EPE'25 – Call for Tutorials

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

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Tutorial Objectives:

Highly utilized three -phase machines show a highly nonlinear electromagnetic behaviour, 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 the 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 considered 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.

Target Audience:

Every interested student, PHD candidate or professional. Tutorial difficulty is considered medium. Prerequisite knowledge is just a basic understanding of power electronics, electrical drives and control of electrical drive systems.

Topical Outline:

I. Introduction	10min	Dr. Andreas Liske
II. General Approach and Prerequisites	20min	
a. Reasons for nonlinearity b. Practical measures for the setup		
III. Identification of flux maps of different machine types a. Permanent Magnet Synchronous Machine & Synchronous Reluctance Machine	20min	
b. Electrically Excited Synchronous Machine	20min	Stephan Göhner
c. Induction Machine	20min	
coffee break		
IV. Mathematical Methods for Flux Map Processing a. Data acquisition & post-processing techniques b. Inversion of flux maps	20min	Leonard Geier
V. Controlling non-linear machines with flux maps	25min	B. Schmitz-Rode
VI. Measuring spatial harmonic flux linkages	20min	Alexander Oerder
VII. Neural Networks as universal flux linkage approximators	15min	
VIII. Summary	10min	Dr. Andreas Liske

The tutorial is planned as 2 blocks of 90min each and will be held as a classical lecture, mixed with dialog with the audience. The presentation itself will be a mix of prepared slides and handwritten supplemental explanations in these slides. This format is well proven and clearly favored by the students in my regular power electronics lectures at KIT.

About the Lecturers:

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.

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 Associate at the Institute for Electrical Engineering at the Karlsruhe Institute of Technology in 2022. Pursuing 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 Associate at the Elektrotechnisches Institut (ETI) at KIT. His interests include power electronics and electrical drives, especially rapid-prototyping Controller-Hardware-in-the-Loop emulation of electrical drives, signal processing and parameter estimation. Pursuing a PhD he currently works in the field of condition monitoring of power electronic systems based on analyzing the controller output variables.

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.