Multi-sampling control of power electronic converters

Name(s) and Affiliation(s) of the Lecturer(s):

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Tutorial Objectives:

Increasing the integration of renewables has been regarded as a critical pathway to de-carbonize the power system. As a bridge between the renewables and the power grid, power electronic converters are of importance to achieve efficient and reliable power conversion. Digital control is the most commonly used technology in power electronic converters due to its flexibility and adaptability. Nevertheless, for the regular single/double-sampling PWM-based control, significant control delay is introduced in the control loop. This control delay affects the achievable control bandwidth, stability margins, and overall dynamic performance.

With the gradually decreasing cost of high-performance microprocessors, multi-sampling control is a potential candidate to overcome the above-mentioned limitations. It relies on sampling the state variable and updating the duty cycle command multiple times within one switching period. As the control delays are inversely proportional to the sampling rate, multi-sampled control can enable dynamic performance close to the one obtained with analog control, for high-enough sampling rate. As a result, multi-sampling has been widely used to improve the control bandwidth of power electronic converters, including dc–ac converters, dc–dc converters, and motor drives. A particularly attractive and emerging application for multi-sampling PWM is within grid-connected converters. Due to delay reduction, multi-sampling PWM can inherently bring the required damping and help passivize the converter impedance in a wide frequency range, thus enabling robust stability.

Besides the average value, the switching ripple is always introduced in the control loop when using multi-sampling, which is the main difference compared to the regular sampling. This brings a set of nonlinearities caused by the vertical crossings between the carrier and the modulating signal. Some effects that may consequentially arise and that must be handled are multiple-switching, pulse-skipping, gain-reduction, and limit-cycle oscillations (jittering). Moreover, aliasing issues may appear. This all motivates the design of suitable digital filters needed to suppress or completely remove the arising nonlinear effects.

To fully utilize the benefits of multi-sampling in a practical application, the objectives of this tutorial will include multi-sampled PWM modeling, non-linearity analysis, ripple filter design, noise attenuation capabilities, and passivity-based multi-sampled control of grid-connected VSCs.

Target Audience:

This tutorial will be beneficial for academic and industrial researchers who are active in control of power converters with fast and robust performance, especially using high-performance micro-processors in low-pulse ratio converters.

Topical Outline:

Introduction: (Estimated time: 30 mins)

- Introduction, part 1 (Frede Blaabjerg, 30 mins)
  - Renewable energy and power electronics

Real Tutorial, Introduction of multi-sampling control and its applications (50 mins)

- Subject 1 (Paolo Mattavelli, 50 mins)
  - Review of small-signal modeling and design of digital control in power electronics
  - Small-signal modeling of multi-sampling
  - Multi-sampling applications
  - Nonlinearities caused by modulating waveform discontinuities

Real Tutorial, Switching ripple analysis and noise attenuation capabilities of multi-sampled PWM (Estimated time: 50 mins)

- Subject 1 (Shan He, 20 mins)
  - Aliasing analysis
  - Ripple filter design
- Subject 1 (Ivan Petric, 30 mins)
  - Propagation modeling and suppression of measurement noise
  - Switching noise sensitivity and its suppression

Real Tutorial, Passivity-based multi-sampling control of grid-connected VSCs (Estimated time: 50 mins)

- Subject 1 (Ivan Petric, 20 mins)
  - Passivity-based control without ripple filters and comparison with active-damping
- Subject 2 (Shan He, 30 mins)
  - Passivity-based control with ripple filters
  - Multi-sampled real-time-update PWM

Summary and discussion (Estimated time: 15 mins)

Provisional Schedule of the Tutorial:

Schedule:
09:30 - 10:00 : Introduction
10:00 - 10:50 : Introduction of multi-sampling control and its applications
10:50 - 11:05 : Coffee break
11:05 - 11:55 : Switching ripple analysis and noise attenuation capabilities of multi-sampled PWM
11:55 - 12:45 : Passivity-based multi-sampling control of grid-connected VSCs
12:45- 13:00 : Summary and discussion

About the Lecturers:

Shan He (Member, IEEE) received the B.S. degree from Northeast Electric Power University, Jilin, China, in 2015, the M.S. degree from Zhejiang University, Hangzhou, China, in 2018, and the Ph.D. from Aalborg University, Aalborg, Denmark, in 2022, all in electrical engineering.

He is currently a Postdoc Fellow with the Department of Energy, Aalborg University. From October to December 2021, he was a visiting researcher with Institute for Power Generation and Storage Systems, RWTH Aachen University, Aachen, Germany. His research interests include modeling and control of grid-connected converters especially using multi-sampling, and power converters in Power-to-X.

Ivan Petric (Member, IEEE) received the B.S. and M.S. degrees from the University of Belgrade, Serbia, in 2017 and 2018, respectively, and the Ph.D. degree from the University of Padova, Italy, in 2022, all in electrical engineering.

He is currently with the Electric Hydrogen Co., California, USA. From 2018 to 2019, he was a Researcher with the Power Electronics, Machines and Control (PEMC) Group, The University of Nottingham, Nottingham, U.K. In 2022, he was a Visiting Researcher with the Electrical Engineering and Computer Sciences (EECS) Department, University of California, Berkeley, CA, USA. His research interests include modeling and digital control of power converters, grid-connected converters for renewable energy sources and smart microgrids, and electrical drives.

Frede Blaabjerg (Fellow, IEEE) was with ABB-Scandia, Randers, Denmark, from 1987 to 1988. From 1988 to 1992, he got the PhD degree in Electrical Engineering at Aalborg University in 1995. He became an Assistant Professor in 1992, an Associate Professor in 1996, and a Full Professor of power electronics and drives in 1998 at AAU Energy. His current research interests include power electronics and its applications such as in wind turbines, PV systems, reliability, harmonics and adjustable speed drives.

He has received 38 IEEE Prize Paper Awards, the IEEE PELS Distinguished Service Award in 2009, the EPE-PEMC Council Award in 2010, the IEEE William E. Newell Power Electronics Award 2014, the Villum Kann Rasmussen Research Award 2014, the Global Energy Prize in 2019 and the 2020 IEEE Edison Medal. He was the Editor-in-Chief of the IEEE TRANSACTIONS ON POWER ELECTRONICS from 2006 to 2012. He has been Distinguished Lecturer for the IEEE Power Electronics Society from 2005 to 2007 and for the IEEE Industry Applications Society from 2010 to 2011 as well as 2017 to 2018. In 2019-2020 he served as a President of IEEE Power Electronics Society. He has been Vice-President of the Danish Academy of Technical Sciences.

Paolo Mattavelli (Fellow, IEEE) received the M.S. (Hons.) and Ph.D. degrees in electrical engineering from the University of Padova, Padova, Italy, in 1992 and 1995, respectively. . Since 1995 he has had faculty positions at the Universities of Padova (Italy), Udine (Italy) and from 2010 and 2012 at Virginia Tech (USA) , as professor and member of the Center for Power Electronics Systems (CPES). He is currently a Full Professor with the University of Padova. His current Google scholar H-index is 83. His major research interests include analysis, modeling, and analog and digital control of power converters, grid-connected converters for renewable energy systems and microgrids, and high-temperature and high-power-density power electronics. Dr. Mattavelli was an Associate Editor for the IEEE Transactions on Power Electronics from 2003 to 2012. He is a Co-Editor-in-Chief for the IEEE Transactions on Power Electronics. From 2005 to 2010, he was the Industrial Power Converter Committee Technical Review Chair for the IEEE Transactions on Industry Applications. For terms 2003-2006, 2006-2009, and 2013-2015, he was a member-at-large of the IEEE Power Electronics Society's Administrative Committee.