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Tutorial on

Direct Flux Control: Emerging Torque Controllers for Traction and Propulsion Motors

Tutorial Presenters

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Biographies of the Presenters

Sandro Rubino (Senior Member, IEEE) received the M.Sc. and PhD degrees in electrical engineering from Politecnico di Torino, Torino, Italy, in 2014 and 2019, respectively. He is currently an Associate Professor at the Energy Department “G. Ferraris” of Politecnico di Torino. His research activities include modelling and controlling multiphase electrical machines and high-performance motor drives. Prof. Sandro Rubino currently serves as the Secretary of the *Industrial Drive Committee (IDC)* of the *IEEE Industry Applications Society (IAS)*. Also, he is an Associate Editor of *IEEE Transactions on Industry Applications* and *IEEE Journal of Emerging and Selected Topics in Power Electronics*. Prof. Sandro Rubino received four paper awards from IAS-IDC and two PhD thesis awards for the design and validation of advanced torque controllers for traction and propulsion motors. He is involved in many research projects with industry aimed at technology transfer from academia.

Radu Bojoi (Fellow, IEEE) received the M.Sc. degree in electrical engineering from the Technical University of Iasi, Iasi, Romania, in 1993, and the PhD degree in electrical engineering from the Politecnico di Torino, Torino, Italy, in 2002. He is currently a Full Professor of power electronics and electrical drives with the Energy Department “G. Ferraris” and the Chairman of the Power Electronics Innovation Center, Politecnico di Torino. Prof. Bojoi is the recipient of eleven IEEE paper awards and a co-author of more than 200 papers covering electrical drives and power electronics for industrial applications, transportation electrification, power quality, and home appliances. He is involved in many research projects with industry, aiming at obtaining new products involving emerging technologies.

Abstract

The energy transition involving 3D mobility (automotive, more-electric aircraft, naval propulsion and generation) is driving the adoption of high-power-density e-motors featuring high magnetic saturation, a wide constant-power speed range, and very high fundamental frequencies at high speeds (up to 35000 rpm, 2 kHz). Moreover, high-power propulsion applications often rely even more on multiphase solutions that implement three-phase modularity, i.e., multi-three-phase e-drives, keeping voltage levels low (< 1200 V) and thus inheriting cutting-edge wide-bandgap three-phase power-electronics technologies developed in the automotive industry.

In parallel with the ongoing evolution of e-motors and traction inverters, they are even more required advanced torque controllers for e-motors featuring 1) accurate torque regulation, 2) ultra-high dynamic performance for NVH mitigation, 3) overmodulation capability up to six-step operation, 4) implementation simplicity towards automatic-code generation and certification, and 5) self-calibrated inner control loops to reduce tuning efforts and guarantee control stability.

The literature reports consolidated torque-control solutions, such as Current Vector Control (CVC) and Direct Flux and Torque Control (e.g., PWM-DTC and DFVC), which perform very well in speed-controlled industrial applications. Nevertheless, simultaneously satisfying the demanding traction and propulsion features previously mentioned 1) – 5) cannot be guaranteed with these conventional solutions. Besides, this issue is further aggravated in multi-three-phase drives due to magnetic coupling between the machine's three-phase winding sets, which can lead to control instability.

To address these issues, advanced torque controllers based on direct control of the stator flux vector have been proposed in the literature, namely Direct Flux Controllers (DFC). These torque controllers have been proposed in the literature in various variants (e.g., FVC and FPC), achieving outstanding experimental results across all e-motors and rapidly gaining adoption in automotive applications.

Therefore, this tutorial is aimed at R&D engineers and academic researchers working in e-mobility to present cutting-edge torque controllers based on the DFC approach.

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