Tutorial at EPE 2019

Model Predictive Control of Power Converters: Principle, Design and Applications

NAME AND AFFILIATION OF THE LECTURERS

- **Ralph Kennel**, Department of Electrical and Computer Engineering, Technical University of Munich, Munich, Germany
- **José Rodríguez**, Faculty of Engineering, Universidad Andres Bello, Santiago, Chile
- **Tomislav Dragičević**, Department of Energy Technology, Aalborg University, Aalborg, Denmark
- **Mateja Novak**, Department of Energy Technology, Aalborg University, Aalborg, Denmark
- **Tobias Geyer**, ABB Corporate Research, Baden-Dättwil, Switzerland

OBJECTIVES

Model Predictive Control (MPC) is a conceptually simple yet powerful methodology to control power converters and electric drives. It has gained a lot of attention in recent years in power electronics applications for the following reasons:

- Very intuitive and easy to understand concept
- Applicable to a great variety of systems
- Easy inclusion of nonlinearities in the model and compensation of dead times
- Simple treatment of constraints

Moreover, it has many advantages over traditional linear controllers including:

- Faster response
- High robustness to parameter variations
- Explicit multivariable control accounting for the process and actuator constraints.

The advances in processing power of digital signal processors have recently promoted MPC into the first commercial applications, which opened a door towards improved performance and efficiency of power electronic converters and drives demanded by the evolving industry applications. Although the MPC algorithms were successfully implemented, the analytically verification of the algorithm's performance and robustness, and design of the weighting factors of the cost function are still one of the open research questions. In this tutorial we will also present two approaches for these problems: an artificial neural networks aided weighting factor design and a performance verification of the predictive controller using the statistical model checking method.

The participants of this tutorial will learn about:

- The basic concepts and ideas about controller design
- Different types of predictive controllers
- Design of predictive controllers for different converter topologies and applications like drives, DC and AC microgrids
- Performance verification of the predictive controller using statistical model checking
- Predictive control of optimized pulse patterns

AUDIENCE

This tutorial is intended for graduate students, practicing engineers, and researchers with interests in the model predictive control design for power electronics converters.

TECHNICAL LEVEL

The technical level of this tutorial will be intermediate. However, beginners with a fundamental knowledge of power electronics and control systems can also follow.

OUTLINE

Part 1: Model predictive control (MPC) in power electronics (45min, R. Kennel)

a) Introduction
b) Classification of predictive control
    a. Trajectory based predictive control
    b. Hysteresis based predictive control
    c. Long-range predictive control
c) Principles of model predictive control

Part 2: Application of MPC to different converter topologies (60min, J. Rodríguez)

a) Current control of a three-phase inverter
b) Power control of an AFE
c) Control of an NPC converter
d) Control of a matrix converter
e) Spectrum control
f) Voltage control of a UPS

Part 3: Predictive control applied to motor drives (60min, J. Rodríguez)
a) Field oriented control using predictive current control
b) Predictive torque control
c) Predictive speed control

Part 4: Application of MPC to microgrids (60min, T. Dragičević)
a) Application of MPC to improve the performance of AC microgrids
b) Application of MPC to improve the performance of DC microgrids
c) Artificial neural network aided weighting factor design

Part 5: MPC based on optimized pulse patterns (60min, T. Geyer)
a) Optimized pulse patterns
b) Model predictive pulse pattern control
c) Experimental results for medium-voltage drives

Part 6: Finite control set (FCS) MPC with long prediction horizons (60min, T. Geyer)
a) Control algorithm based on sphere decoding
b) Performance evaluation for NPC converter applications
c) Recent advances

Part 7: Performance verification of FCS-MPC (45min, M. Novak)
a) Introduction to timed-automata (TA) and statistical model checking approach
b) Modelling the system using the TA networks
c) Performance verification of the FCS-MPC controlled power electronics converters

PROVISIONAL SCHEDULE

09:30 – 10:15 Part 1: Model predictive control (MPC) in power electronics (R. Kennel)
10:15 – 11:15 Part 2: Application of MPC to different converter topologies (J. Rodríguez)
11:15 – 11:30 *Coffee break*
11:30 – 12:30 Part 3: Predictive control applied to motor drives (J. Rodríguez)
12:30 – 13:00 Part 4: Application of MPC to microgrids (T. Dragičević)
13:00 – 14:00 *Lunch break*
14:00 – 14:30 Part 4: Application of MPC to microgrids (continued) (T. Dragičević)
14:30 – 15:30 Part 5: MPC based on optimized pulse patterns (T. Geyer)
15:30 – 15:45 *Coffee break*
15:45 – 16:45 Part 6: Finite control set MPC with long prediction horizons (T. Geyer)
16:45 – 17:30 Part 7: Performance verification of FCS-MPC (M. Novak)

ABOUT THE INSTRUCTORS

Ralph M. Kennel was born in 1955 at Kaiserslautern (Germany). In 1979 he got his diploma degree and in 1984 his Dr.-Ing. (Ph.D.) degree from the University of Kaiserslautern. From 1983 to 1999 he worked on several positions with Robert BOSCH GmbH (Germany). Until 1997 he was responsible for the development of servo drives. Dr. Kennel was one of the main supporters of VECON and SERCOS interface, two multi-company development projects for a microcontroller and a digital interface especially dedicated to servo drives. Furthermore, he took actively part in the definition and release of new standards with respect to CE marking for servo drives.

Between 1997 and 1999 Dr. Kennel was responsible for "Advanced and Product Development of Fractional Horsepower Motors" in automotive applications. His main activity was preparing the introduction of brushless drive concepts to the automotive market.

From 1994 to 1999 Dr. Kennel was appointed Visiting Professor at the University of Newcastle-upon-Tyne (England, UK). From 1999 - 2008 he was Professor for Electrical Machines and Drives at Wuppertal University (Germany). Since 2008 he is Professor for Electrical Drive systems and Power Electronics at Technische Universitaet Muenchen (Germany). His main interests today are: Sensorless control of AC drives, predictive control of power electronics and Hardware-in-the-Loop systems.

Dr. Kennel is a Senior Member of IEEE, a Fellow of IET (former IEE) and a Chartered Engineer in the UK. Within IEEE he was Treasurer of the Germany Section as well as Region 8 – furthermore he has been Distinguished Lecturer of the Power Electronics Society (IEEE-PELS). Dr. Kennel has received in 2013 the Harry Owen Distinguished Service Award from IEEE-PELS as well as the EPE Association Distinguished Service Award in 2015.

Dr. Kennel was appointed “Extraordinary Professor” by the University of Stellenbosch (South Africa) from 2016 to 2019 and as “Visiting Professor” at the Haixi Institute by the Chinese Academy of Sciences from 2016 to 2021. There he was appointed as "Jiaxi Lu Overseas Guest Professor" in 2017. In 2018 Dr. Kennel was appointed Guest Professor at Harbin Institute of Technology (HIT), Harbin, China.

José Rodríguez (M'81-SM'94-F'10) received the Engineer degree in electrical engineering from the Universidad Tecnica Federico Santa Maria, in Valparaiso, Chile, in 1977 and the Dr.-Ing. degree in electrical engineering from the University of Erlangen, Erlangen, Germany, in 1985. He has been with the Department of Electronics Engineering, Universidad Tecnica Federico Santa Maria, since 1977, where he was full Professor and President. Since 2015 he is the President of Universidad Andres Bello in Santiago, Chile. He has coauthored two books, several book chapters and more than 400

journal and conference papers. His main research interests include multilevel inverters, new converter topologies, control of power converters, and adjustable-speed drives. He has received a number of best paper awards from journals of the IEEE. Dr. Rodriguez is member of the Chilean Academy of Engineering. In 2014 he received the National Award of Applied Sciences and Technology from the government of Chile. In 2015 he received the Eugene Mittelmann Award from the Industrial Electronics Society of the IEEE.

Tomislav Dragičević (S'09-M'13-SM'17) received the M.Sc. and the industrial Ph.D. degrees in Electrical Engineering from the Faculty of Electrical Engineering, Zagreb, Croatia, in 2009 and 2013, respectively. From 2013 until 2016 he has been a Postdoctoral research associate at Aalborg University, Denmark. From March 2016 he is an Associate Professor at Aalborg University, Denmark where he leads an Advanced Control Lab.
He made a guest professor stay at Nottingham University, UK during spring/summer of 2018. His principal field of interest is design and control of microgrids, and application of advanced modeling and control concepts to power electronic systems. He has authored and co-authored more than 155 technical papers (more than 70 of them are published in international journals, mostly IEEE Transactions) in his domain of interest, 8 book chapters and a book in the field.
He serves as Associate Editor in the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, in IEEE Emerging and Selected Topics in Power Electronics and in IEEE Industrial Electronics Magazine. Dr. Dragičević is a recipient of the Končar prize for the best industrial PhD thesis in Croatia, and a Robert Mayer Energy Conservation award.

Mateja Novak received the M.Sc. degree in Electrical Engineering and Information Technology from Zagreb University, Croatia, in 2014. Until 2016 she was working as a Research Associate at the Faculty of Electrical Engineering and Computing in Zagreb on advanced technologies in power plants and rail vehicles project. She is currently working toward the Ph.D. degree in power electronics at Aalborg University, Denmark. Her research interests include finite control set model predictive control, multilevel converters, statistical model checking and renewable energy systems.

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, and another three years at the University of Auckland, Auckland, New Zealand. In 2012, he joined ABB's Corporate Research Centre, Baden-Dättwil, Switzerland, where he is currently a Senior Principal Scientist for power conversion control. He was appointed as an Extraordinary Professor at Stellenbosch University, Stellenbosch, South Africa, from 2017 to 2020.

He is the author of more than 120 peer-reviewed publications, 30 patent applications, 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 model predictive control, variable speed drives and utility-scale power converters.

Dr. Geyer is the recipient of four prize paper awards, including the 2018 First Place Prize Paper Award of the Transactions on Power Electronics. He served as an Associate Editor for the Transactions on Industry Applications. Since 2013 he has been serving as an Associate Editor for the Transactions on Power Electronics. He was an international program committee vice chair of the IFAC conference on Nonlinear Model Predictive Control in Madison, WI, USA, in 2018.