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IECON 2022 Tutorial Proposal

- **Title of the Proposal:** Advanced AI/ML/IoT Techniques for Battery Management and Fast Charging Systems for Transportation Electrification and E-mobility

- **Presenter(s):** Akash Samanta, *Student Member*, *IEEE*, and Sheldon Williamson, *Fellow*, *IEEE*, Department of Electrical, Computer and Software Engineering, Ontario Tech University, Oshawa, ON, Canada

- **Brief description:** Transportation electrification is the need of the day to mitigate environmental pollution and the shortage of fossil fuels, typically used in transportation sector. Energy storage systems are an integral component of e-transportation as it largely determines their performance and commercial viability. Regarding this, lithium-ion batteries (LIBs) are widely preferred for due to their high energy density, high power density, longer cycle life, and low self-discharge rate. However, the internal characteristics of LIB are highly nonlinear and extremely sensitive to the operating and environmental parameters. Moreover, one single cell can only supply a very small amount of voltage and power thus hundreds and thousands of individual cells are connected in series and parallel to obtain the required amount of voltage and current to drive the e-power train. Apart from nonlinearities, every cell is slightly different in characteristics and their aging profiles are also different. Therefore, an effective battery management system (BMS) is a must for all high-power applications of LIB packs like electric vehicles to ensure optimum capacity utilization and operational safety. To that BMS not only monitors the external battery parameters and estimates different battery states, but it also performs cell balancing, thermal management, and predictive maintenance alerts. Ineffective battery management leads to fire and catastrophic failure. Now, as the characteristics of each cell are different and subject to different aging thus it is necessary to monitor each cell within a battery pack. However, as mentioned before that the high-power battery packs consist of many series and parallel connected cells thus monitoring each cell with physical sensors is not practically feasible. Moreover, states like state of charge, state of health, and remaining useful life cannot be directly measured with physical sensors. Thus, several estimation techniques are introduced by researchers. However, with the revolution of data-driven techniques and advancement of micro-computers, data-driven artificial intelligence (AI) and machine learning (ML) techniques standout recently. Therefore, it is worthwhile to discuss the AI and ML techniques and recent developments in the context of BMS. It is well-known that the data is the backbone of any AI and ML-based techniques thus collecting the historical and present operational data is extremely important. Furthermore, collecting high-resolution data and data processing in real-time needs the internet of things (IoT) for accessing advanced platforms such as cloud computing and cloud data storage. With the integration of IoT in BMS, the possibility of the concept of connected vehicles and application of EVs as grid-tied distributed energy storage systems for demand-side management could also be possible. Where BMS will provide the necessary state information to the grid aggregator over the IoT platform.

  The range anxiety and the long waiting time to recharge the battery pack are among the primary barriers to the wide adoption of electric vehicles. Recently with the introduction of fast charging techniques for LIBs, the issue is minimized to a significant extent. Now to ensure the safety with fast chargers requires advance BMS that demands superfast data acquisition, processing and control, and very accurate and precise state estimation. Here the advanced AI and ML techniques with low computational cost and the application of digital twin technology will play a vital role.

Therefore, it is worth discussing the advanced AI, ML, IoT, and Digital Twin technologies in detail for optimum battery uses ensuring ultimate safety. That will eventually encourage the wide adoption of electric vehicles and the development of the e-transportation industry. In addition, the recent research and developments, current issues, and challenges that industry and researchers are facing will be discussed to highlight the way forward towards developing industry ready BMS and fast chargers. Finally, examples of practical BMS and testing facilities will be shown to encourage further research and developments for real-world EV applications.

- **Duration:** 3.5 Hours

- **Outline:**

Sl. No.	Topics	Subtopics
1	Overview of BMS and fast charging techniques for e-transportation and the latest developments	➢Definition of the BMS ➢Purpose of BMS ➢Typical components of BMS ➢Working of BMS ➢ Safety features of BMS ➢Recent research and developments on BMS ➢Overview of different charging techniques ➢Different standards and protocols of charging ➢Drawbacks of conventional charging techniques ➢ Fast charging techniques, standards, and protocols ➢ Recent development in fast charging techniques
2	Application of AI and ML in BMS including current issues and challenges	➢Overview of AI and ML in the context of BMS ➢ Introduction to data-driven battery state estimation techniques for BMS ➢Application of AI and ML in the state estimation of lithium-ion batteries ➢Advantages of using AI and ML-based state estimations in BMS ➢Introduction to AI and ML-based smart controls in BMS ➢Recent advancements like deep learning, extreme learning, and their applications on BMS ➢Current issues and challenges in the AI and ML-based techniques and future research scopes
3	Application of IoT and Digital Twin technologies towards industry ready BMS including future research trends	➢Introduction to IoT ➢Components of IoT in the context of BMS ➢Importance of integrating IoT in BMS for e-transportation ➢Recent developments and application of IoT in BMS in the domain of e-transportation ➢Overview of digital twin technology ➢Application of digital twin in BMS ➢Recent research and developments of digital twin technologies for BMS ➢Research trends in IoT and digital twin technologies for BMS in the e-transportation domain

4	Practical examples of design, testing, and development of BMS for real-world EV applications	➢Discussion on a few practical BMS and its design aspects ➢Necessary testing facilities ➢Example of a few real-world developments and ongoing research and developments in our laboratory

- **Motivation and Focus:** With the increasingly stringent requirements of safety standards in the e-transportation domain, accurate and real-time information on battery parameters and states is a must. Among several other energy storage technologies, lithium-ion batteries (LIBs) are widely used in e-transportation due to their high energy density, high power density, longer cycle life, and low self-discharge rate. However, the characteristic of LIB is highly nonlinear and subject to changes with aging and changes in environmental parameters such as temperature and vibration. Therefore, conventional equivalent electric circuit models, equivalent electrochemical models, and numerical models for state estimation are not accurate enough. Moreover, it is very challenging to develop adaptive models. Here, data-driven AI and ML-based techniques are preferred as those could be designed flexibly and adaptive to operational and environmental changes. The effectiveness of data-driven techniques entirely depends on the large volume of historic and present data. Several AI and ML techniques are available in the literature. However, the test data from cell manufacturers are not usually presented to the researchers and final product-making industries in the e-transportation domain due to confidentiality. Therefore, an in-depth discussion on the recent developments, current issues, and challenges in the application of AI and ML in practical BMS is the need for the data instead of focusing on developing new techniques. Acquisition and processing the high-resolution data in real-time by the low capacity onboard are some of the other challenges. Here, IoT and other advanced technologies like cloud computing and storage will play a vital role. Thus, discussing the available IoT technologies and more so the feasibility of it will be covered in sufficient detail. Furthermore, with the application of digital twin technologies, it is possible to have the solutions for battery digital modeling, real-time state estimation, dynamic charging control, dynamic thermal management, and dynamic equalization control in the intelligent battery management system. Therefore, the opportunities of applying the digital twin technology in the domain of LIB management will be discussed. To speed up the switching from conventional fossil fuel-based transportation to e-transportation, the range anxiety must need to be minimized. Here, fast charging technology is playing a vital role. A detailed concussion of the present technologies and especially the issues and challenges that are bottlenecking the developments is to be covered to provide a way forward towards developing industry-ready advanced BMS. Several practical examples of BMS, industry standards, and testing facilities will be shown to encourage more research and developments in the focused field.

- **Short CV of the Presenter(s):**

Akash Samanta (*Student Member, IEEE*) received B. Tech degree (1st class) in Electrical Engineering from the West Bengal University of Technology in 2012 and M. Tech (1st class) and MBA degree in Electrical Engineering and Energy Management from the University of Calcutta in 2018 and 2014 respectively. Formerly, he was appointed as Project Officer and Solar Energy Master Trainer in the Department of Energy Management, Indian Institute of Social Welfare and Business Management, Kolkata, India. He is currently a Doctoral Research Scholar with the Department of Electrical, Computer and Software Engineering, Ontario Tech University, Oshawa, ON, Canada. His research interest includes electric energy storage systems, battery management systems, power electronics converters, and the application of machine learning and artificial intelligence in the related field.

Sheldon Williamson (Fellow, IEEE) received the B.E. degree (Hons.) in electrical engineering from the University of Mumbai, Mumbai, India, in 1999, and the M.S. and Ph.D. degrees (Hons.) in electrical engineering from the Illinois Institute of Technology, Chicago, IL, USA, in 2002 and 2006, respectively. He is currently a Professor with the Department of Electrical, Computer and Software Engineering and the Director of Smart Transportation Electrification and Energy Research (STEER) Group, Faculty of Engineering and Applied Sciences, Ontario Tech University, Oshawa, ON, Canada. His current research interests include advanced power electronics, electric energy storage systems, and motor drives for transportation electrification. He holds the prestigious NSERC Canada Research Chair position in electric energy storage systems for transportation electrification.

- **Relevant publications:**

[1] S. Surya, A. Samanta, V. Marcis and S. Williamson, "Hybrid Electrical Circuit Model and Deep Learning-based Core Temperature Estimation of Lithium-ion Battery Cell," (early access) in *IEEE Transactions on Transportation Electrification*, May 2022.

[2] L. Patnaik, A. V. J. S. Praneeth and S. S. Williamson, "A Closed-Loop Constant-Temperature Constant-Voltage Charging Technique to Reduce Charge Time of Lithium-Ion Batteries," in *IEEE Transactions on Industrial Electronics*, vol. 66, no. 2, pp. 1059-1067, Feb. 2019.

[3] P. A. Cassani and S. S. Williamson, "Design, Testing, and Validation of a Simplified Control Scheme for a Novel Plug-In Hybrid Electric Vehicle Battery Cell Equalizer," in *IEEE Transactions on Industrial Electronics*, vol. 57, no. 12, pp. 3956-3962, Dec. 2010.

[4] M. S. Sidhu, D. Ronanki and S. Williamson, "State of Charge Estimation of Lithium-Ion Batteries Using Hybrid Machine Learning Technique," *IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society*, 2019, pp. 2732-2737.

[5] M. S. Sidhu, D. Ronanki and S. Williamson, "Hybrid State of Charge Estimation Approach for Lithium-ion Batteries using k-Nearest Neighbour and Gaussian Filter-based Error Cancellation," *2019 IEEE 28th International Symposium on Industrial Electronics (ISIE)*, 2019, pp. 1506-1511.