E-Drives Modeling and Torque Control for Electrical Vehicles

Master’s Degree in Mechatronic Engineering

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General Overview

E-Drives traction application issues:

- Highly **non-linear motors**
- Need for **control in the high-speed range**
- Need for **control out of machine‘s nominal conditions** (**temperature** variation)

Tesla model 3

State of art of torque control for traction application:

- LUT- based Field Oriented Control (**FOC**)
- Direct Torque Control (**DTC**)
- PoliTO solution: Direct Flux Vector Control (**DFVC**)

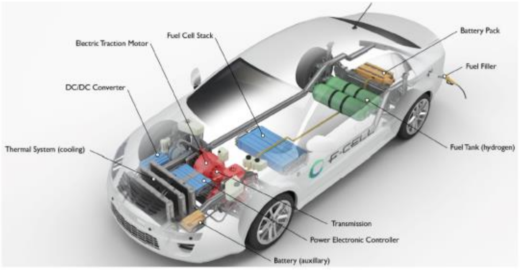
Polestar 3

Usually non circuital, discrete-time average models are used for simulation of E-Drives

Elements of the Control

E-Drives modeling

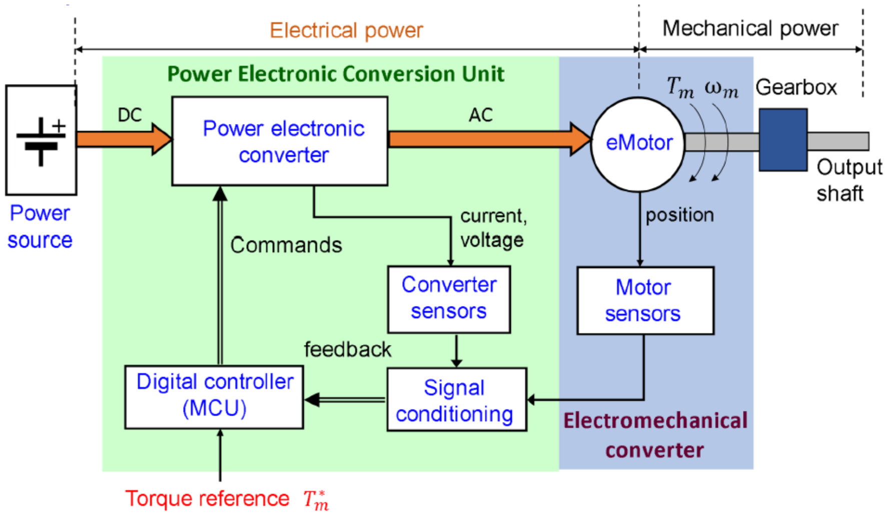
- Elements of the electric vehicle taken into account:
  - DC power source (considered as an ideal voltage source)
  - Power electronic converter
  - Synchronous motor
- Instataneous developed model vs mean value benchmark model



EV architecture

Control strategies

- Reference control: DFVC
- Developed control: 4D LUT-based FOC
- DFVC vs 4D LUT-based FOC



Example for EV block scheme

Objectives

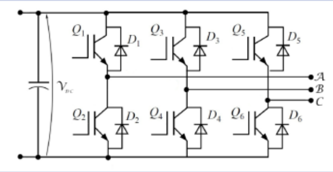
Goals of the thesis:

- Set up a **new circuital model** of the e-Drive, valid for **instantaneous simulation**, **compatible** with both **Simulink** and **PLECS** environments

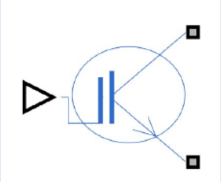
- Develop a **Field Oriented Control technique with 4-dimensional Look-up Tables** (LUTs) to be implemented in Matlab/Simulink using C-language: 4D LUT-based FOC

The thesis is carried out in the context of a research collaboration between the **PEIC** interdepartmental center of Politecnico di Torino and the **Punch Torino** company

Power Electronic Converter

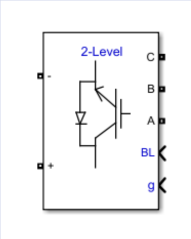


The **converter** chosen is a **three-phase two levels inverter based on IGBT technology**



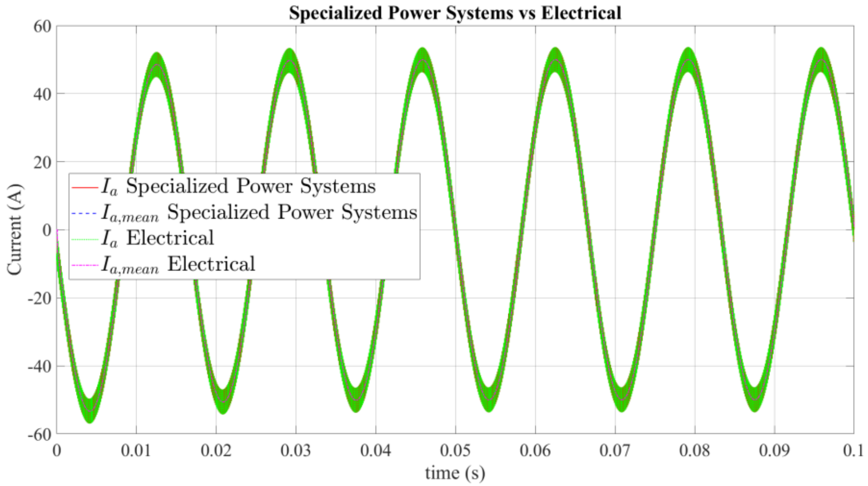
Simscape

Electrical symbol for the IGBT block

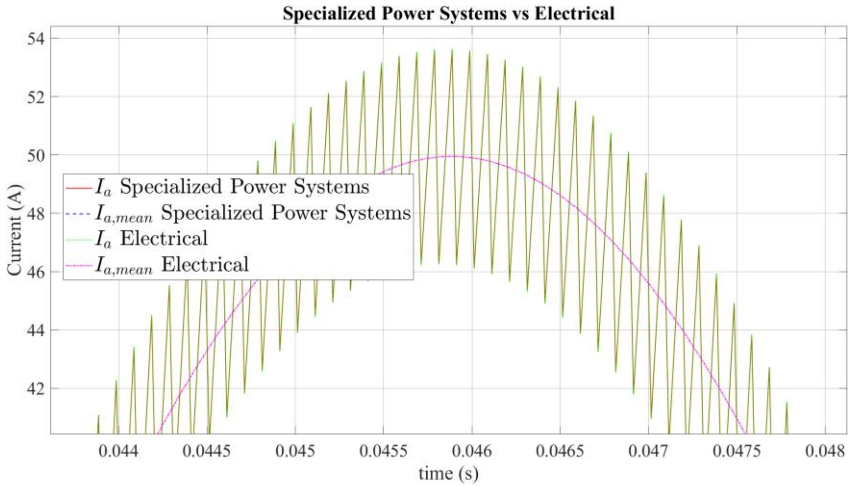


Simscape → Specialized Power System

Two-level converter block



View of the current of phase a in the inverter test

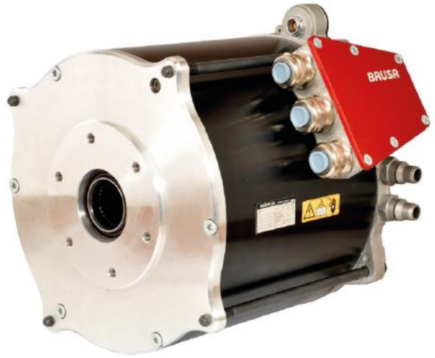


Magnification of current of phase a in the inverter test

IPM Synchronous Motor

Internal Permanent Magnets (**IPM**) machine:

- **Permanent magnets buried** in the rotor surface
- Normally **high torque density**
- The rotor is anisotropic
- Both **PM and reluctance torque**: $T_{pm} \gg T_{rel}$



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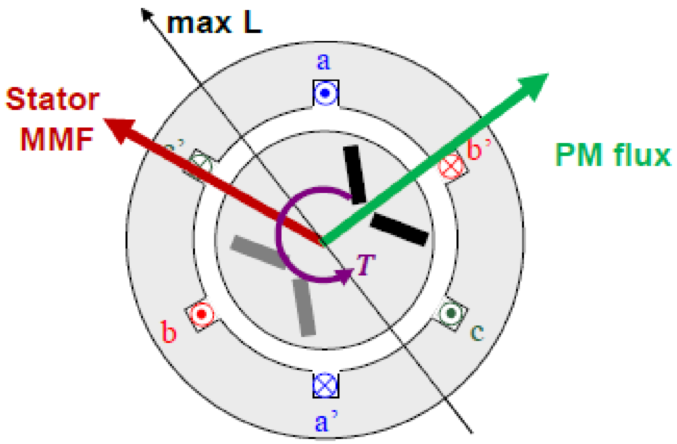
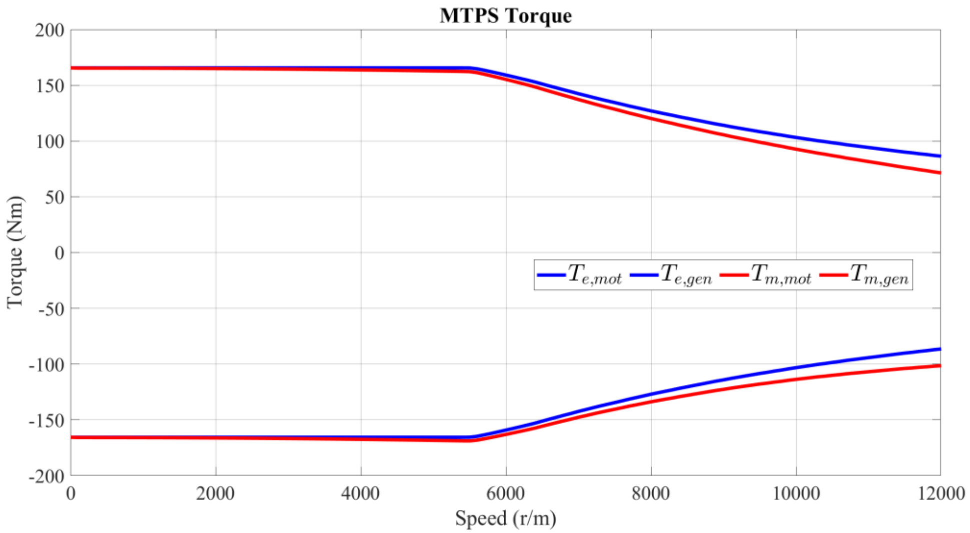


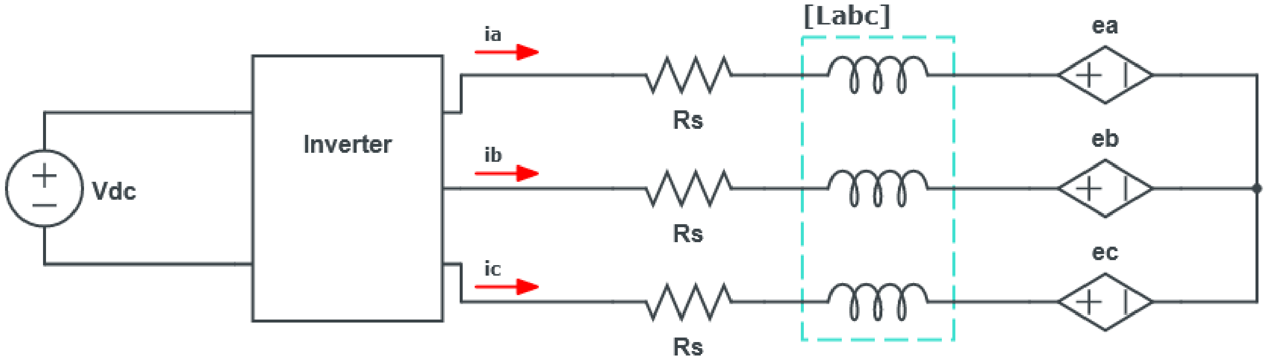
IPM synchronous motor



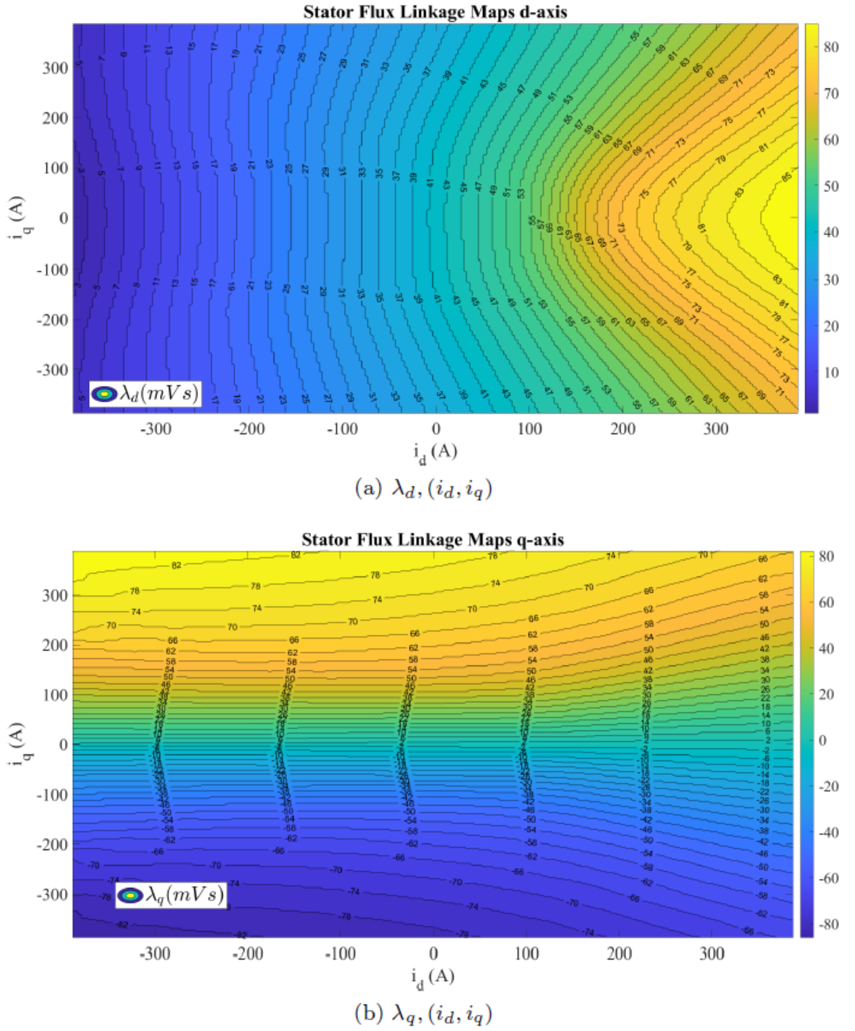
Maximum torque production vs. speed at 400 V_{DC} and 25°C

The **modelling approach** considered for the e-Motor is the **Voltage Behind Reactance** (VBR) model

The VBR model represents the **motor** as an RLE load, with **coupled inductors** and **controlled voltage generators** imposing the **back-EMF** voltages computed by the motor model

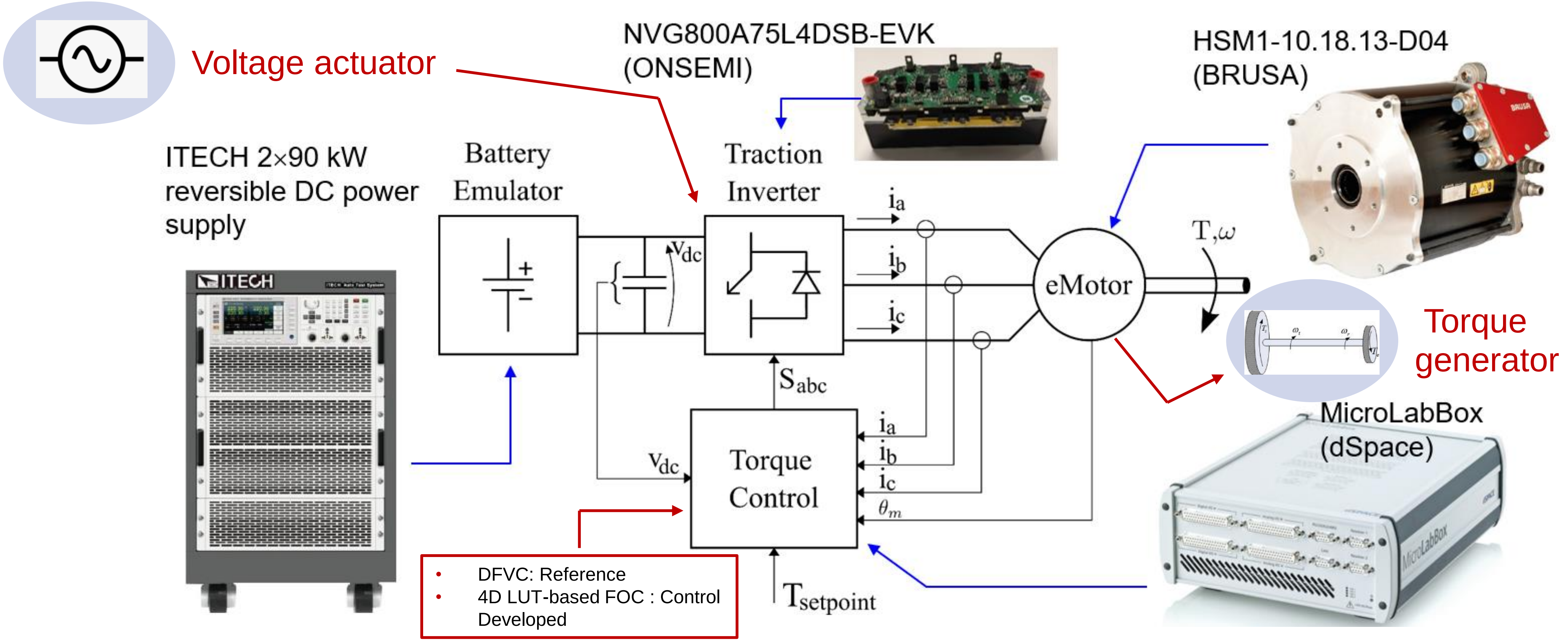


VBR model



Flux-linkage maps of the IPM motor

Example of e-Drive structure for development purposes



- DFVC: Reference
- 4D LUT-based FOC : Control Developed

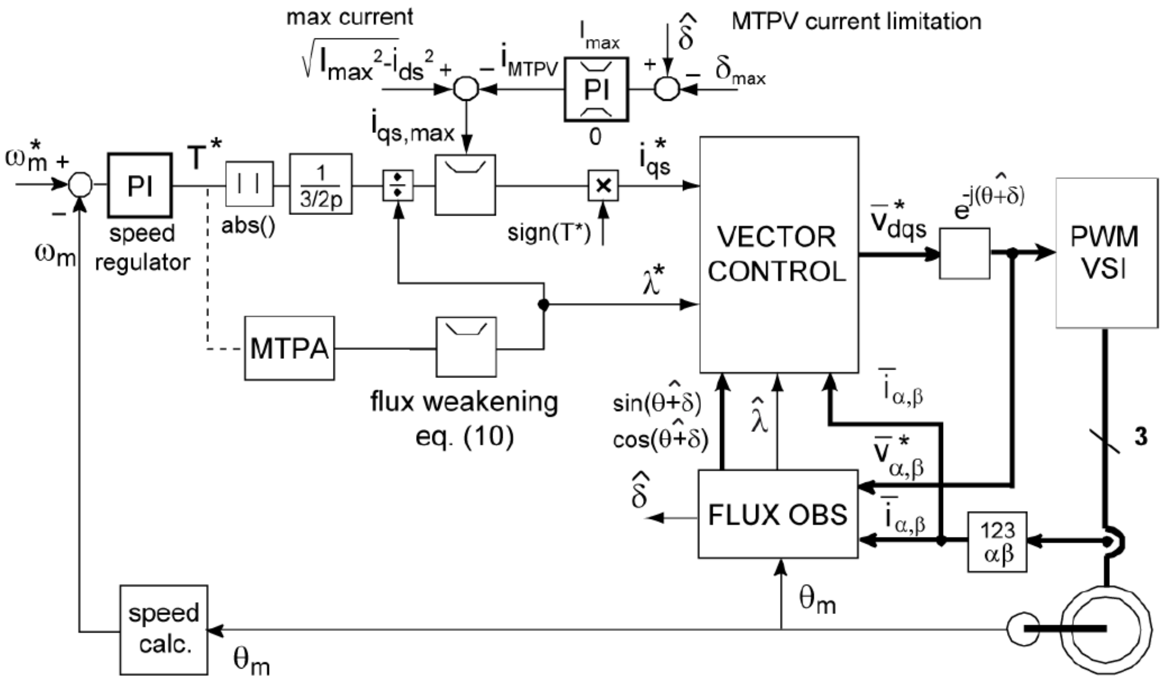
DFVC

Pros:

- The **flux weakening operation** is performed **without** using any outer **voltage regulator**
- **Decoupled control of stator flux amplitudes and torque-producing current**
- Guarantees **maximum torque** production **under inverter current and voltage constraints**

Cons:

- Torque producing current **controller on q_s-axis** is **affected** by electric **parameters sensitivity**
- The d_s **-axis position need** to be **estimated using an observer**



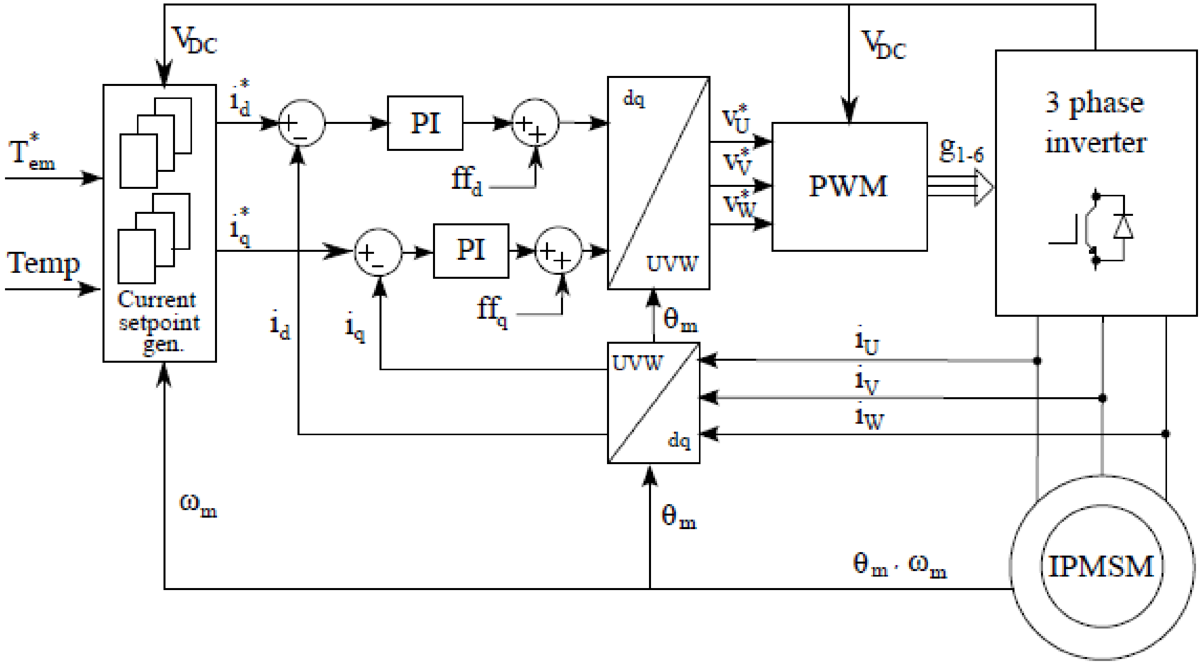
DFVC control scheme

Pros:

- **Overcomes** the issues due to **machine electric parameters variation with temperature**
- Enables the **control** of the machine in the **deep flux weakening region without instabilities**

Cons:

- Requires **several 4D-LUTs to ensure the stable operation in all the possible working points**

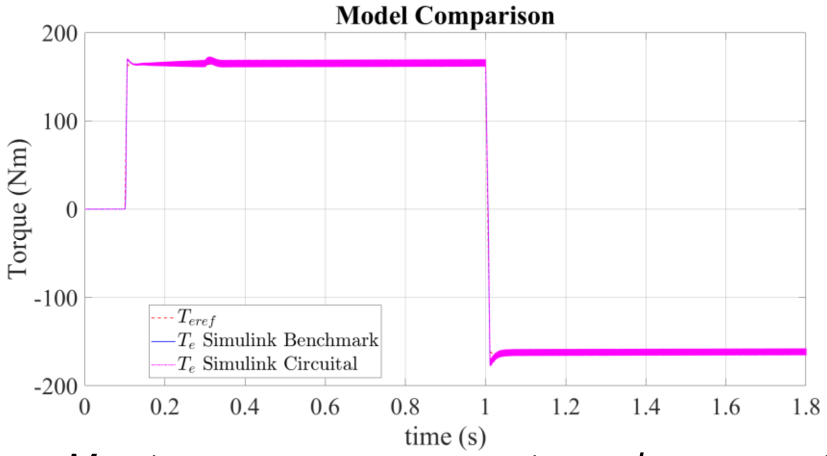


4D FOC control scheme

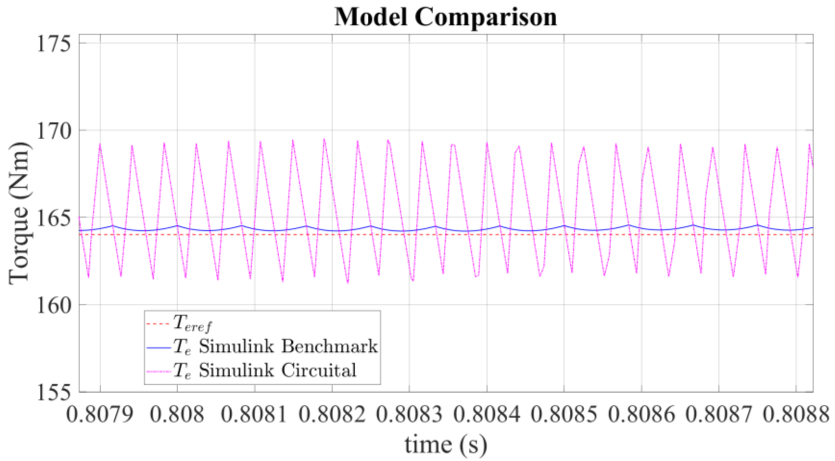
The **VBR model** developed is **compared** with a **non-circuital, discrete-time average model** used as the benchmark

Name	Symbol	Quantity	Unit
Motor			
Pole Pairs	pp	5	-
Stator Resistance	R_s	0,01	Ω
Stator Leakage Inductance	L_{ls}	0,003	H
Maximum Torque	T_{max}	165	Nm
Inverter			
Switching Frequency	f_{sw}	12	kHz
Dead Time	t_{DT}	2	μs
DC-link voltage	v_{DC}	400	V

Motor and Inverter parameters

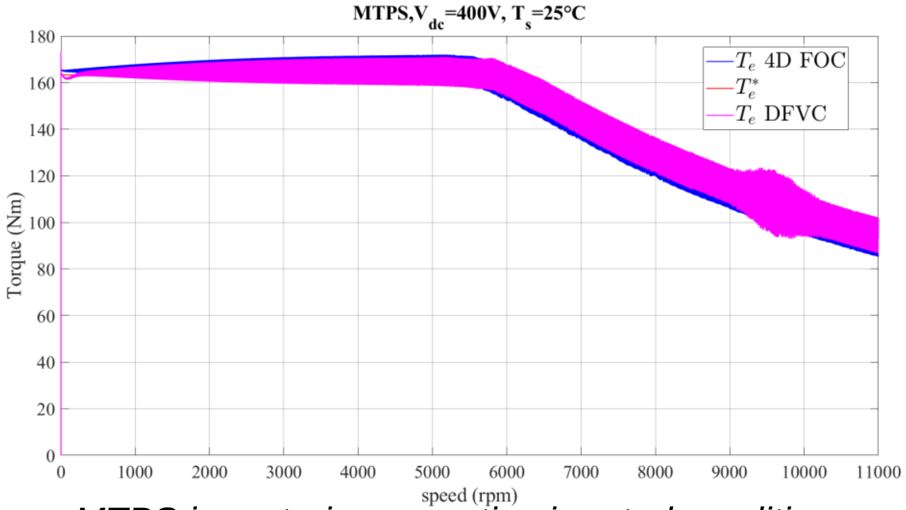


Max torque response as motor and as generator

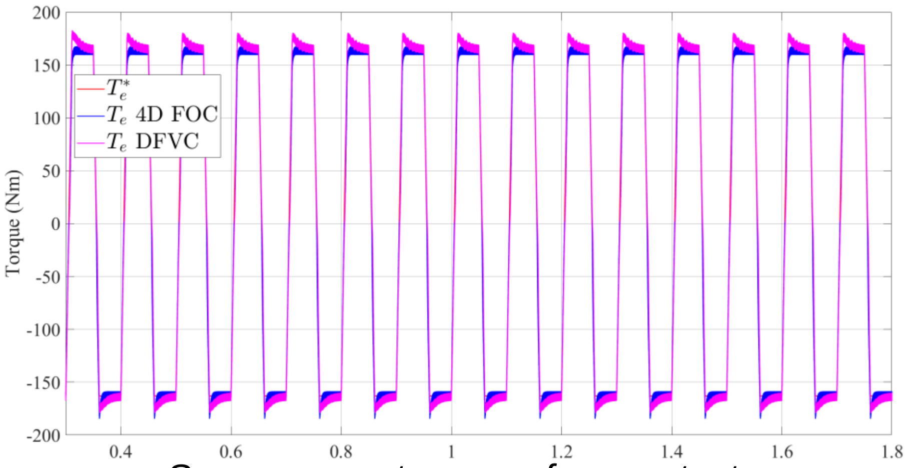


Zoom-in

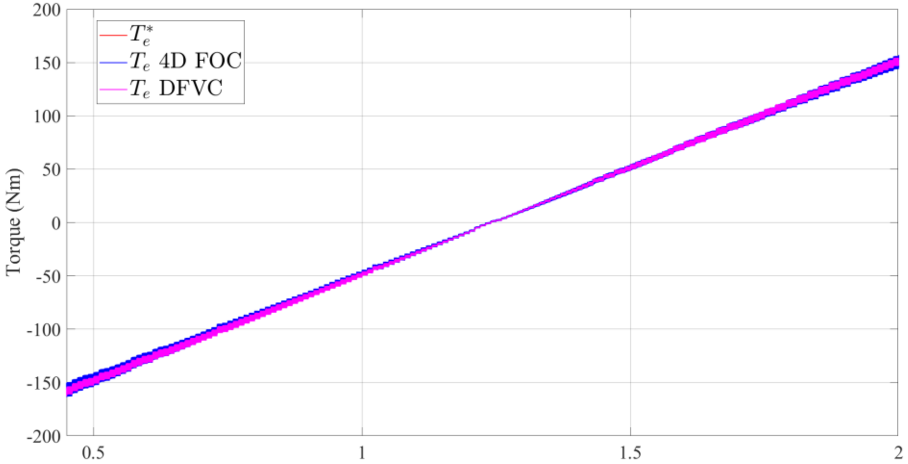
Simulation Results: 4D LUT-based FOC vs DFVC



MTPS in motoring operation in rated conditions



Square wave torque reference test



Torque accuracy test comparison

Conclusion

Personal contributions

- Development of simulation models using a circuital approach based on Simscape
- Realization of a valid alternative to the existent PoliTO DFVC found in the 4D LUT-based FOC, satisfactorily implemented in the C-language

Future developments

- The circuital characteristic of the e-Motor model developed represents a strong base for future work focused on the fault tolerance
- The 4D LUT-based FOC control scheme developed due to its simplicity, flexibility and reliability can be the starting point in the field of fault tolerant control strategies

Thanks for your attention!