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Tutorial Title

Methods to Identify & Control Highly Non-Linear Three-Phase Machines

Instructor Team

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Abstract

Highly utilized three-phase machines show a highly nonlinear electromagnetic behavior, making it very challenging or even impossible to control them using standard control-algorithms. One very appropriate and well-proven method to cope with this nonlinearity is the measurement of multi-dimensional flux linkage maps for each possible operating point of the given machine. During operation a look-up-table is used to adjust the gain of the used control-algorithm to the actual differential inductance in each given operating point. The flux maps are also used in non-linear model predictive control (MPC) schemes to enhance dynamics. And besides machine-control the flux maps are implemented in high accuracy simulations to test new control algorithms. So with this method, the nonlinearities are stored in flux linkage maps and are fed-forward to the controller in each control cycle. To obtain the flux linkage maps, several methods are described in literature. One of the most-common methods is the steady-state method in which the device-under-test (DUT) is mounted in a hardware test-bench together with a load-machine. The load machine is speed-controlled and guarantees constant rotational speed, whereas the DUT is current controlled, enabling to drive it to every operation point in the dq-current plane. The downside to this method is the need of a real-power hardware test-bench, which is quite a cost factor and general effort. The other well-known method is the locked-rotor test in which the DUT's rotos is locked and hence the rotational speed is zero. Here, no load machine is necessary but other restrictions apply, for example that no speed-dependent effects can be measured. In state-of-the-art implementations, the flux maps depend on the rotor-oriented direct and quadrature current components, considering the major nonlinearity-effects of magnetic saturation and cross-coupling. To be able to also consider nonlinearities that are due to the rotor and stator geometry, the dependency on the rotor angle must be taken into account as well. With these angle-dependent flux linkage maps, the angle-dependent error can be fed-forward e.g. in repetitive control schemes, enhancing control quality significantly. In this tutorial different methods to obtain multi-dimensional flux maps of permanent magnet synchronous machines (PMSM), synchronous reluctance machines (SynRM), electrically excited synchronous machines (EESM) and induction machines (IM) are presented. This includes steady state-tests, locked-rotor-tests, and a new approach that replaces flux maps with a physics-informed neural network. In addition to the flux-map-identification, also one well-proven control method that makes use of these flux maps and enables for high dynamics is presented. Of course, also hands-on tips from our long-term lab-experience, dealing with several motor test-benches ranging from few hundred Watts (Pedelec/E-Bike motors) to several 100kW (automotive) for over a decade will be given in each of the described topics.

Instructor Team Biographies

Dr. Andreas Liske received the Dipl.-Ing. degree in electrical engineering and communication technology from the Technical University of Karlsruhe and the PhD degree in electrical engineering from the Karlsruhe Institute of technology (KIT) in 2010 and 2020 respectively. Since 2010 he was lecturer and since 2012 senior engineer at the Institute of Electrical Engineering (ETI) at the KIT. In 2020 he became assistant professor and group-leader of the research team “Control and modelling of power electronics systems” at the very same institute. Dr. Liske teaches 4 lectures in power electronics, modeling, and control of electrical machines at the KIT.

One of his research topics was an adaptive current control scheme which highly depends on the fast and precise identification of the inverter induced current slopes. In this context, he and his team developed several improvements and new methods. He was an invited speaker to present those new ideas at several international seminars and conferences, e.g. ECPE Cluster seminars, industry led Symposiums and as invited talk on the Southern Power Electronics Conference (SPEC 2022).

His recent research focuses on extending the methods and applications of real-time dx/dt-measuring in the context of power electronics, modeling, and control of electrical drive systems.

Johannes Stoß received the B.Sc. and M.Sc. degrees in electrical engineering from the Karlsruhe Institute of Technology, Germany, in 2015 and 2018, respectively. Since 2018, he has been working as a Research Assistant at the Institute of Electrical Engineering (ETI), Karlsruhe Institute of Technology (KIT). One of his first research topics was the proper implementation of a PCB-integrated planar sensor coil for di/dt-measuring in an inverter. He published his results as design guidelines for this very topic in 2019. Currently, he is working on the identification of spatial flux linkage harmonics of electrical machines as well as dynamic machine control.

Alexander Oerder received his M.Sc. degree in electrical engineering from the Karlsruhe Institute of Technology, Germany, in 2019. During his master’s thesis, he developed a measurement-based method for identification of spatial flux linkage harmonics in permanent magnet synchronous motors. After gaining experience on the design, manufacturing, commissioning and measurement of electric drive system in the industry, he started working as a Research Assistant at the Institute for Electrical Engineering at the Karlsruhe Institute of Technology in 2022. Pursuing his a PhD, he currently evaluates data-driven motor control and identification algorithms for electric motors.

Stephan Goehner was born in 1998 in Hannover, Germany. He studied electrical engineering and information technology at Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany, where he received his B.Sc. (2020) and M.Sc. (2022). Since 2023 he is research assistant in the research group for control of power electronics systems at Institute of Electrical Engineering (ETI) at KIT. His main research topics are modeling, parameter identification and control of electric drives with focus on synchronous machines. In his recent work, he examined flux linkage identification of permanent magnet and electrically excited synchronous machines using steady state and locked rotor tests.

Benedikt Schmitz-Rode received the B.Sc. and M.Sc. degrees in electrical engineering from the Karlsruhe Institute of Technology (KIT), Germany, in 2016 and 2019, respectively. Since 2020 he has been working as a research assistant at the Institute of Electrical Engineering (ETI) at KIT to receive a PhD. His research interests include power electronics and electrical drives, especially condition monitoring of power electronic systems, rapid-prototyping Hardware-in-the-Loop emulation of electrical drives, parameter identification and signal processing.

Leonard Geier was born in Göttingen, Germany in 1994. He received the B.Sc. and M.Sc. degrees in mechatronics engineering from the Karlsruhe Institute of Technology (KIT), Germany, in 2019 and 2022, respectively. Since 2022 he has been working as a research associate at the Institute of Electrical Engineering at KIT to receive a PhD. His research interests include power electronics and electrical drives, especially modelling, parameter identification and control strategies.

Benjamin Bachowsky received the B.Sc. and M.Sc. degrees in electrical engineering from the Karlsruhe Institute of Technology (KIT), Germany, in 2016 and 2020, respectively. Since 2021, he has been working as a Research Associate at the Elektrotechnisches Institut (ETI) at KIT. His research focus is on identification and dynamic control of electrical drives, in particular model predictive control strategies and new adaptive methods for online identification.