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Mini Review

AI Technology for More Reliable Lithium-Ion Battery in Propulsion System of Electric Aircraft

Tahmineh Raoofi[1] and Melih Yildiz[2]*

[1]Department of Industrial Engineering, Eastern Mediterranean University, Turkey

[2]Faculty of Aviation and Space Sciences, Erciyes University, Turkey

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***Corresponding author:** Melih Yildiz, Faculty of Aviation and Space Sciences, Erciyes University, Turkey

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Abstract

Utilizing electrochemical energy storage (batteries) as a main unit of the propulsion system in electric aircraft is expected to be the dominant technology that offers more efficient and cleaner operation. Specifically, Lithium-Ion Batteries (LIB) capable of providing higher energy density and power at a lower cost are the most probable candidate to serve as a source of energy in the Electric Propulsion System (EPS). However, the safety, reliability, and durability of LIB is still controversial. Due to influences associated with design, production and adverse operational conditions, LIB safety might not be assured. To solve this deficiency and enhance safety, Battery Management System (BMS) is designed to monitor battery status and control its safe operation via measurement of the current, voltage and temperature at the cell, module and pack level. Smart BMS leverages a data-driven approach and artificial intelligence in which the battery's internal dynamics is not directly considered can accurately estimate the battery states and implement robust control strategies. However, applying AI techniques such as machine learning and neural networks in BMS involves key challenges. The research aims to review the challenges of smart BMS and identify the research gaps to improve battery safety and reliability.

Keywords: Electric propulsion system; Lithium-ion battery; Battery reliability; Battery management system; State estimation; Artificial Intelligence

Abbreviations: AI: Artificial Intelligence; BMS: Battery Management System; EPS: Electric Propulsion System; LIB: Lithium-Ion Battery; PHM: Prognostics and Health Management; SoH: State of Health; TMS: Thermal Management System

Introduction

The safe and reliable operation of LIB is a direct function of operational and environmental conditions [1,2]. BMS is a vital component in monitoring, measuring, and estimating the battery status, and developing control commands with the aim of limiting the battery in a safe operational window [3,4]. Figure 1 shows a topology of X*Y battery cells and BMS functions including state estimation, health management, fault diagnostics, cell balancing, and thermal management system [5]. To produce an adequate level of power and energy as a source of electric propulsion, hundreds to thousands of cells need to be connected in series and parallel. Each battery cell failure might lead to the over-discharge of other battery cells and their aging, which deteriorates the health of the battery module and the overall reliability of the battery pack [5]. Therefore, BMS at a cell level measure and monitor battery performance. There are different methodologies for battery management and state estimation designed and implemented such as physics-based, model-based, and data-driven approaches [6]. Nonetheless for the implemented method, specifically in battery management of electric aircraft propulsion system, adopting robust techniques, is not that much straight forward in practice. To clarify, methods in which long-time processes are required, such as internal resistance measuring as a sign of the State of Health (SOH) could not fit electric propulsion application [7].

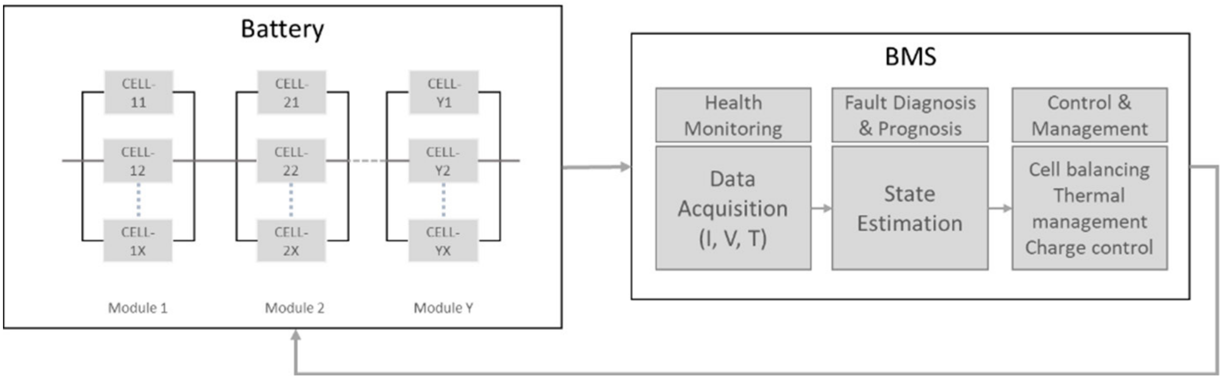

Figure 1: Battery cell connection topology (adopted from [5]) and BMS functions.

On the other hand, the model-based approach, using an electrochemical or Equivalent Circuit Model (ECM), has its own disadvantages. Regarding ECM, various SOH, different charge and discharge rates, and aging effects after high cycling are not considered [8,9]. Consequently, the data-driven approach is recommended to solve experimental problems and inaccuracies of the process [8]. A data-driven approach based on AI can map the nonlinear performance of the battery and accurate estimation its status [9]. In addition, battery management utilizing intelligent approaches will result in more accuracy, independent of battery model, better and it is less sensitive to system noise [9]. However, to implement the idea of intelligent BMS in an EPS, a variety of uncertainties including diversity of data, complexity of computation [10] and less developed airworthiness requirements should be first overcome. In the next section summary of the required consideration of AI in BMS of EPS is discussed.

Specific features and challenges of AI strategies in BMS of future EPS

As mentioned before, many benefits are involved in employing data-driven approaches using intelligent algorithms in BMS. However, the disadvantages including dependency on sample training, complexity of computation and time-consuming processes [9], should be taken into consideration to the benefit of safety and reliability of EPS. Based on performed analysis of existing works in the field of application of intelligent approaches in BMS performed by Raoofi T and Yildiz M [11], the specific features and challenges for next generation of EPS are stated as following.

Battery will work in real condition: In the process of developing and training of sample data, broader environmental circumstances including different range of temperature, levels of noise, electromagnetic interference, and battery degradation is vital [12].

Onboard learning is essential for EPS state estimation: There should be a compromise between online data training for state estimation so that model parameters are being updated in accordance with changes in environmental and operational conditions and computational time.

Precise and accurate state estimation: In accordance with the analyzed literature, utilizing hybrid algorithms as an alternative of a single process, merging intelligent techniques with efficient optimal estimators such as filters [13]and finally, co-estimation in which more than one estimation is performed, will enhance the BMS performance in an accurate manner with less error.

Big data as data source: Utilizing big data technology, AI will be reinforced by large data and memory devices to facilitate the computation and analysis. Therefore, acquired data from battery continuously communicated to the platform of big data, so that real data will be trained in using online tests and will provide more accurate results [10] so state estimation and battery reliability will be improved.

Reliable sensing needs accurate sensors: Progress in designing and applying real-time, accurate sensors, combined with leveraging multi-sensor data fusion technology, to attain information of battery internal characteristics and performance is crucial [9].

Certification is required for aircraft to fly: Present airworthiness certification regulations are inadequate to assure safety of engaging data-driven methods in the battery management of EPS. The process of AI safety risk assessment and learning assurance should be completely defined as well.

What are the core research gaps?

According to the complete review performed in reference [11], analysis reveals open areas that need additional study. First, more investigation for AI model development, defining BMS safety tasks, in which real-world/ flight operation is considered in data training and validation, testing and model verification, is essential. Secondly, State of Function (SOF) estimation, which can provide important information about the operation of the aircraft and decision-making during flight, has been less studied. Their studies should offer how intelligent algorithms can support accurate estimation of SOF. It is also true for Prognostics and Health Management (PHM), which is a preventive maintenance method that can accurately analysis on health status of battery and forecast the remaining useful life of it. Finally, because of the novelty of AI application in this field and scarcity of experience, extra research regarding definition of safety adequate barriers seems necessary during design and certification process to prevent introduction of new hazards to the operations.

Conclusion

In this mini review the challenges and opportunities for applying AI techniques in battery management of electric aircraft are discussed. Nevertheless, essential factors like state of charge have been used earlier in battery management, in recent research is linked with utilizing intelligent technologies. In this regard academics are on the lookout for more accurate methods. Machine learning approaches offer a higher precision in comparison with other current methods but there are some disadvantages such as processing complexity and time, reliability, etc. In addition, AI techniques in aircraft application is not ready for certification and authority acceptance Finally, it should be noted that technical improvement in LIB and BMS are essential, but then again finding a solution for uncertainties of certification process will provide a bright horizon for wide-ranging employment of it in the future.

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