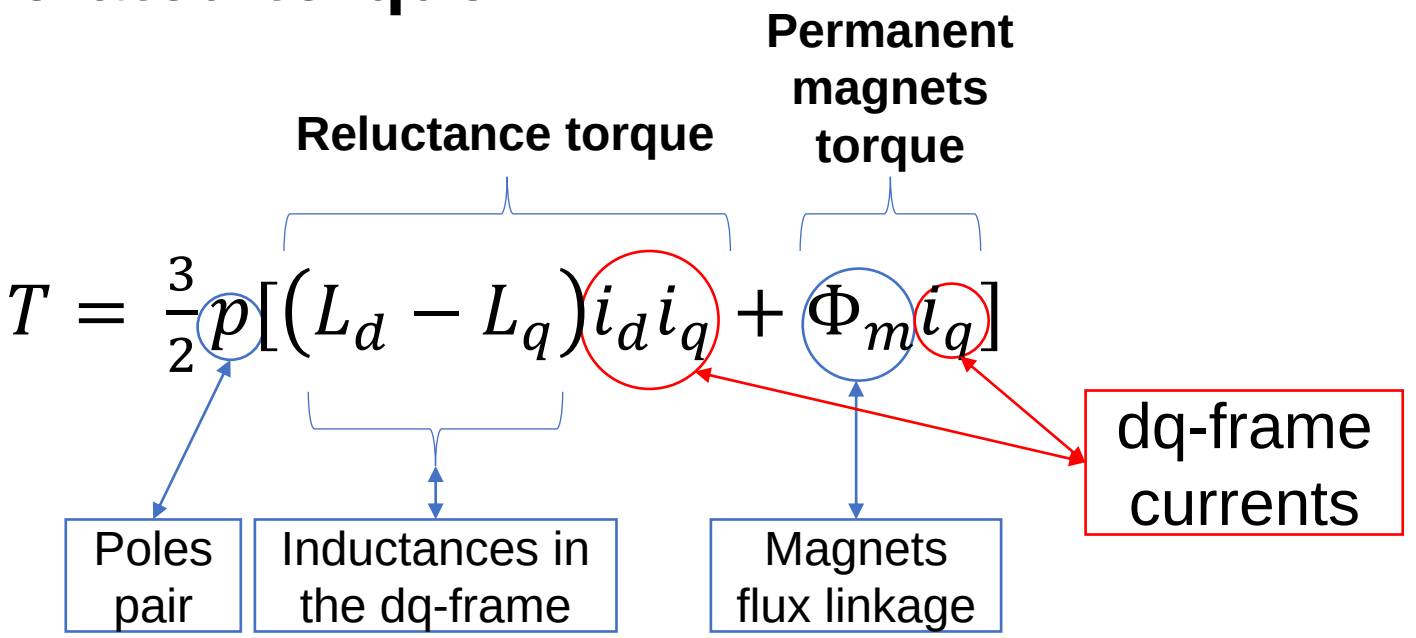
- **Motor Under Test (MUT): permanent magnet assisted synchronous reluctance (PMASR)** motor which can be modeled as a star connected inductive load → **three-phase inverter**
- **Driving Machine (DM)** configurable to set shaft speed or load torque
- **Torque meter** to measure MUT generated torque





Electric Motor Torque Control

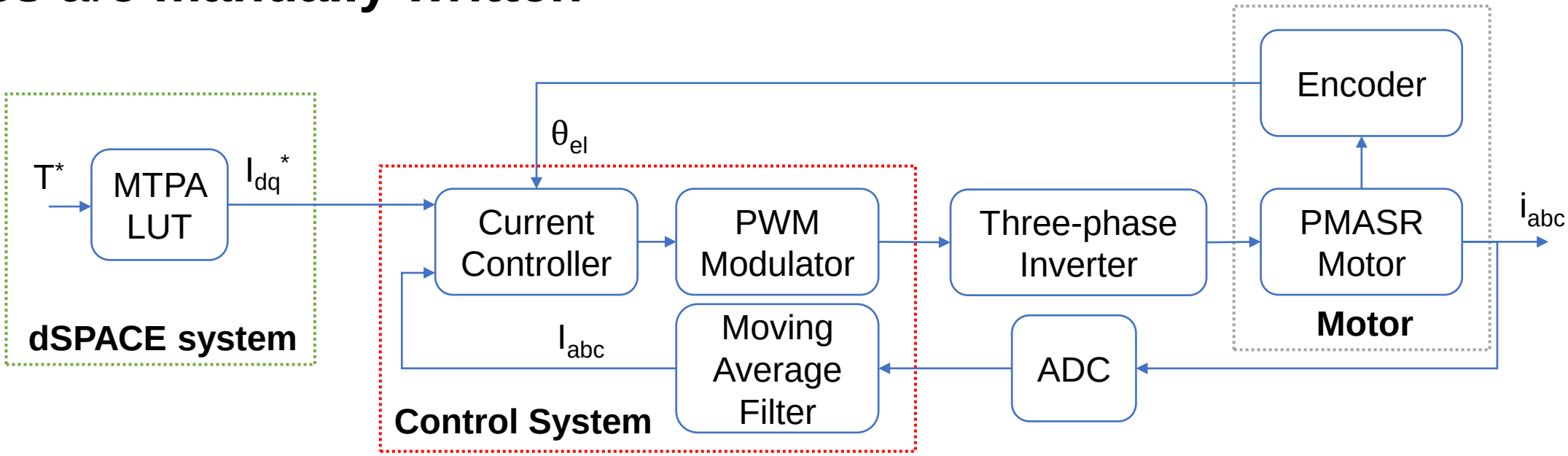
- **PMASR motor generated torque**:



It is possible to generate torque depending on the dq-frame current values

Electric Motor Torque Control

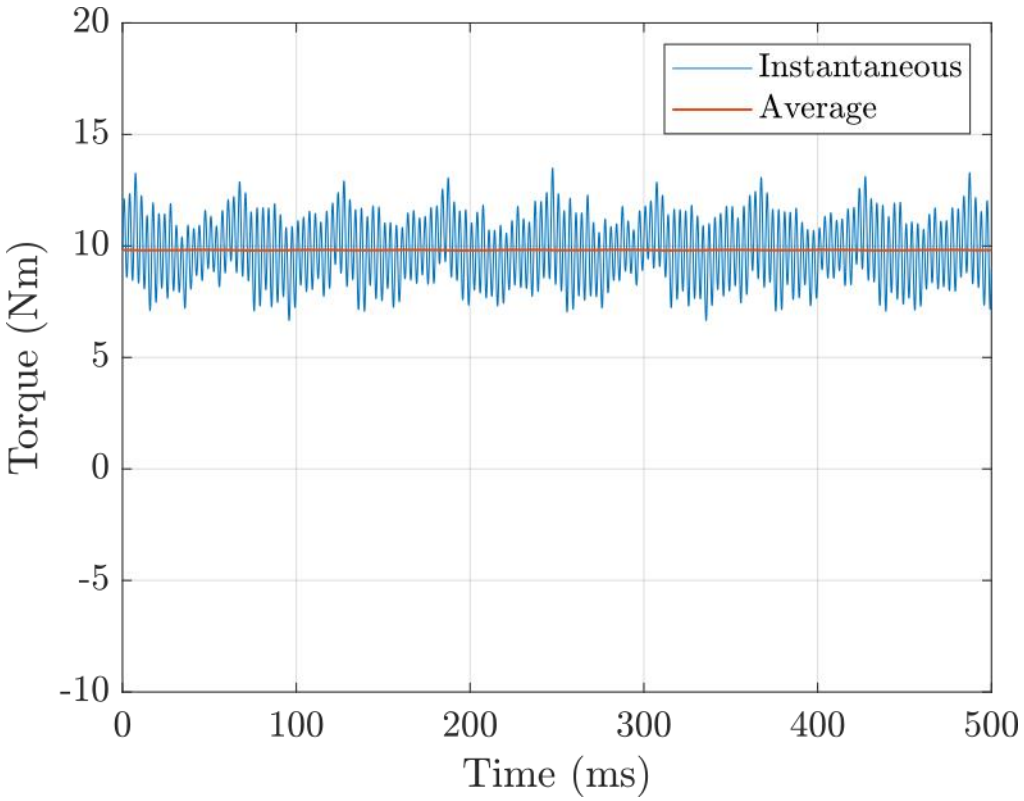
- **Maximum Torque Per Ampere (MTPA) look-up table (LUT)** on **dSPACE system** to provide reference currents in the **dq-frame**
- **Encoder** to retrieve mechanical and electrical angle
- **Encoder** and **dSPACE system communication manager VHDL codes** are **manually written**



Electric Motor Torque Control – Experimental Validation

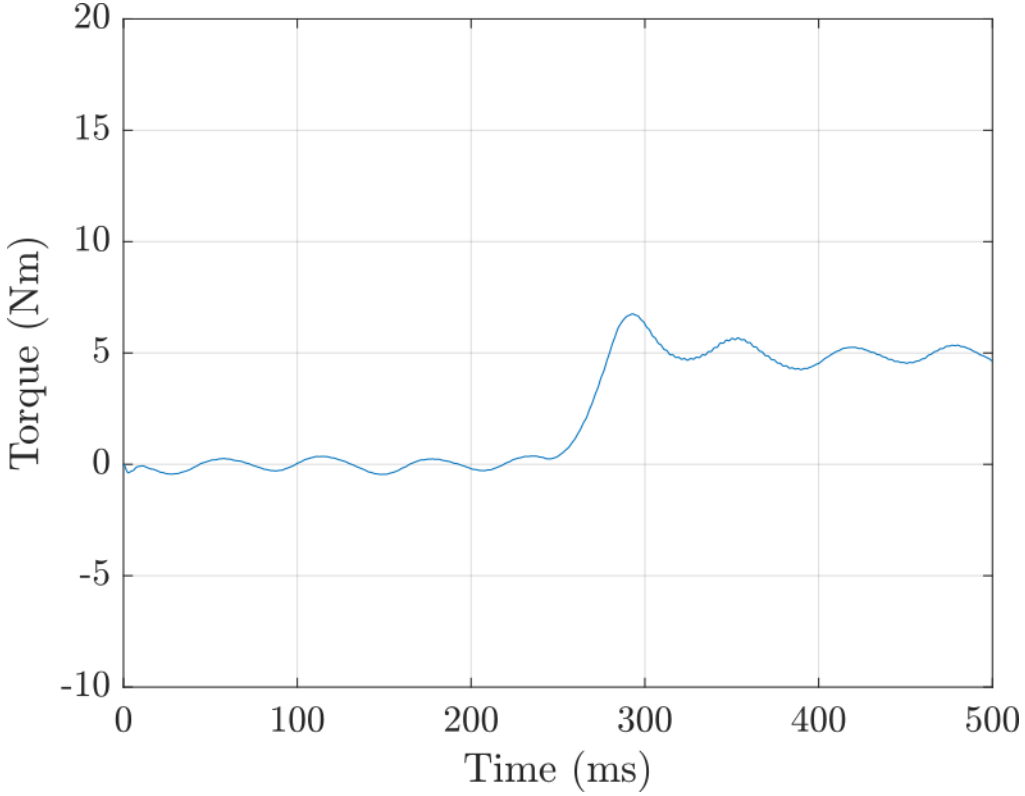
The **DM** imposes a given **rotational speed**

Torque regulation



Reference torque = 10 Nm

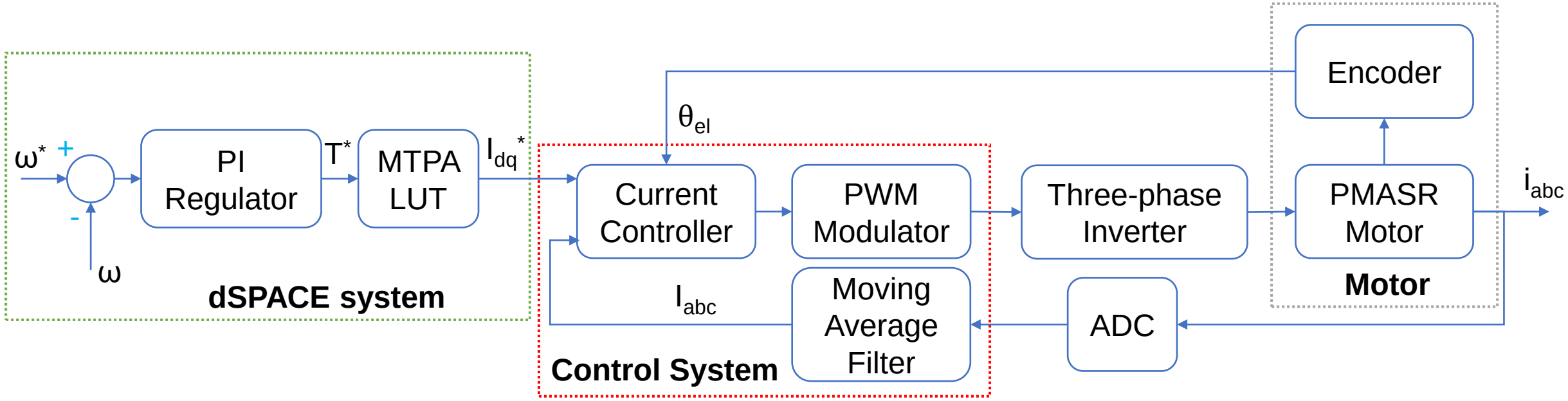
System response after **reference torque variation**



Reference torque: 0 Nm → 5 Nm

Electric Motor Speed Control

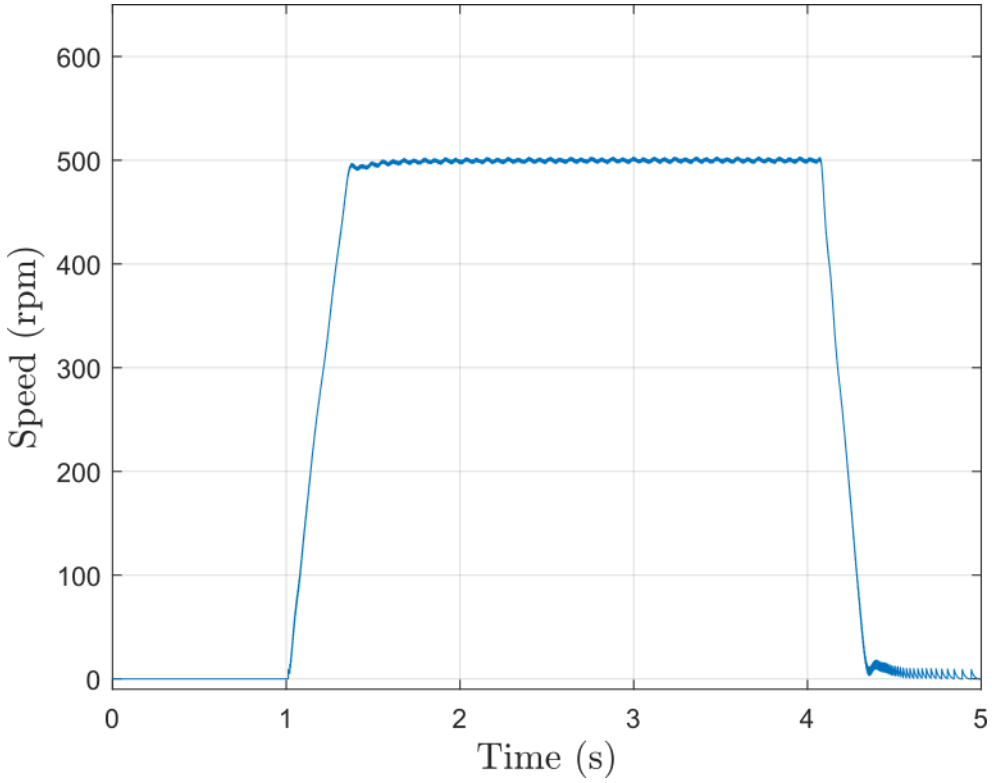
- **External speed control loop on dSPACE system**
- **PI regulator** to provide the **reference torque value**



Electric Motor Speed Control – Experimental Validation

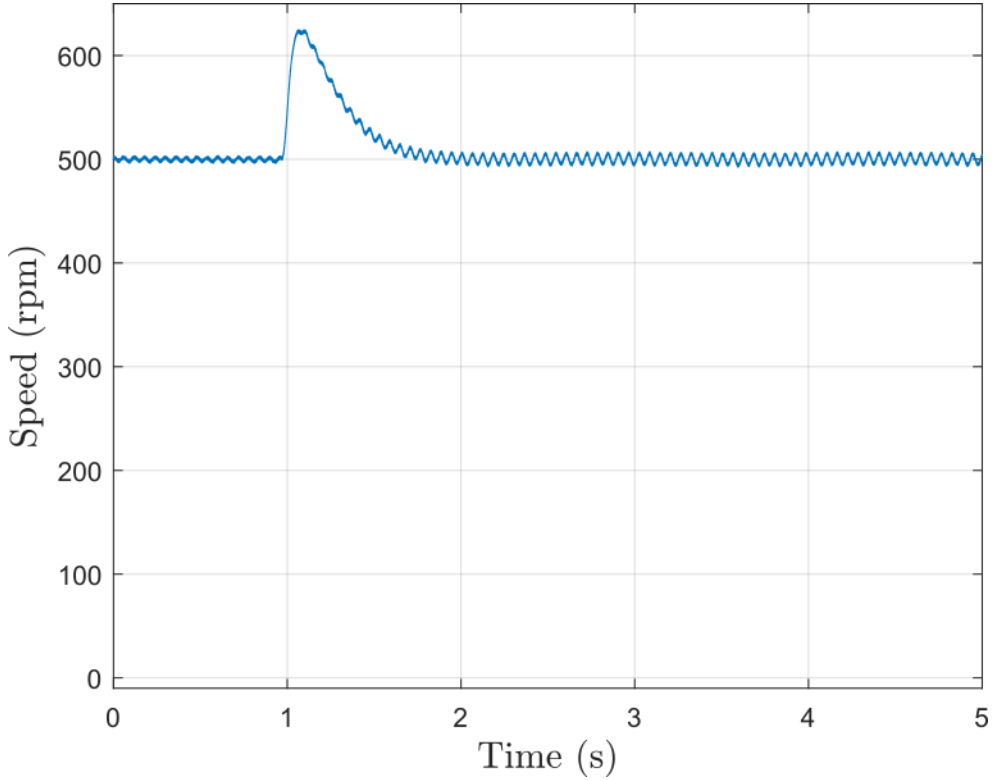
The **DM** imposes a given **load torque**

Speed regulation



Reference speed: 0 rpm → 500 rpm → 0 rpm

System response after **load torque reduction**



Reference speed = 500 rpm

Conclusions

- The **correct control systems operations** have always been obtained → the **Simulink HDL Coder tool effectiveness is proved** for the **minimization** of the programming effort.

- **Personal contributions:**
  - **design** of each **power converter control system**
  - **simulation of each component** to ensure the correct operation
  - **generation of the corresponding VHDL code**, **modifying it accordingly**
  - **implementation of the control systems on the FPGA**
  - **implementation of additional blocks** (**VHDL codes manually written**)
  - **experimental validation** of the designed control systems

Thank you for your attention!

High-performance Digital Control of Power Converters

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