Review of State of Health Monitoring Techniques inBattery Management System

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Abstract.

As in recent trends, the Electric Vehicles are tremendously growing and major research works are found in Battery Management System. This paper comprehensively analysis about the State Of Health (SOH) and its methodologies in applications of Battery Management System (BMS). Various algorithms along with the flowchart have been briefly discussed. The comparative analyses along with the various methodologies are included in the table for reference. The SOH monitoring and controlling applications in lithium-ion batteries and fuel cells are considered and discussed as regarding main topics. The model-based methods along with the real time applications with input and output features has briefed in general with a comparison. The algorithms with real time application in Machine Learning and AI techniques has given a highlight and its applications in real time examples are briefed. Thus, this paper briefs about BMS and discharge methods of the battery of the SOH techniques and highlights upon various algorithms which is used as model-based methods in Battery management system as well as SOH techniques.

Keywords. Battery Management System, State of Health, Experimental Method Analysis, Machine Learning, Model Based Methods.

1. INTRODUCTION

Nowadays, Electric vehicles are a trending technology in various applications, and one of its applications is used in Battery Management Systems (BMS). BMS monitors and protects the battery by considering its safe operation area such as Overvoltage/under voltage, Overpressure, over temperature/under temperature [1]. Also, to prevent the current leakage where battery cell is charged by an intelligent battery pack and makes use of rechargeable battery which has to be managed in an electronic or power storage system by considering available data for calculating and monitoring it in the environment and is efficiently used in the EV applications [2]. BMS consists of many cells stacked together within a smart battery pack to release the cell’s energy to meet the load demand. Stability plays a significant role in the whole Battery Management System, where users can monitor each cell individually by authenticating and reporting the data [3]. There are many IC’s available in BMS. It includes some functional blocks to keep track of all voltage balance, monitor temperature and the energy recovery in electric vehicle systems, and sometimes the state of the battery can also be monitored by considering the state of the machine for simplicity purposes as shown in Fig.1.1. By considering standard parameters like SOC (State Of Charge) [4][5], SOH (state of health) [6], SOP (state of power), and SOS (state of safety), BMS computation can be determined [7].

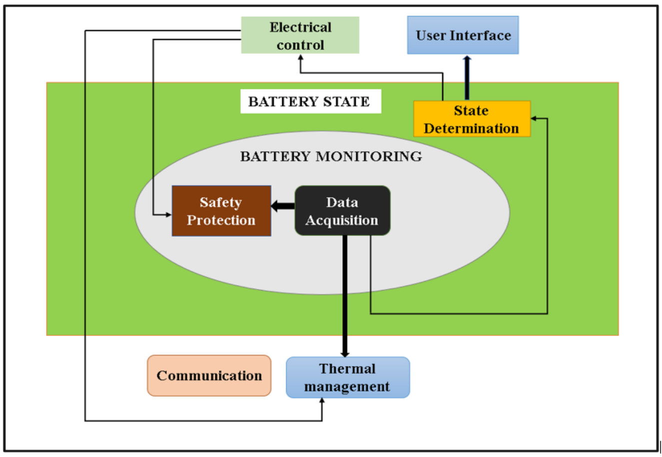

Figure 1.1 Battery Management System[8]

It can track the total number of cycles and energy consumed per kWh for the total operating time [9]. BMS also uses wireless kWh for the total operating time [9]. BMS also uses wireless communications for communicating with the hardware when it comes to internal purposes at the basic level of the cell.

When it comes to the external purpose, the hardware level will be high, making use of PCs, laptops, etc. For internal communication, BMS restricts with bulk number of cells [9]. When it comes to modular architecture with an increasing number of nodes, hardware combination cannot be used as it is limited, and cost plays a major role as cell price comes into existence which is comparable.

The protection of BMS is also important, so we can include a relay that acts as a protective switch by detecting faults when the battery's SOA crosses its limit. The balancing part of the BMS is handled by the balancers where energy is shuffled and also by passive regulators by connecting charged cells of an increasing number to the load side, and the major task is to maintain voltage at the same level for cells where the battery is composed, to prevent overcharging thus the battery's capacity can be maximized. Thus, BMS (Battery management system) plays a major role in electric and hybrid vehicles such as electric cars and lithium-ion batteries [10].

In electric train traction batteries, BMS is used to manage the high power and large battery packs. Some BMS applications are also found in Garbage compressors, Industrial machines, Hoists, Cranes, Robots, Forklifts, etc.

2. STATE OF HEALTH

SOH stands for the State of Health, and it is a battery condition to estimate the charge in smart battery packs by considering some of the Safe Operating Area (SOA) and aging limitations at the same time for monitoring the battery conditions for electric vehicle applications [11] as shown in Figure 2.1.

By considering ideal parameters, when manufacturing SOH's battery condition is 100 percent and due to some aging process, the battery's performance will decrease [12]. It is calculated by considering the ratio of capacitance, impedance to its initial rating.

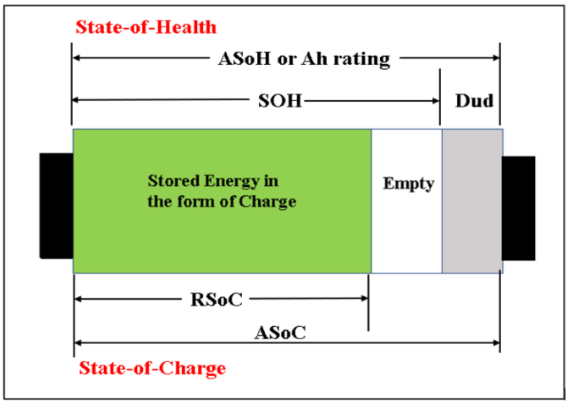

Figure 2.1 State of Health[13]

Nowadays, Lithium-ion batteries are used in SOH's battery for reliability purposes. A detailed analysis has been carried out to check for safety measures in power storage or energy storage requirements.

Currently, the study has been carried out in self-discharge rate, Number of operating cycles, power capability to ensure battery monitoring system by considering internal impedance, resistance, and capacitance aspects.

Some of the health features (HFs) for SOH battery estimation are the physical parameters to characterize the battery capacity, Electrochemical models with some degradation mechanisms.

The factors affecting the behaviour of the battery in SOH's batteries are dealt with by some of the algorithms and Artificial Neural Networks (ANNs) techniques by considering the capacity loss in the cycling behaviour of the power periodically [14]. The response of the voltage will be varied by considering the rate of current at different SOH parameters.

The battery parameters like SOC and SOH are the approaches used in various battery system methods such as Kalman Filter, Enhanced Coulomb Counting, and voltage methods in applications of Electric and Hybrid vehicles, HVDC, and photovoltaic applications systems [15].

3. SOH TECHNIQUES

As the Electric Vehicle Technology is tremendously growing in past few years, the Battery Management System (BMS) acts as a central coordinating system or main control system so as to provide reliability, efficiency, stability and safe use of battery by considering some standard parameters like State of Charge (SOC), State of Health (SOH), State of Power (SOP)[16][17].

SOC is used to collect the energy being consumed by battery and storage specifications of the battery. SOP is used for determining the power required for the battery and the flowchart of SOH Monitoring is shown in Figure 3.1.

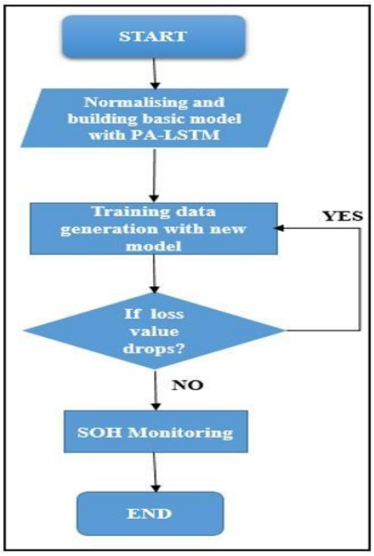

Figure 3.1. Flow Chart of SOH Monitoring[18]

SOH is a battery condition to estimate the charge and to detect degradation level of the battery in real-time automotive applications.

The Battery performance can be analyzed by SOH in HEV and AI applications [19] and discusses about the distribution of energy and how to improve their self-discharge rate, consumption of energy during their lifetime. So, some of the standard methods/techniques are used for SOH's battery estimation by considering internal resistance of the battery, battery's impedance, state of machine, state of discharge [20] and its capacity [21].

The SOH Battery estimation methods can be divided into 3 methods which include Experimental methods, Model-Based methods and Machine Learning methods. From the standard methods, machine learning technology can be implemented and it includes some of the techniques such as Support Vector Regression, Neural Network, Fuzzy logic and other standard algorithms.

In Experimental methods, some techniques include Impedance measurement, ICA/DVA, Internal resistance measurement, Capacity level etc. and these methods are usually conducted in laboratories.

Some Model Based methods include Adaptive filtering such as Kalman Filters, EKF, UKF, RLS, MAFFRLS, Electrochemical models and Enhanced Coulomb counting methods etc. SOH's battery uses PA-LSTM algorithm for monitoring accuracy of battery and also by updating the learning mechanism where data obtained from the experimental results are close to real time data model dynamically and can further be used in approach of Lithium-ion batteries.

4. VARIOUS METHODS OF SOH TECHNIQUES

In SOH Battery estimation, there are 3 types of methods namely Experimental technique, Machine learning methods and Model Based methods as shown in Figure 4.1.

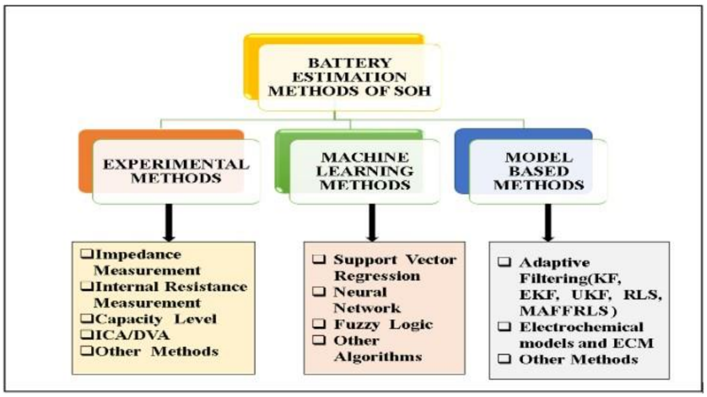

Figure 4.1 Battery SOH Estimation Methods[22]

5. EXPERIMENTAL METHOD ANALYSIS OF BATTERY SOH ESTIMATION

Usually, these Experimental methods are often time consuming and preferable equipment's have to be used in specific to meet the criteria or requirements, so these methods are usually performed in laboratories. The aging behaviour of the battery can be determined using these methods by collecting raw data measurements and understanding the behaviour of these collected data. Some of the techniques used in Experimental methods are discussed below:

• Impedance Measurement of the Battery:

The major technique which is used frequently to measure the impedance of the battery is Electrochemical Impedance Spectroscopy (EIS) which dealt with energy storage and conversion and it acts as a SOH indicator of battery. This technique is conducted as a function of frequency as a sinusoidal AC current is applied and output voltage response is calculated. Meanwhile, it is a non-destructive method and it is found that impedance of the battery is directly proportional to the aging phenomena.

The EIS method discusses about the super capacitor, cycling effect and energy storage in real-time applications of EV and major advantage is the accuracy which can be calculated efficiently in the aging phenomenon of the battery [23].

• Internal Resistance Measurement of the Battery:

In this technique, by applying AC sinusoidal current the voltage drops and current pulse is the most frequently used method to deter- mine the Internal Resistance which is based on the principle of Ohm's Law and acts as a SOH indicator.

By considering the parameters like aging and degradation whose impact decreases the resistance values with SOH battery conditions. With the help of Joule's law, loss of energy in Battery is evaluated by considering the impacting parameters. The main advantage of this method is the accuracy in domains of evaluating battery's internal resistance in different environmental working conditions and widely used in laboratories but is often a time-consuming process.

• Capacity Level:

In this technique, battery charging capacity is evaluated and energy stored in a battery is evaluated by a capacitor and it is inversely proportional to the aging phenomenon of the battery [24]. Here, time is the major factor to decide number of charging/discharging cycles based on the output voltage under different working conditions of the temperature for different levels of degradation by experimentally evaluating the capacity fading level in Lithium-ion battery applications [25].

• ICA/DVA and Other Methods:

ICA and DVA stands for Incremental Capacity Analysis and Differential Voltage Analysis respectively. These methods have to be done experimentally by testing battery SOH which is time consuming and these parameters vary with aging of the battery. By using some of the destructive methods such as X-ray Diffraction, state of the battery and machine can be determined from inside and estimation can be changed feasibly with modification of specific working conditions [26].

6. MACHINE LEARNING METHOD ANALYSIS

This method is basically a combination of both standard methods which include Experimental and Model Based methods. To estimate battery SOH some data has to be gathered using machine learning algorithms in process of learning to setup the standard algorithms [27].

• Support Vector Regression (SVR):

In this technique, training data is to be evaluated which requires a controller of high performance to manage the energy and taking into consideration real time data and experimentally to determine the online SOH indicator using Electrochemical Impedance Spectroscopy (EIS) technique. This SVR algorithm is also used to estimate RUL (Remaining Useful Life) of the battery and its applications in Fuel cells, e-Bikes, Hybrid Electric vehicles etc.

• Fuzzy Logic:

This technique is used for nonlinear systems and is the most commonly used machine learning method along with EIS technique to evaluate the training data to be accurate which often uses Gaussian Algorithm process [28] to estimate the battery SOH in Lithium-ion batteries along with WLTC profiles [29].

• Neural Networks:

It is the most frequently used machine learning algorithm and it takes less data for computational analysis combining with EIS measurements and results are found to be more accurate with ample amount of data received than the Fuzzy Logic.

The main disadvantage of this method is difficulties faced in complex as well as nonlinear systems and also it requires a controller of high performance.

• Other Methods:

Some algorithms such as Gaussian algorithm makes use of training data to track accuracy of SOH battery in Lead Acid Batteries as well as Lithium-ion batteries.

Back Propagation Neural Network (BPNN) is the algorithm to trace the battery parameters like Internal Impedance, Resistance and to track the energy level and tolerance was found to be less.

Particle-filter based algorithm is used extensively for different vehicle applications and its accuracy on estimation of battery SOH and requirement of training data is found to be less for computational purpose in machine learning process.

RLS (Recursive Least Square) algorithm and LSTM-NN (Long Short-Term Memory Neural Network) are also used which are trending research topics and has to be tested experimentally for better accuracy of the SOH battery indicator.

7. MODEL BASED SOH BATTERY ESTIMATION ANALYSIS

In the research for evaluating the Battery SOH and real time feasibility, model-based methods have come into existence with filtering and standard indicators to determine battery capacity, impedance, energy level [30] etc. Some of the techniques are:

• Kalman Filters:

In order to evaluate the SOH battery parameters, an adaptive filtering algorithm is used in real time to consider the ECM (Equivalent Circuit Models). The advantage of these filters are some nonlinear systems as well as complex system battery state and parameters can be evaluated using Kalman Filters (KF), Extended Kalman Filters (EKF), Unscented Kalman Filter (UKF), Dual Kalman Filters etc.

• Electrochemical methods:

Differential equations of nonlinear systems as well as complex systems can be evaluated accurately and these models are found to be complex in tracing the battery's parameters and behaviour. It uses recursive parameter [31] for identification purpose and to predict online SOH indicator and capacity effects in SOC battery. For accurate results the battery behaviour can be predicted using ECM techniques where they have less complexity equations.

The main drawback of this method is the difficulty level of the equations and complexity of the algorithm to trace behaviour of SOH battery parameters like internal resistance and diffusion time of the battery.

• Other Methods:

Observers are also used in Model Based SOH estimation methods due to its robustness against error margin and diffusion time parameter for variations in temperature [32]. Least Square Based Filters is widely used one of the algorithms for testing the battery states in the OCV (Open Circuit Voltage) along with RLS algorithm for testing the high performance of a battery model.

MAFFRLS (Multi Adaptive Forgetting Factors RLS) is also used along with PSO (Particle Swam Optimization) algorithms for better efficiency and accurate results in temperature and time variations of dataset in Battery models.

8. COMPARATIVE ANALYSIS

In Support Vector Regression (SVR) method, the quality and quantity are entirely based upon the data used in the training and uses a controller when there is a need of high performance to control the training data. Compared to the other methods, the results obtained in the SVR is of accurate and applicable for any systems. The main advantage of SVR is as the system results obtained are of accurate and hence the system is stable and efficient. It can also be used to solve the regression problems. The main disadvantage of using SVR algorithm is that it is difficult for humans to understand the code and it takes long training time. In Feed Forward Neural Network (FNN) Algorithm, mathematical relationships are used for the algorithm with some input features to dynamics of battery such that SOH Estimation can be done in an accurate manner and rule used in FNN is of back propagation learning. The equations used in FNN are of mapping function where some function can be almost approximated to other functions. The main advantages of using FNN are the computation required to analyze the mathematical relations is less, so this type of algorithm is beneficial.

As large equations are being used, overfitting problem exists as to store the data of large number of parameters. In Recurrent Neural Network (RNN) Algorithm, the main input to be considered are current, temperature, voltage and output used to determine the application of SOH in functions of temperature in BMS applications [33]. The main advantage of using RNN Algorithm is information can also be easily stored in functions of time which is easy task and memory requirement is less. The pixel quality is effective and time series can be easily predicted. The disadvantage of this RNN algorithm is to train the RNN task and sometimes long sequences such as tanh function cannot be processed easily and gradient problems usually occur for this type of algorithm. In case of Particle Swarm Optimization (PSO) Algorithm the principle is based on the latest technology and its applications are still being in research for Electric Vehicles and Plug-in hybrid Electric vehicles. It makes use of Swarm Intelligence where parameters control can be done using simple concept and efficiency of computation compared to other algorithms is found to be extremely good and effective. This PSO algorithm can be easily implemented for different and various systems so that the over fitting problem can be overcome by this algorithm.

The main disadvantage of this algorithm is that it provides solution of some techniques which is of low quality and each time when the program is updated, memory updating has to be done which is time consuming and tedious process or task.

Table 1 COMPARISON OF EXPERIMENTAL BASED METHODS.

Methods	**Advantages**	**Disadvantages**
Internal Resistance measurements [34]	• Simple to implement and direct method to understand. • Less complexity and high level of accuracy.	• Estimation through online cannot be made. • Time consuming and tedious task.
Internal Impedance Measurements	• High accuracy and simplicity. • Reliable and degradation of the battery methods can be easily understood.	• Battery degradation and discharges is difficult to analyze.
ICA/DVA and Capacity Level [35]	• This technique is much faster than other methods. • It is fast to analyze and provides high level of accuracy.	• Sometimes this method is not reliable and feasible. • Operating conditions of the battery is difficult to analyze when fully charged.

Table 2 COMPARISON OF MODEL BASED METHODS.

Methods	**Advantages**	**Disadvantages**
Kalman FilterBased (KF) methods	• Simple to understand and accurate to interpret theoutput • It is bounded to errors	• For advanced systems and versions system is complex. • A controller of high performance is required and not valid for nonlinear systems [39].
Electrochemical models	• High accuracy and reliable • The battery degradation phenomenon can be understood and predicted easily.	• The computational level of high-performance con- troller is required [40]. • Structure of the battery is difficult to analyze.
Least Square Based methods	• This Technique is much precise and robust than other techniques. • The structure is easy to analyze.	• The model is mostly concentrated on accuracy and high-level performance controller is required [41].

Table 3 COMPARISON OF MACHINE LEARNING BASED METHODS [36].

Parameters	**Support Vector Regression Algorithm**	**Feed Forward Neural Network Algorithm**	**Recurrent neural network (RNN) Algorithm**	**Particle Swarm Optimization (PSO) Algorithm [37]**
INPUT	I(t), V(t), T(t)	I(t), V(t), T(t)	I(t), T(t), SOC(t), R/C(t)	I(t), V(t), T(t)
OUTPUT	SOH(t)	SOH(t)	SOH(t)	SOH(t)
FUNCTION	Regression and Classification Hyperplane Equation	Supervised Learning, Sigmoid function, Mapping of function to approximate value	Non-Linear, Auto-Regressive Network, Time Series Based Function	Swarm Intelligence, Randomized, Population Based Optimization Method
EQUATION	y=wx+b(Hyperplane) Condition: $-a > y-wx+b < a$	f(x)=yf(x) for all (x,y)	Current state equation: $h_t=f(h_{t-1}, x_t)$ Output equation: $y_t=W_{hy}h_t$ Activation Function: $h_t=\tanh(W_{hh}h_{t-1}+W_{xh}x_t)$	$x_i^{k+1}= x_i^k+ v_i^{k+1}$
ADVANTAGES	• Overfitting can be prevented as it has good regularization capabilities. • Using Kernel function, it handles non-linear data efficiently • Stable and Efficient. • Can be used to solve both classification and regression.	• Easy to setup. • Less computation. • Complex and Non- linear systems can be analyzed.	• Easy information is stored accordingly with time. • It is good for effective pixel extension. • Helps in prediction of time series.	• Simple concept. • Easy implementation. • Robustness to control parameters • High computational Efficiency.

LIMITATIONS	• The difficult task is to choose an appropriate Kernel function. • For large datasets, it takes long training time [38]. • It is difficult to understand the algorithm or models of SVR for humans.	• There exists Vanishing and Exploding Gradient problem. • Large model size. • There exists Overfitting of large number of parameters.	• Gradient Vanishing and problems are exploding. • It is difficult to train an RNN task. • As tanh function is used for activation function, it cannot process long sequences.	• Low convergence rate in iterative process. • Memory updating required and falls under local search. • Low quality solution.

Table 4 COMPARISON OF SOH ESTIMATION METHODS.

Methods	**Advantages**	**Disadvantages**
Experimental Based methods	• Simple to understand and accuracy is more. • Computational level is low	• Time consuming. • The measurements and the equipment to be used should be specific [42].
Machine Learning methods	• High accuracy and reliable compared to other two methods. • Easy to implement and process can be carried out easily.	• The computational level is difficult to understand and depends more on the training data [43]. • Sometimes the algorithms are difficult to under- stand for humans.
Model Basedmethods	• A simple structure is required to analyze the training data and easy to implement. • Accuracy level is high and robust estimation of battery parameters can be done.	• The model is mostly concentrated on accuracy levels of training data and pre-experimental setup is required. • The development process of the battery is time consuming and rely more on computational time.

9. CONCLUSION

As Electric vehicles are tremendously growing in recent technologies, BMS (Battery Management System) plays an important role in monitoring and controlling the various applications of Battery. This paper briefs about the different computational efficiency and the current technologies used in BMS. With respect to SOH, various techniques have been implemented for better performance. The objective, uncertainties, accuracy and efficiency has been discussed in this paper. Regarding SOH techniques, various algorithms have been used along with recent technologies of Machine Learning. It discusses about different algorithm advantages, limitations, standard equations along with the technology being implemented with a comparison structure. In brief, BMS and its applications, SOH with its techniques, Intelligent Algorithms have been highlighted in terms of input and output features. This paper has highlighted the real time applications with respect to EV and HEV with Lithium-ion batteries, Fuel cells, Lead acid batteries etc. Some model-based methods using different algorithms and techniques for the SOH estimation methods are key concerns. Overall, battery parameters with respect to EV model accuracy, adaptability, compatibility with best estimation methods for real time identifications and their applications summarized in a brief manner.

10. REFERENCES

[1] Lipu, MS Hossain, M. A. Hannan, Tahia F. Karim, Aini Hussain, Mohamad HM Saad, Afida Ayob, Md Sazal Miah, and TM Indra Mahlia. ”Intelligent algorithms and control strategies for battery management system in electric vehicles: Progress, challenges and future outlook.” Journal of Cleaner Production (2021): 126044.

[2] Sreedhar, R., and K. Karunanithi. ”Design, simulation analysis of universal battery management system for EV applications.” Materials Today: Proceedings (2021).

[3] Gabbar, Hossam A., Ahmed M. Othman, and Muhammad R. Abdussami. ”Review of Battery Management Systems (BMS) Development and Industrial Standards.” Technologies 9, no. 2 (2021): 28.

[4] Naguib, Mina, Phillip Kollmeyer, and Ali Emadi. ”Lithium-Ion Battery Pack Robust State of Charge Estimation, Cell Inconsistency, and Balancing.” IEEE Access 9 (2021): 50570-50582.

[5] Chandran, Venkatesan, Chandrashekhar K Patil, Alagar Karthick, Dharmaraj Ganeshaperumal, Robbi Rahim, and Aritra Ghosh. "State of charge estimation of lithium-ion battery for electric vehicles using machine learning algorithms." World Electric Vehicle Journal 12, no. 1 (2021): 38

[6] Singirikonda, Srinivas, and Y. P. Obulesu. ”Advanced SOC and SOH Estimation Methods for EV Batteries—A Review.” Advances in Automation, Signal Processing, Instrumentation, and Control (2021): 1963-1977.

[7] Laadjal, Khaled, and Antonio J. Marques Cardoso. ”A review of supercapacitors modelling, SoH, and SoE estimation methods: Issues and challenges.” International Journal of Energy Research 45, no. 13 (2021): 18424-18440

[8] ”Battery Management System (BMS) for Electric Vehicles.” Circuit Digest. December 05, 2018. Accessed November 30 , 2021. https://circuitdigest.com/article/battery-management-system-bms-for- electric-vehicles.

[9] Anselma, Pier Giuseppe, Phillip Kollmeyer, Jeremy Lempert, Ziyu Zhao, Giovanni Belingardi, and Ali Emadi. ”Battery state-of-health sensitive energy management of hybrid electric vehicles: Lifetime prediction and ageing experimental validation.” Applied Energy 285 (2021): 116440.

[10] Vichard, Lo¨ıc, Alexandre Ravey, Pascal Venet, Fabien Harel, Serge Pelissier, and Daniel Hissel. ”A method to estimate battery SOH indica- tors based on vehicle operating data only.” Energy 225 (2021): 120235.

[11] Lin, Jiayuan, Xinhua Liu, Shen Li, Cheng Zhang, and Shichun Yang. ”A review on recent progress, challenges and perspective of battery thermal management system.” International Journal of Heat and Mass Transfer 167 (2021): 120834.

[12] Kalaf, Omer, Davut Solyali, Mohammed Asmael, Qasim Zeeshan, Babak Safaei, and Alyaseh Askir. ”Experimental and simulation study of liquid coolant battery thermal management system for electric vehicles: A review.” International Journal of Energy Research 45, no. 5 (2021): 6495- 6517.

[13] Selvabharathi, D., and N. Muruganantham. ”Battery health and performance monitoring system: A closer look at state of health (SoH) assessment methods of a lead-acid battery.” Indonesian Journal of Electrical Engineering and Computer Science 18, no. 1 (2020): 261-267.

[14] Yue, Q. L., C. X. He, H. R. Jiang, M. C. Wu, and T. S. Zhao. ”A hybrid battery thermal management system for electric vehicles under dynamic working conditions.” International Journal of Heat and Mass Transfer 164 (2021): 120528.

[15] Hashemi, Seyed Reza, Ajay Mohan Mahajan, and Siamak Farhad. ”Online estimation of battery model parameters and state of health in electric and hybrid aircraft application.” Energy 229 (2021): 120699.

[16] Lee, Jeong, Jun-Mo Kim, Junsin Yi, and Chung-Yuen Won. ”Battery management system algorithm for energy storage systems considering battery efficiency.” Electronics 10, no. 15 (2021): 1859.

[17] Saraswathi, RJ Vijaya, and V. Vasan Prabhu. ”Battery Safety Enhancement in Electric Vehicles—A Review Paper.” Emerging Solutions for e- Mobility and Smart Grids (2021): 175-183.

[18] Qu, Jiantao, Feng Liu, Yuxiang Ma, and Jiaming Fan. ”A neural-network-based method for RUL prediction and SOH monitoring of lithium-ion battery.” IEEE access 7 (2019): 87178-87191.

[19] Sivaraman, P., and C. Sharmeela. ”IoT-Based Battery Management System for Hybrid Electric Vehicle.” Artificial Intelligent Techniques for Electric and Hybrid Electric Vehicles (2020): 1-16.

[20] Deng, Zhongwei, Xiaosong Hu, Xianke Lin, Le Xu, Yunhong Che, and Lin Hu. ”General discharge voltage information enabled health evaluation for lithium-ion batteries.” IEEE/ASME Transactions on Mechatronics (2020).

[21] Kilic, Ensar, Ramazan Bayindir, and Samet Ayik. ”Real-Time Monitoring with Labview of the Battery Management System and the Estimated Electric Vehicle Battery SoH.” In Sixth International Conference on Intelligent Computing and Applications, pp. 565-576. Springer, Singapore,2021.

[22] Noura, Nassim, Loïc Boulon, and Samir Jemeï. "A review of battery state of health estimation methods: Hybrid electric vehicle challenges." World Electric Vehicle Journal 11, no. 4 (2020): 66.

[23] Locorotondo, Edoardo, Vincenzo Cultrera, Luca Pugi, Lorenzo Berzi, Marco Pierini, and Giovanni Lutzemberger. ”Development of a battery real-time state of health diagnosis based on fast impedance measurements.” Journal of Energy Storage 38 (2021): 102566.

[24] Kaur, Kirandeep, Akhil Garg, Xujian Cui, Surinder Singh, and Bijaya Ketan Panigrahi. ”Deep learning networks for capacity estimation for monitoring SOH of Li-ion batteries for electric vehicles.” International Journal of Energy Research 45, no. 2 (2021): 3113-3128.

[25] She, Chengqi, Lei Zhang, Zhengpo Wang, Fengchun Sun, Peng Liu, and Chunbao Song. ”Battery State of Health Estimation Based on Incremental Capacity Analysis Method: Synthesizing from Cell-Level Test to Real- World Application.” IEEE Journal of Emerging and Selected Topics in Power Electronics (2021).

[26] Wang, Xueyuan, Xuezhe Wei, Jiangong Zhu, Haifeng Dai, Yuejiu Zheng, Xiaoming Xu, and Qijun Chen. ”A review of modeling, acquisition, and application of lithium-ion battery impedance for onboard battery management.” ETransportation 7 (2021): 100093.

[27] Oji, Tsuyoshi, Yanglin Zhou, Song Ci, Feiyu Kang, Xi Chen, and Xiulan Liu. ”Data-Driven Methods for Battery SOH Estimation: Survey and a Critical Analysis.” IEEE Access 9 (2021): 126903-126916.

[28] Li, Xiaoyu, Changgui Yuan, Xiaohui Li, and Zhenpo Wang. ”State of health estimation for Li-Ion battery using incremental capacity analysis and Gaussian process regression.” Energy 190 (2020): 116467.

[29] Jianfang, Jia, Wang Keke, Pang Xiaoqiong, Shi Yuanhao, Wen Jie, and Zeng Jianchao. ”Multi-Scale Prediction of RUL and SOH for Lithium- Ion Batteries Based on WNN-UPF Combined Model.” Chinese Journal of Electronics 30, no. 1 (2021): 26-35.

[30] Mc Carthy, Kieran, Hemtej Gullapalli, and Tadhg Kennedy. ”Online state of health estimation of Li-ion polymer batteries using real time impedance measurements.” Applied Energy (2021): 118210.

[31] Ungurean, Lucian, Mihai V. Micea, and Gabriel Carstoiu. ”Online state of health prediction method for lithium-ion batteries, based on gated recurrent unit neural networks.” International journal of energy research 44, no. 8 (2020): 6767-6777.

[32] Khaleghi, Sahar, Yousef Firouz, Maitane Berecibar, Joeri Van Mierlo, and Peter Van Den Bossche. ”Ensemble gradient boosted tree for SoH estimation based on diagnostic features.” Energies 13, no. 5 (2020): 1262.

[33] Eddahech, Akram, Olivier Briat, Nicolas Bertrand, Jean-Yves Deletage, and Jean-Michel Vinassa. ”Behavior and state-of-health monitoring of Li-ion batteries using impedance spectroscopy and recurrent neural net- works.” International Journal of Electrical Power and Energy Systems 42, no. 1 (2012): 487-494

[34] Qaisar, Saeed Mian. ”Li-Ion Battery SoH Estimation Based on the Event-Driven Sampling of Cell Voltage.” In 2020 2nd International Conference on Computer and Information Sciences (ICCIS), pp. 1-4. IEEE, 2020

[35] Roy, Sourov, and Faisal Khan. ”Detection of degraded/aged cell in a li-ion battery pack using spread spectrum time domain reflectometry (SSTDR).” In 2020 IEEE Applied Power Electronics Conference and Exposition (APEC), pp. 1483-1488. IEEE, 2020.

[36] Vidal, Carlos, Pawel Malysz, Phillip Kollmeyer, and Ali Emadi. "Machine learning applied to electrified vehicle battery state of charge and state of health estimation: State-of-the-art." IEEE Access 8 (2020): 52796-52814.

[37] Pan, Dawei, Hengfeng Li, and Yuchen Song. "A Comparative Study of Particle Filters and its Variants in Lithium-ion Battery SOH Estimation." In 2020 International Conference on Sensing, Measurement and Data Analytics in the era of Artificial Intelligence (ICSMD), pp. 198-203. IEEE, 2020.

[38] Li, Weihan, Monika Rentemeister, Julia Badeda, Dominik Jöst, Dominik Schulte, and Dirk Uwe Sauer. "Digital twin for battery systems: Cloud battery management system with online state-of-charge and state-of-health estimation." Journal of energy storage 30 (2020): 101557.

[39] Park, Seongyun, Jeongho Ahn, Taewoo Kang, Sungbeak Park, Youngmi Kim, Inho Cho, and Jonghoon Kim. "Review of state-of-the-art battery state estimation technologies for battery management systems of stationary energy storage systems." Journal of Power Electronics (2020): 1-15.

[40] Wang, Yujie, Jiaqiang Tian, Zhendong Sun, Li Wang, Ruilong Xu, Mince Li, and Zonghai Chen. "A comprehensive review of battery modelling and state estimation approaches for advanced battery management systems." Renewable and Sustainable Energy Reviews 131 (2020): 110015.

[41] Gou, Bin, Yan Xu, and Xue Feng. "State-of-health estimation and remaining-useful-life prediction for lithium-ion battery using a hybrid data-driven method." IEEE Transactions on Vehicular Technology 69, no. 10 (2020): 10854-10867.

[42] Sauer, Dirk Uwe Sauer, Hendrik Zappen Zappen, Marcus Knips Knips, Hannes Nordmann Nordmann, Markus Lelie Lelie, Thomas Braun Braun, and Florian Ringbeck Ringbeck. "Battery Management System Hardware Concepts: An Overview." (2018).

[43] Yang, Ruixin, Rui Xiong, Hongwen He, Hao Mu, and Chun Wang. "A novel method on estimating the degradation and state of charge of lithium-ion batteries used for electrical vehicles." Applied Energy 207 (2017): 336-345.