IEEE P2668 Evaluation for Smart Battery Management Systems

Subjects: Engineering, Electrical & Electronic

Contributor: Hao Wang , Kim Fung Tsang , Chung Kit Wu , Yang Wei , Yucheng Liu , Chun Sing Lai

In smart cities and smart industry, a Battery Management System (BMS) focuses on the intelligent supervision of the status (e.g., state of charge, temperature) of batteries (e.g., lithium battery, lead battery). Internet of Things (IoT) integration enhances the system's intelligence and convenience, making it a Smart BMS (SBMS). However, this also raises concerns regarding evaluating the SBMS in the wireless context in which these systems are installed. Considering the battery application, in particular, the SBMS will depend on several wireless communication characteristics, such as mobility, latency, fading, etc., necessitating a tailored evaluation strategy. An IEEE P2668-Compatible SBMS Evaluation Strategy (SBMS-ES) was proposed to overcome this issue. The SBMS-ES is based on the IEEE P2668 worldwide standard, which aims to assess IoT solutions' maturity.

IEEE P2668 Internet-of-Things smart battery management

1. Introduction

Battery sales are growing in the global market. As predicted by Grand View Research, the global battery market size achieved USD 108.4 billion in 2019, and it is expected that growth with a Compound Annual Growth Rate (CAGR) of 14.1% from 2020 to 2027 will occur [1]. The growth of the battery market, including lithium and lead-acid batteries, is mainly attributed to the demand for automotive and renewable energy applications [2][3]. Besides, batteries are employed in other areas, such as solar power plant energy storage, data centers, offshore drilling platforms, north and south poles, and airplane and vehicle cranking [4].

The usage of batteries requires extra attention, particularly in the critical applications. Otherwise, an inappropriate installation or use may cause additional costs or even accidents such as fires or explosions. The main risk of the battery usage is from the operating temperature, influenced by the internal chemical processes of the battery [5]. The reasons are twofold: on the one hand, the life of batteries decreases substantially when the temperature rises. As a result, the battery's maintenance expenses will increase. On the other hand, the effects can be devastating when batteries are exposed to severe temperatures. The expansion of frozen electrolytes at low temperatures and State-of-Charge (SOC) can cause battery ruptures. In addition, uncontrolled reactions, thermal runaway, may occur due to a high operating temperature. A thermal runaway is a self-heating process that leads the battery to shut down or explode [6][7]. Due to the positive net heat energy in processes, the exothermic reaction in batteries is self-sustaining. Hence, the safe employment of batteries raises many concerns considering these mentioned risk features. Furthermore, extreme caution should be particularly paid when batteries are deployed in critical applications, to prevent severe consequences.

Hence, monitoring battery status during the operation is essential to prevent risks [8]. Smart Battery Management Systems (SBMSs) are proposed to complete such tasks by implementing the supervision of various critical features, such as operating temperature, State of Health (SOH), SOC, etc. Traditional BMSs employ Controller Area Network (CAN)-bus and I2C/SPI communication protocols. However, traditional BMSs are believed to have unreliability, high cost, and complexity as negatives, which have resulted in the emergence of new types of BMS [9]. Compared to conventional BMS, the SBMS applies wireless communication methods to report the monitoring results, providing improved reliability, lower cost, and sensor deployment feasibility [9]. With wireless communication technologies employed, the SBMSs is recognized as one of the many Internet-of-Things (IoT)-based smart applications. The IoT refers to the connection of physical items ("things") equipped with various elements and technologies, including sensors, software, etc., to exchange data with other devices and systems through the internet [10]. These physical objects can share and gather data with minimum human interaction, using state-of-art technologies, such as big data analytics, cloud computing, and mobile communications.

Various categories of SBMS, including experimental or model-based methods, have been presented to contribute to battery status such as temperature, etc. However, the SBMS also brings new challenges. A failure may occur if the wireless communication techniques are inappropriately applied. For example, wireless communication techniques with high latency are unsuitable for time-critical SBMSs. However, a general SBMS evaluation strategy is lacking to address this challenge. As a result, developers are not able to evaluate the performance of their SBMS, and it is hard to determine the best configuration for their applications.

To solve this problem, the SBMS evaluation strategy (SBMS-ES) is proposed in this entry. The SBMS-ES is a comprehensive evaluation strategy which considers the impact of the IoT on the SBMS. Integrating the IEEE P2668 global standard makes the SBMS-ES a general strategy that could be widely applied. The SBMS-ES identifies the essential features of the SBMS and designs a scoring guideline for each of them. A weighted average value is calculated as the final score, based on the evaluated sub-scores of attributes, to indicate the overall performance of the SBMS. The weighting is obtained through implementing an Analytic Hierarchy Process (AHP), a broadly utilized decision-making procedure. The final score is applied to rank the candidate SBMS solutions, to find the most desired one regarding the scenario demands.

2. Works on SBMS

Cloud computing and IoT have been widely utilized by researchers, based on traditional BMS, to design SBMS solutions. Kim et al. [11] introduced IoT-enabled battery conditional monitoring and fault diagnosis for Li-ion large-scale applications. Moreover, a digital battery twin was developed, by combining battery monitoring and data-driven modeling approaches. In [12], an SOC estimate method for lithium-ion and lead-acid batteries was based on an adaptive extended H-infinity filter. In addition, a state-of-health estimate system with particle swarm optimization was designed to monitor the battery's capacity and power degradation as it ages. With cloud computing and IoT, a digital twin was built to implement monitoring simultaneously. Xinrong et al. [13] proposed a Wireless Smart Battery Management System (WSBMS) to manage battery cells in electric vehicles (EVs). The developed system aimed to improve performance in fault tolerance and scalability. A balancing algorithm was presented to balance battery cells with various features, such as numbers. Friansa et al. [14] suggested an IoT-based battery monitoring system for microgrid batteries. A human–machine interface was designed using an ExtJS/HTML5 framework to store information, which can be accessed on a desktop. Tetsu et al. [15] developed a cloud-connected battery management system that monitors shared batteries' status. The designed system continually connects to the batteries, managing their SOC and monitoring changes in their attributes via a location data cloud. It supports e-mobility and can be applied to Electric Vehicles (EV). The authors of [16] presented a smart battery management system to prolong battery life. Authors of [17] proposed a control strategy to minimize the side reaction-induced capacity loss, by changing the cell series-parallel configuration dynamically inside the battery pack.

In addition to the aforementioned SBMS, researchers also have proposed works aiming to study the performance of the wireless communication protocol in the BMS. Alonso et al. [18] researched wireless channel parameters and data rates in a BMS. The main work was to estimate the transmission capacities of different antenna types in various frequency bands. The study also concentrated on Planar Inverted-F- Antenna and CAN-bus communication. Kumtachi et al. [19] improved the reliability of a multi-hop wireless communication protocol for BMS electric vehicles. Specifically, the approach achieves successful communication within 20 ms for over 99% of packets by overhearing those incoming packets without optimal routes.

The mentioned works have made remarkable contributions to the study of SBMS. However, these works solely focused on battery or communication performance monitoring in BMS. The field of SBMS lacks a systematic strategy for evaluating the overall performance of solutions. As a result, designers cannot decide the best configuration for their SBMS. A comprehensive evaluation of SBMS is necessary.

3. P2668 Interoperable Standardized Management Framework

3.1. IEEE P2668 Global Standard

The IEEE P2668 standard defines methods and criteria for evaluating the performance of IoT objects, the evaluation outcome of which is expressed as a quantitative indicator, namely the IDex [20]. The IDex categorizes the maturity of (IoT) objects into five levels, ranging from one (the lowest maturity) to five (the most excellent maturity) [21]. The final IDex value is expected to satisfy the requirement of IoT stakeholders for a clear indication. IDex can also be used to forecast performance changes under various operating circumstances and to present recommendations for increasing the performance of IoT objects. The main objective of IDex is to evaluate the performance of IoT solutions and provide advice on corresponding improvements.

3.2. Overview of SBMS-ES

The SBMS can be evaluated by IDex since it utilizes IoT technology. The specialized scheme for the employment of IDex in the SBMS is called SBMS-ES (evaluation scheme). This section introduces the general construction of SBMS-ES, step by step. The quantitative score of each SBMS solution can be obtained to its comprehensive performance, applying SBMS-ES. By comparing the final scores of SBMS with various configurations (e.g., different communication protocols), the best solution among the candidates can be decided.

A flowchart of SBMS-ES is illustrated in **Figure 1**. It is divided into three subsections, i.e., the attributes evaluation, the weighting allocation, and the final score calculation. The attribute evaluation introduces the identified essential attributes in SBMS-ES and the justifications. Furthermore, the evaluation principles of the attributes are illustrated. The weighting allocation describes how the weighting for each attribute is determined. The final score calculation depicts the way to calculate the final score and select the most desired SBMS solution. The details of these subsections are specified in the following Section 3.3, Section 3.4 and Section 3.5.

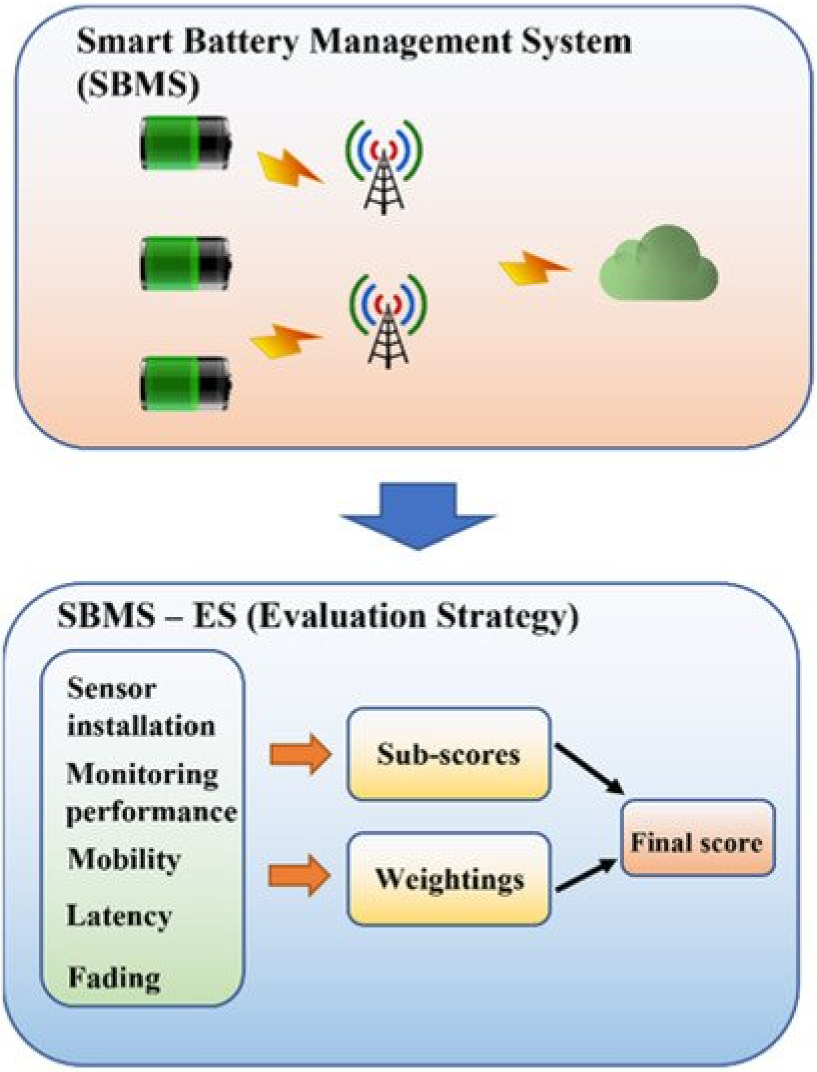

Figure 1. Flowchart of SMBS-ES.

3.3. Evaluation Attributes in SBMS

Five key attributes are typically identified in SBMS-ES for evaluation, i.e., sensor installation, monitoring performance, mobility, latency, and fading. The attribute descriptions and sub-scores evaluation principles for each attribute are given in this section.

3.3.1. Senor Installation

As mentioned, the SBMS implements battery status monitoring based on the relative sensors' feature measurements. To be specific, a straightforward method directly measures the battery status of concern. On the opposite, the indirect method measures the other features to implement data modeling, i.e., estimating the status of concern based on the measured features. Both methods will need sensors for the measurement. Hence, the installation of sensors is part of the SBMS evaluation.

Sensor installation is evaluated in two aspects, i.e., the location of sensors, and the number of sensors. As discussed previously, installing a sensor inside a battery will change the original structure, which entails risks and extra costs. On the contrary, the influence is limited if the sensors are installed outside the battery, e.g., fixed on the battery surface. Hence, it is encouraged to install sensors outside.

Moreover, the number of sensors utilized to obtain the concentrated battery status will be considered when evaluating SBMS. The monitoring scheme that needs more measurements will require more sensors to be deployed, which will bring an increase of installation costs. Moreover, a larger packet size is requested by such schemes for data transmission. The monitoring scheme with fewer sensors is more recommended for the SBMS when the monitoring performance is consistent.

3.3.2. Monitoring Performance

The monitoring performance represents the estimation accuracy of the battery status, which can be measured by the Mean Absolute Error (MAE) [22]. The value of the MAE of the SBMS needs to be as low as possible to improve its evaluation score of this aspect.

3.3.3. Mobility

The mobility of a communication network is the technology that enables nodes to make communications with a moving status. A moving node that employs a communication technique without the function of mobility will suffer from poor communication quality.

The SBMS application scenario can be stationary or mobile [12]. Considering this, the mobility of the applied IoT technology in SBMS needs to be considered. If the battery (such as a lead-acid battery) is utilized in a moving vehicle, the capacity for mobility of the network is essential. Otherwise, mobility is not important in the SBMS if the batteries are fixed in the application scenario.

References

1. Battery Market Size, Share & Trends Analysis Report by Product (Lead Acid, Li-ion, Nickle Metal Hydride, Ni-cd), by Application (Automotive, Industrial, Portable), by Region, and Segment Forecasts, 2020–2027. Available online: https://www.grandviewresearch.com/industry-analysis/battery-market (accessed on 10 June 2022).
2. Zhang, F.; Yao, S.; Zeng, X.; Yang, P.; Zhao, Z.; Lai, C.S.; Lai, L.L. Operation Strategy for Electric Vehicle Battery Swap Station Cluster Participating in Frequency Regulation Service. Processes 2021, 9, 1513.
3. Lai, C.S.; Jia, Y.; Lai, L.L.; Xu, Z.; McCulloch, M.D.; Wong, K.P. A comprehensive review on large-scale photovoltaic system with applications of electrical energy storage. Renew. Sustain. Energ. Rev. 2017, 78, 439–451.
4. Choi, H.S.; Choi, J.W.; Whangbo, T.K. Design and Development of a Battery State of Health Estimation Model for Efficient Battery Monitoring Systems. Sensors 2022, 22, 4444.
5. Rodríguez, A.; Plett, G.L.; Trimboli, M.S. Improved transfer functions modeling linearized lithium-ion battery-cell internal electrochemical variables. J. Energy Storage 2018, 20, 560–575.
6. Akbarzadeh, M.; Kalogiannis, T.; Jaguemont, J.; He, J.; Jin, L.; Berecibar, M.; Van Mierlo, J. Thermal modeling of a high-energy prismatic lithium-ion battery cell and module based on a new thermal characterization methodology. J. Energy Storage 2020, 32, 101707.
7. Navega Vieira, R.; Mauricio Villanueva, J.M.; Sales Flores, T.K.; Tavares de Macedo, E.C. State of Charge Estimation of Battery Based on Neural Networks and Adaptive Strategies with Correntropy. Sensors 2022, 22, 1179.
8. Yang, J.; Hu, C.; Wang, H.; Yang, K.; Liu, J.B.; Yan, H. Review on the research of failure modes and mechanism for lead-acid batteries. Int. J. Energy Res. 2017, 41, 336–352.
9. Samanta, A.; Williamson, S.S. A Survey of Wireless Battery Management System: Topology, Emerging Trends, and Challenges. Electronics 2021, 10, 2193.
10. Stoyanova, M.; Nikoloudakis, Y.; Panagiotakis, S.; Pallis, E.; Markakis, E.K. A survey on the internet of things (IoT) forensics: Challenges, approaches, and open issues. IEEE Commun. Surv. Tutor. 2020, 22, 1191–1221.
11. Kim, T.; Makwana, D.; Adhikaree, A.; Vagdoda, J.; Lee, Y. Cloud-Based Battery Condition Monitoring and Fault Diagnosis Platform for Large-Scale Lithium-Ion Battery Energy Storage Systems. Energies 2018, 11, 125.
12. Li, W.; Rentemeister, M.; Badeda, J.; Jöst, D.; Schulte, D.; Sauer, D.U. Digital twin for battery systems: Cloud battery management system with online state-of-charge and state-of-health estimation. J. Energy Storage 2020, 30, 101557.

13. Huang, X.; Acharya, A.B.; Meng, J.; Sui, X.; Stroe, D.-I.; Teodorescu, R. Wireless Smart Battery Management System for Electric Vehicles. In Proceedings of the 2020 IEEE Energy Conversion Congress and Exposition (ECCE), Detroit, MI, USA, 11–15 October 2020.
14. Friansa, K.; Haq, I.N.; Santi, B.M.; Kurniadi, D.; Leksono, E.; Yuliarto, B. Development of Battery Monitoring System in Smart Microgrid Based on Internet of Things (IoT). Procedia Eng. 2017, 170, 482–487.
15. Tanizawa, T.; Suzumiya, T.; Ikeda, K. Fujitsu Cloud-connected battery management system supporting e-mobility. Sci. Tech. J. 2015, 51, 27–35.
16. Gupta, K.; Gaidhane, V.H. Smart IoT-Enabled Battery Management System for Electric Vehicle. In Proceedings of the International Conference on Communication and Artificial Intelligence, Mathura, India, 19–20 November 2021.
17. Karunathilake, D.; Vilathgamuwa, M.; Mishra, Y.; Farrell, T.W. Capacity Loss Reduction Using Smart-Battery Management System for Li-ion Battery Energy Storage Systems. In Proceedings of the IEEE 29th International Symposium on Industrial Electronics (ISIE), Delft, The Netherlands, 17–19 June 2020.
18. Alonso, D.; Opalko, O.; Sigle, M.; Dostert, K. Towards a Wireless Battery Management System: Evaluation of Antennas and Radio Channel Measurements Inside a Battery Emulator. In Proceedings of the IEEE 80th Vehicular Technology Conference (VTC2014-Fall), Vancouver, BC, Canada, 14–17 September 2014.
19. Kumtachi, T.; Kinoshita, K.; Watanabe, T. Reliable wireless communications in battery management system of electric vehicles. In Proceedings of the 2017 Tenth International Conference on Mobile Computing and Ubiquitous Network (ICMU), Toyama, Japan, 3–5 October 2017.
20. Wu, C.K.; Tsang, K.F.; Liu, Y.; Zhu, H.; Wei, Y.; Wang, H.; Yu, T.T. Supply chain of things: A connected solution to enhance supply chain productivity. IEEE Commun. Mag. 2019, 57, 78–83.
21. Zhu, H.; Tsang, K.F.; Liu, Y.; Wei, Y.; Wang, H.; Wu, C.K.; Wan, W.H. Index of Low-Power Wide Area Networks: A Ranking Solution toward Best Practice. IEEE Commun. Mag. 2021, 59, 139–144.
22. Guo, Y.; Yang, Z.; Liu, K.; Zhang, Y.; Feng, W. A compact and optimized neural network approach for battery state-of-charge estimation of energy storage system. Energy 2021, 219, 119529.