EPE'2021 –Tutorial Announcement

Model Predictive Control of Power Electronic Systems: Methods, Results and Challenges

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Scope and Benefits:

Model predictive control (MPC) is a control approach that has recently been gaining more popularity in the field of power electronics due to its numerous advantages such as explicit inclusion of design criteria and restrictions, design versatility and inherent robustness. In academia, direct MPC with reference tracking, also known as finite control set MPC (FCSMPC), is the favored and most widely published MPC method. Reasons for this include the advent of powerful micro-processors as well as its allegedly straightforward and simple design procedure. Because of the latter, researchers advocate the use of FCS-MPC in industry as a superior alternative to established control methods. However, industry is reluctant to adopt new control methods that do not provide significant economic benefits. To achieve these benefits with control, it is mandatory to improve some key aspects of the system performance; this, in turn, is typically achieved with more complicated control methods.

Motivated by the previous observations, the objective of the tutorial is to elucidate the design simplifications that adversely affect the behavior of FCS-MPC, and suggest MPC methods that improve the power electronic system performance. In particular, this tutorial focuses on (a) design guidelines that improve the performance of FCS-MPC, and (b) alternatives that either use a modulator (indirect MPC) or have an embedded modulator (model predictive pulse pattern control and gradient-based MPC) and achieve superior performance compared with conventional control techniques. Moreover, particular emphasis will be put on the associated challenges of the real-time implementation of the discussed MPC algorithms on embedded systems. To this end, implementation-related issues will be discussed and methods to tackle them will be presented. Finally, the performance of the MPC methods in question is assessed and their main strong points and weaknesses are identified.

Overall, the tutorial aims at providing a balanced mix of theory and application-related material. Special care is taken to ensure that the presented material is intuitively accessible to the power electronics practitioner. This is achieved by augmenting the mathematical formulations by illustrations and simple examples.

By the end of the tutorial, the attendees:

- will have a new insight on the design of MPC-based controllers with different formulations,

• will be able to understand what design options exist that maximize the system performance,
• will be able to recognize the design and implementation challenges of the discussed methods, and
• will be able to develop MPC-based controllers that outperform conventional control techniques and push the system performance to its physical limits.

Contents:

The outline of the tutorial day is as follows:

• Part 1: Introduction to FCS-MPC with short and long prediction horizons: Basic control concepts and basic ingredients of MPC (plant model, optimal control problem, receding horizon policy), formulation of the FCS-MPC problem with short and long horizons, implementation-related issues, computationally efficient solution of the FCS-MPC problem using sphere decoding, several case studies.

• Part 2: Guidelines for the design of FCS-MPC-based controllers: Analysis of the factors that affect the closed-loop performance of FCS-MPC, design guidelines that enable maximization of the system performance, performance assessment based on two different case studies.

• Part 3: Model predictive pulse pattern control: Introduction to optimal modulation (optimized pulse patterns, OPPs), stator flux trajectory tracking, formulation of the OPP controller in the framework of MPC, refinements and extensions, performance assessment.

• Part 4: Indirect MPC and gradient-based MPC: Introduction to carrier-based pulse width modulation, formulation of the constrained optimal control problem, implementation challenges, performance assessment.

Schedule:

Monday, 6 September 2021 - Tutorial day (Virtual)

09:30 – 11:00	Part 1: Introduction to FCS-MPC (T. Geyer)
11:00 – 11:30	Coffee break
11:30 – 13:00	Part 2: Design guidelines for FCS-MPC (P. Karamanakos)
13.00 – 14:00	Lunch break
14:00 – 15:30	Part 3: Model predictive pulse pattern control (T. Geyer)
15:30 – 16:00	Coffee break
16:00 – 17:30	Part 4: Indirect and gradient-based MPC (P. Karamanakos)

Who should attend:

The target audience of this tutorial are researchers from both academia and industry (e.g., university students at, or above, the M.Sc. level, academics, and engineers in industry focusing on research and development) who are interested in an introduction to MPC for power electronics systems and its different approaches.

Technical Level:

The tutorial aims to provide the fundamentals of MPC and the discussed methods, and gradually builds on top of them. Thus, the required knowledge level spans over a wide range, starting from a beginner level. Ideally, the attendees should have a good understanding of the basics of power electronics and electrical machines (voltage source inverters, pulse width modulation, three-phase induction machines) and system modeling (coordinate transformations, linear systems, state-space representation, discrete-time systems). Familiarity with modern control theory (optimal control) and exposure to optimization (integer programming, quadratic programming) are helpful but not a prerequisite.

About the Lecturers:

Tobias Geyer received the Dipl.-Ing. and Ph.D. degrees in electrical engineering from ETH Zurich, Zurich, Switzerland, in 2000 and 2005, respectively, and the Habilitation degree in power electronics from ETH Zurich, Zurich, Switzerland, in 2017.

After his Ph.D., he spent three years at GE Global Research, Munich, Germany, three years at the University of Auckland, Auckland, New Zealand, and eight years at ABB's Corporate Research Centre, Baden-Dättwil, Switzerland. There, in 2016, he became a Senior Principal Scientist for power conversion control. He was appointed as an extraordinary Professor at Stellenbosch University, Stellenbosch, South Africa, from 2017 to 2023. In 2020, he joined ABB's medium-voltage drives business as R&D platform manager of the ACS6000/6080.

He is the author of 35 patent families and the book "Model predictive control of high power converters and industrial drives" (Wiley,2016). He teaches a regular course on model predictive control at ETH Zurich. His research interests include medium-voltage and low-voltage drives, utility-scale power converters, optimized pulse patterns and model predictive control.

Dr. Geyer is the recipient of the 2017 First Place Prize Paper Award in the IEEE Transactions on Power Electronics, the 2014 Third Place Prize Paper Award in the IEEE Transactions on Industry Applications, and of two Prize Paper Awards at conferences. He is a former Associate Editor for the IEEE Transactions on Industry Applications (from 2011 until 2014) and the IEEE Transactions on Power Electronics (from 2013 until 2019). He was an international program committee vice chair of the IFAC conference on Nonlinear Model Predictive Control in Madison, WI, USA, in 2018. Dr. Geyer is a Distinguished Lecturer of the IEEE Power Electronics Society in the years 2020 and 2021. He has been an IEEE Senior Member since 2010.

Petros Karamanakos received the Diploma and the Ph.D. degrees in electrical and computer engineering from the National Technical University of Athens (NTUA), Athens, Greece, in 2007, and 2013, respectively.

From 2010 to 2011 he was with the ABB Corporate Research Center, Baden-Dättwil, Switzerland, where he worked on model predictive control strategies for medium-voltage drives. From 2013 to 2016 he was a PostDoc Research Associate in the Chair of Electrical Drive Systems and Power Electronics, Technische Universität München, Munich, Germany. Since September 2016, he has been an Assistant Professor in the Faculty of Information Technology and Communication Sciences, Tampere University, Tampere, Finland. His main research interests lie at the intersection of optimal control, mathematical programming, and power electronics, including model predictive control for power electronic converters and ac drives.

Dr. Karamanakos received the 2014 Third Best Paper Award of the IEEE Transactions on Industry Applications and two Prize Paper Awards at conferences. He serves as an Associate Editor of the IEEE Transactions on Industry Applications and the IEEE Open Journal of Industry Applications. He has been an IEEE Senior Member since 2019.