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Torque control of multiphase synchronous machine

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Research context and motivation

Although the **three-phase** machine is the natural choice for industrial and traction eDrives, it has some disadvantages:

- high power levels lead to high phase currents if the available voltage is limited
- f**ault events** cause the **inoperability** of the machine

The **multiphase machine** may replace the three phase solution in particular applications:

- the **current per phase can be reduced** to manage high power loads
- the **system's reliability increases** thanks to the redundant structure

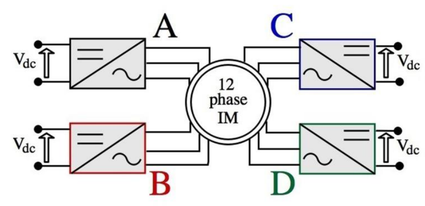
The **multi three phase** machines have recently gained **more interest** thanks to:

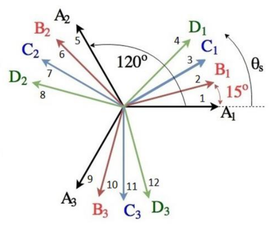
- the **use of independent three-phase inverters to exploit the three phase solutions**
- modularity and easiness to control

Concerning the **multiphase synchronous machine,** a **lack in the literature** is still present both in the **modeling approach** and in the **definition** of an effective **torque control strategy**

Two **research contracts** are ongoing:

- Development of a machine control architecture and of a torque control solution for automotive application with **Polestar – Volvo Cars** company
- Development of a torque control solution with **Punch Torino** company





polestar

PUNCH | Torino

G. Sala, M. Mengoni, G. Rizzoli, M. Degano, L. Zarri and A. Tani, "Impact of Star Connection Layouts on the Control of Multiphase Induction Motor Drives Under Open-Phase Fault," in *IEEE Transactions on Power Electronics*, vol. 36, no. 4, pp. 3717-3726, April 2021

Addressed research questions/problems

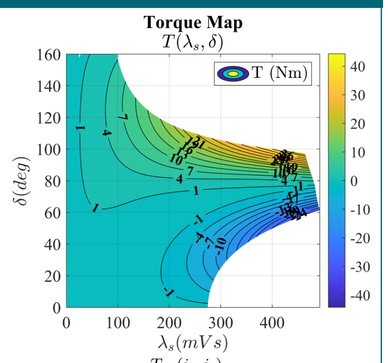
The main topic addressed in the research are:

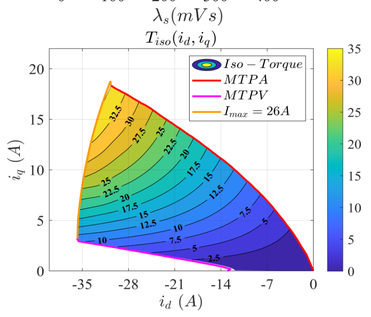
- Development and testing of a torque control for traction three-phase AC drive using a new approach entitled **Flux Polar Control (FPC)** [1] (patent pending)
- Design of an experimental **identification procedure of the electric parameters of the induction machine** [2]
- State-of-the-art of multiphase machine modeling and torque control techniques

Novel contributions

Flux Polar Control (FPC) of AC Motor

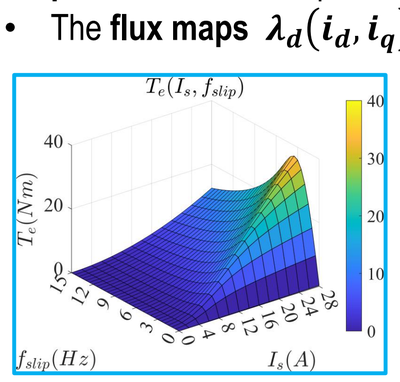
- **Direct control** of machine **flux vector** in its polar components: the **amplitude** $\boldsymbol{\lambda}$ and the **phase** $\boldsymbol{\delta}$ (machine **load angle**)
- **Torque map** definition using flux $\boldsymbol{\lambda}$ and load angle $\boldsymbol{\delta}$
- The **inner regulators** are **decoupled** (model equation in stator flux-oriented reference frame)
- The **tuning** of the regulators **does not depend on the of the machine type and the operating point**, it is only related to the selected switching frequency
- **No additional regulator** is required to perform the **MTPV** operation with flux weakening
- **FPC** is **a plug-and-play torque control strategy**

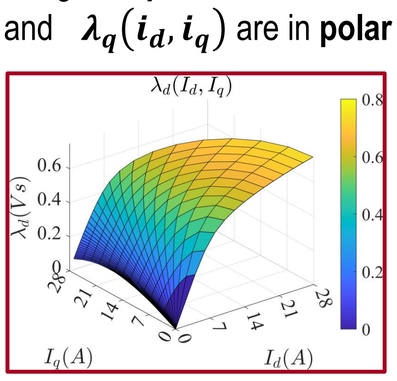


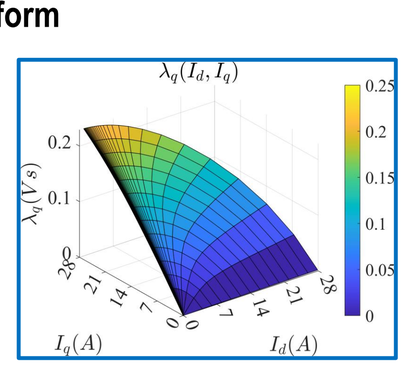


Experimental Flux Mapping of Induction Machine for Traction

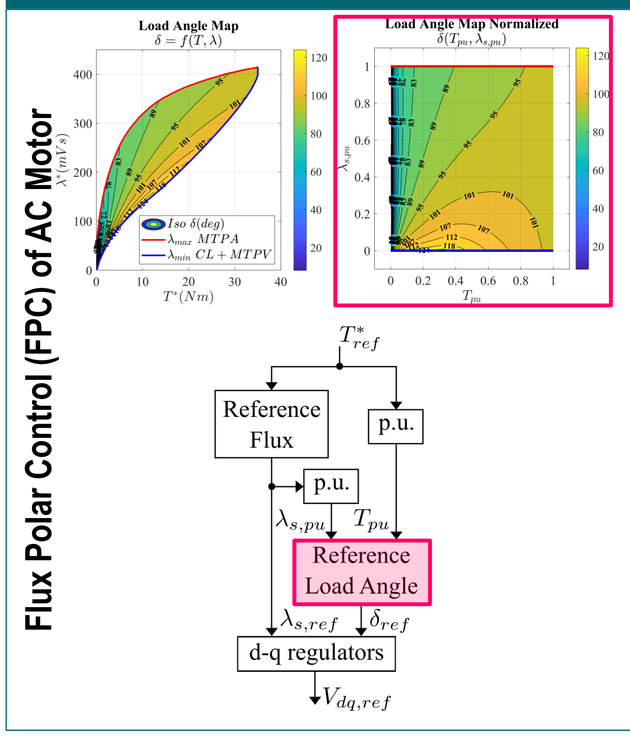
- **New procedure** to **map the steady-state dq flux maps of the induction machine**
- **All the equivalent circuit parameters** can be obtained exploiting the main control loci
- A proper **characterization of the current-frequency behavior** of the **electric circuit parameters** in the operative ranges **is performed**
- The **flux maps** $\boldsymbol{\lambda_d(i_d, i_q)}$ and $\boldsymbol{\lambda_q(i_d, i_q)}$ are in **polar form**

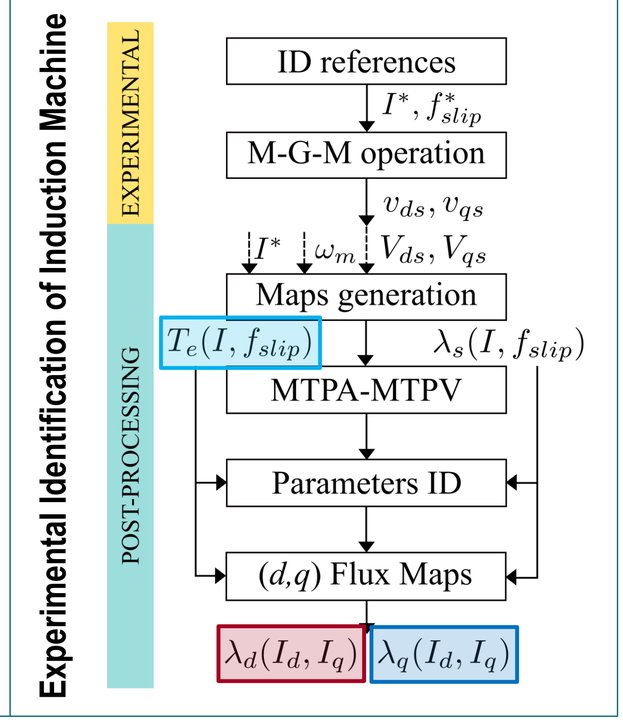






Adopted methodologies





Future work

The Ph.D. activities will concern the modeling and the development of torque control strategies for multi three-phase synchronous motors. The machine under study is a twelve phase PMSM using a configuration with four three-phase winding sets.
The main topics that will be investigated are:

- **Development of multi three-phase SM models**: multiphase synchronous machine models will be devised to check the effectiveness of the torque control techniques
- **FPC in multi-phase configuration**: both VSD and MS approaches will be adopted to check the effectiveness of this torque control strategy for multi three-phase motors
- Development of **a decoupling algorithm for multi three-phase SM:** each winding set will have to be independent of the others to enable the decoupled control of the motor

Submitted and published papers

1. *S. Rubino, F. Mandrile,* ***L. Tolosano****, E. Armando and R. Bojoi,* ***"Direct Flux and Load Angle Vector Control of Permanent Magnet Synchronous Motors****", 2021 IEEE Energy Conversion Congress and Exposition (ECCE), pp. 4668-4675.* ***Second Prize Paper Award of Industrial Drives Committee of Industry Application Society 2022***
2. *L.* ***Tolosano****, E. Armando, S. Rubino, F. Mandrile and R. Bojoi* ***"Experimental Identification of Induction Machine Flux Maps for Traction Applications"*** *2022 IEEE Energy Conversion Congress and Exposition (ECCE)*

List of attended classes

- 02LWHRV – Communication (01/12/2021, 1 CFU)
- 01SHMRV – Entrepreneurial Finance (01/12/2021, 1 CFU)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (05/11/2021, 1 CFU)
- 01RGBRV – Optimization methods for engineering problems (07/06/2022, 6 CFU)
- 02SFURV – Programmazione scientifica avanzata in matlab (21/04/2022, 6 CFU)
- 08IXTRV – Project management (24/11/2021, 1 CFU)
- 01RISRV – Public speaking (01/12/2021, 1CFU)
- 01SYBRV – Research integrity (10/11/2021, 1 CFU)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (12/11/2021, 1 CFU)
- 01TSLRO – Soluzioni innovative per veicoli elettrici e/o ibridi (31/03/2022, 3 CFU)
- 02RHORV – The new Internet Society: entering the black-box of digital innovate (01/12/2021, 1 CFU)
- 01QORRV – Writing Scientific Papers in English (05/05/2022, 3 CFU)
- European Ph.D. School Gaeta 2022 (23-27/05/2022, 30 h)

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering