MACHINE LEARNING TECHNIQUES FOR RELIABLE BATTERY STATE OF HEALTH ESTIMATION

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

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Scope and Benefits:

Lithium-ion batteries have become a commodity in our daily routine, powering portable electronic devices and electric vehicles, and facilitating renewables' grid-integration. Nevertheless, the performance of lithium-ion batteries is degradaing during long-term usage. Thus, accurately obtaining the batteries' state of health (SOH) is critical to prolong the service life of the battery and ensure the safe and reliable operation of the system. Machine learning (ML) techniques are gaining widespread use in the field of electrical engineering as a whole, and for SOH estimation of Lithium-ion batteries in particular. The introduction of ML and statistics in electrical engineering is a consequence of the field slowly subsidising some of the more expensive laboratory testing by using data collected during real-life operating conditions. The main purpose of this tutorial is to provide the audience with a basic understanding of how ML can be applied to ensure reliable and efficient battery SOH estimation.

Contents:

The tutorial will start with a brief overview of the Lithium-ion battery storage technology, its operating principles, characteristics, advantages, limitations, and latest developments. Furthermore, an important part of the tutorial will be dedicated to the battery performance parameters (e.g., capacity, resistance), which are traditionally related to the battery SOH, and their degradation during operation at various conditions (temperature, load current, number of cycles, idling time etc.). This part will conclude with the need of reliable battery SOH estimation algorithms. The second part of the tutorial will start with an overview of ML methods and will continue with key aspects related to predictive modeling and model validation focusing on quantitative predictive models for Li-ion battery SOH estimation. The models will include sequential and non-sequential approaches, univariate and multivariate outcomes, and Bayesian frameworks. Finally, the third part of the tutorial will focus on

battery SOH estimation using ML methods. Aspects of battery feature (health indicators) reduction are introduced using techniques such as principal component analysis and partial least squares. The performance of various ML methods for battery SOH estimation (i.e., neural networks, support vector regression, ensemble learning) will be discussed, along with parametrization approaches and challenges.

Schedule:

Friday, 9 September 2022 - 2nd Tutorial Day - Morning

09:30 - 10:10 **PART I: Lithium-ion batteries – performance and degradation (40 minutes)**

- Lithium-ion batteries – status, challenges, and applications
- Performance parameters and their behavior
- What is battery SOH?
- Why do we need battery SOH estimation?

10:10 – 11:00 **PART II: Machine Learning Techniques and Bayesian statistics (60 minutes)**

- Overview of machine learning methods.
- The bias-variance trade-off and cross validation
- Bayesian statistics and sequential model updating
- Auto-regressive models, Kalman-filtering, and state intervention for SOH estimation.

11:00 - 11:30 **Coffee break**

11.30 - 13:00 **PART III: Battery SOH Estimation using Machine Learning (60 minutes)**

- Feature dimensionality reduction using principle components analysis and auto-encoders.
- Feature selection using subset selection, partial least squares, and shrinkage methods.
- Support vector regression, Gaussian process regression, and neural networks.
- Boosting, ensemble learning, and interpreting black-box methods.

13:00 - 14:00 Lunch break (Optional – if ordered)

Who should attend:

The targeted participants are 1) university researchers who are interested in battery state of health estimation and application of machine learning for this purpose; 2) university researchers who are interested in the application of machine learning in various electrical engineering fields; 3) industry battery system designers and developers who would like to have better understanding about battery SOH and its estimation throughout machine learning techniques.

Technical Level:

Technical Level: beginner – intermediate; basic knowledge in batteries and machine learning represent an advantage for following the tutorial

About the Lecturers:

Daniel-Ioan Stroe received the Dipl.-Ing. degree in automatics from "Transilvania" University of Brasov, Romania, in 2008, and M.Sc. degree in wind power systems from Aalborg University, Aalborg, Denmark, in 2010. He has been with AAU Energy, Aalborg University since 2010, from where he obtained his Ph.D. degree in lifetime modeling of Lithium-ion batteries in 2014. He is currently an Associate Professor with AAU Energy and the leader of the Batteries research group. He was a Visiting Researcher with RWTH Aachen, Germany, in 2013. He has co-authored one book and over 150 scientific peer-review publications most of them in topics related to Lithium-ion battery performance and lifetime modeling and battery state estimation. Furthermore, he is serving as a special issue editor and topic editor for various journals. Daniel current research interests are in the area of energy storage systems for grid and e-mobility, Lithium-based batteries testing and modeling, and lifetime estimation and diagnostics of Lithium-ion batteries.

Søren B. Vilsen recieved his B.Sc. degree in mathematics in 2013, his M.Sc. degree in applied mathematics in 2015, and his Ph.D. degree in statistics in 2018 from Aalborg University, Aalborg, Denmark. He is currently an Assistant Professor with the Department of Mathematical Sciences working closely with the Batteries research group at AAU Energy. His current research interests are statistical learning, evolutionary computation, deep learning, and sequential models with application to Lithium-based battery state estimation and lifetime prediction.

Xin Sui received the B.Eng. degree from Northeast Electric Power University, Jilin, China, in 2015, and the M.Sc. degree in from Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing, China, in 2018, both in electrical engineering. In 2022, Xin received the Ph.D. degree in machine learning for battery state of health estimation from Aalborg University, Aalborg, Denmark. She is currently a postdoctoral researcher with the Center for Research on Smart Battery (CROSBAT), AAU Energy, Aalborg University. Her research interests include battery state of health estimation, lifetime extension, and machine learning.