Hindawi
Advances in Materials Science and Engineering
Volume 2022, Article ID 3379574, 8 pages
https://doi.org/10.1155/2022/3379574

Review Article

Review on Li-Ion Battery with Battery Management System in Electrical Vehicle

M. Siva Ramkumar,[1] **C. Subba Rami Reddy**,[2] **Agenya Ramakrishnan**,[1] **K. Raja**,[3] **S. Pushpa**,[4] **S. Jose**,[5] **and Mani Jayakumar**[6]

[1]*Department of Electrical and Electronics Engineering, Karpagam Academy of Higher Education, Coimbatore, India*
[2]*Department of Electrical and Electronics Engineering, B V Raju Institute of Technology, Narsapur, Telangana 502313, India*
[3]*Department of Mechanical Engineering, VelTech Rangarajan Dr Sagunthala R&D Institute of Science and Technology, Chennai, Tamil Nadu 600062, India*
[4]*Department of Electrical and Electronics Engineering, Panimalar Engineering College, Chennai, Tamil Nadu 600123, India*
[5]*Department of Technology Management, School of Mechanical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu 632014, India*
[6]*Department of Chemical Engineering, Haramaya Institute of Technology, Haramaya University, P.B. No. 138, Dire Dawa, Ethiopia*

Correspondence should be addressed to Mani Jayakumar; drjayakumarmani@haramaya.edu.et

Received 30 March 2022; Revised 27 April 2022; Accepted 30 April 2022; Published 13 May 2022

Academic Editor: Samson Jerold Samuel Chelladurai

In this paper, functions of BMS in elections vehicles are explained. The BMS consists of number of electronics components for monitoring and controlling the functions of batteries in electrical vehicles (EVs). Nowadays, the EV has more concentrations because it has number of merits like compact in size, does not require fossil fuel so it is environment friendly, and cost-saving. The main components in EV are batteries because batteries decide the performance and efficiency of EV. So, we should give more importance to batteries. Battery is controlled and monitored with the help of BMS. The BMS protects the battery and increases life time and efficiency due to charging discharging process.

1. Introduction

Electrical vehicles are automobiles that are powered entirely or partially with the aid of energy [1]. Electric powered vehicles have minimum operating expenses since they have fewer moving components to maintain, and they may be additionally very eco-friendly due to the fact they use very little fossil fuels (petrol or diesel) [2]. Consider Figure 1. It is a basic block diagram of EV with battery management system. The acceleration/pedal is connected to the power converter through the electronic control unit. The power converter is connected to the bidirected electric motor [3]. The electric motor is connected to wheels through the mechanical drive. Battery is directly connected to the power converter. The BMS is bidirectionally connected to battery and electric control unit [4].

BMS measures and monitors the speed of them vehicle power usage from batteries of vehicle and power usage from the batteries [5]. BMS also monitors state of change (SOC), state of health (SOH), temperature, over charging, and over discharging the battery.

When the battery over discharging process BMS give to signal to Electronics Control Unit. This unit produces control signal to converter and adjusts speed of motion [6].

This process protects increase the life time of battery and increase the performance and efficiency of EV.

1.1. Types of Electrical Vehicles. Electric vehicles have low running cost as they have much fewer shifting parts for keeping and also very environmentally pleasant as they use little or no fossil fuels (petrol or diesel). Even as a few EVs

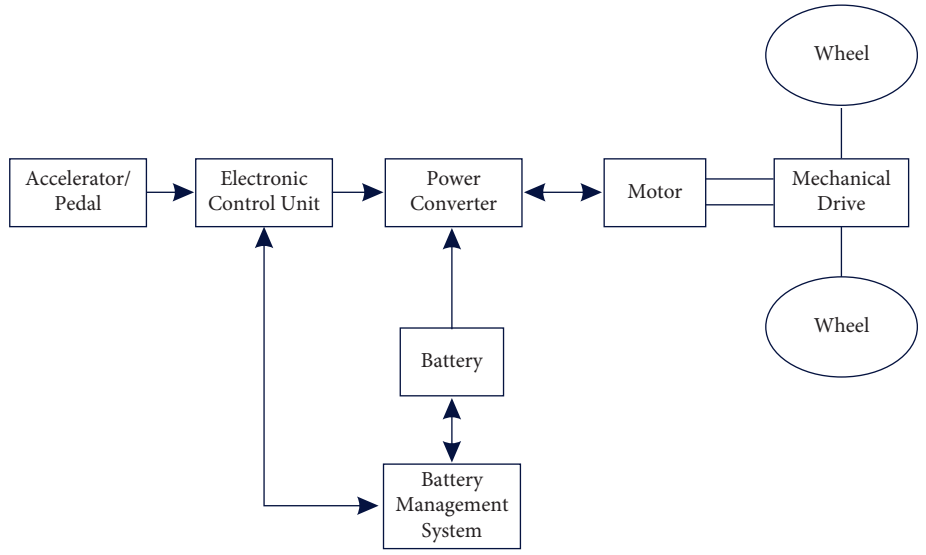

Figure 1: Block diagram of BMS in EV.

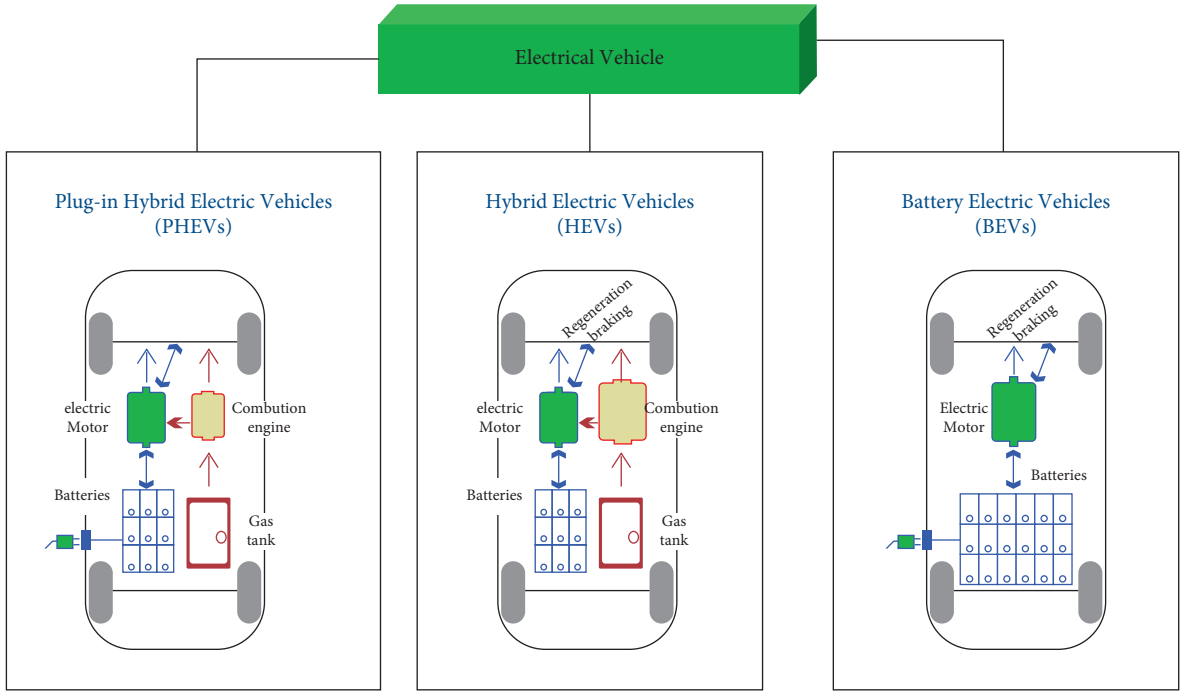

Figure 2: Types of electrical vehicles.

used lead acid or nickel steel hydride batteries, the same old for contemporary battery electric powered cars is now considered to be lithium-ion batteries as they have a greater durability and are top notch at keeping power, with a self- those batteries as they are able to enjoy thermal runaway, that have, for example, caused fires or explosions inside the tesla models, even though efforts had been made to improve the protection of these batteries [7].

Based on the storage system, electrical vehicles are mainly classified in three ways (Figure 2):

(1) Battery electric vehicles (BEVs)

(2) Plug-in hybrid electric vehicles (PHEVs)

(3) Hybrid electric vehicles (HEVs)

1.1.1. Battery Electric Vehicles (BEVs). The battery electrical vehicle is a complete electrical vehicle because here the electrical batteries are only used for the energy system [8].

The large capacity battery packs are used for electrical vehicle battery [9].

This type of electrical vehicle has some advantages and disadvantages [10].

Advantages are as follows:

(i) Environment friendly

(ii) No fossil fuel requirement

(iii) Less maintenance

Disadvantages are as follows:

(i) Charging time of battery

(ii) Speed limit

1.1.2. Plug-In Hybrid Electric Vehicles (PHEVs). Plug in Hybrid Vehicle is the combination of ICE with an Electric Motor along with batteru back-up . Which is also known as Hybrid EVs [11].

PHEVs normally have larger battery packs and more efficient electric motors than HEVs as the electric system does a lot of the heavy lifting while driving [12]. This means that the PHEVs can drive only one mode like electrical mode (or) ICE mode [13]. Driving a PHEV is like to drive a hybrid, as the car will automatically recharge the battery and switch between ICE and electric power based on conditions. Yet, drives have the choice of beating up PHEVs with both energy and electricity [14].

Advantages are as follows:

(i) Lower CO_2 emissions

(ii) Better fuel economy

Disadvantages are as follows:

(i) Relatively expensive

(ii) Complex to maintain

1.1.3. Hybrid Electric Vehicles (HEVs). Hybrid EV is a combination of Electrical Morton with internal combustion engine [15].

This is mainly used for highway driving normally which acts as an electrical vehicle, when the speed wants to be increased. Internal combustion engine is used [16].

HEV technology automatically charges the battery through what is known as regeneration retardation and activates the electric motor system when conditions are suitable, meaning motorists do not have to cover charge or plug the buses into power outlets.

Advantages are as follows:

(i) Small fuel requirement

(ii) Used in both electrical mode and ICE mode [17]

Disadvantages are as follows:

(i) It also produced carbon emission

(ii) It also required fossil fuel

While capability numbers vary between battery models and makers, lithium-ion battery technology has been well-proven to possess a considerably higher energy density than lead acid batteries. This suggests that a lot of energy will be kept in a very lithium-ion battery victimization as an equivalent physical area.

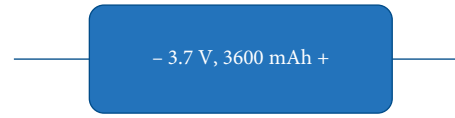

Figure 3: Single cell arrangement.

2. Li-Ion Battery

Most of the nickel-based system uses lithium-ion batteries because they have higher voltage and higher density. The Li-ion battery cells are made up of prismatic or punch or cylindrical design.

Li-ion batteries are very important components in the battery management system. This Li-ion battery banks are classified into 2 ways. 30–1000VAC or 6–1500VDC is defined as high voltage [18].

Under 30VAC and 60VDC is a low voltage device working configuration of Li-ion battery:

In Li-ion batteries, cells are connected in various configurations depending on requirement capacity.

(i) Single cell configuration

(ii) Series configuration

(iii) Parallel configuration

(iv) Series-parallel configuration

2.1. Single Cell Arrangement. Single cell arrangement is defined as single battery or simplest pack of battery because these types of arrangement consist of only one battery placed in the storage system [19].

It is very compact and easily handles the small appliance. Normally, Li-ion battery has 3.7 V, e.g., mobile phone, wall clock, and tab let. Figure 3 represents the single cell arrangement of battery.

2.2. Series Cell Arrangement. Some of applications need high rating voltage. In this situation, a number of single cells (Li-ion) are connected in series combination. Because sum of voltage rating of each cell is considered as total value of battery, the nominal voltage rating of Li-ion battery cell is 3.7 V. Required voltage is 10.2 V means; three battery cells are connected in series [20]. Figure 4 shows the series cell arrangement of batteries.

Total voltage = 3.7 + 3.7 + 3.7 = 11.1 V.

Each cell has 3.7 V, the total number of cells is 3.50, and sum of three cell voltages is 11.1 V.

Similarly, the required voltage is more, and the number of series connection Li-ion batteries is increased. [21].

2.3. Parallel Cell Arrangement. Parallel cell arrangement is used for higher current rating requirement. Li-ion batteries normally have nominal voltage and current ratings as 3.7 V and 3400mAh. Three numbers of Li-ion batteries are connected in parallel [22]. Figure 5 shows the parallel cell arrangement of batteries.

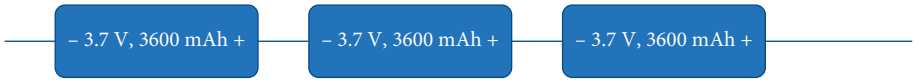

Figure 4: Series cells arrangement.

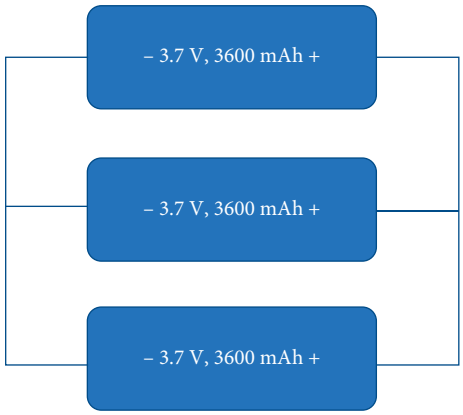

Figure 5: Parallel cell arrangement.

2.4. Serial-Parallel Arrangement. For the purpose of higher voltage and higher capacity battery pack, this serial-parallel arrangement is used.

Figure 6 explains the series-parallel arrangement of the battery cells.

In series-parallel arrangement, positive temperature coefficient switches and charge interrupt devices are used for protecting batteries from overcurrent and higher pressure [23].

Though the nominal voltage of lithium-ion cells with different chemistries varies between 3.2 to 3.7 V (with the exception of Lithium Titanate cell which has the nominal voltage of 2.4 Volts), the charging voltage of lithium cells is generally 4.2 V and 4.35 V.

3. Why the BMS Is Required in EV

In the last few years, there has been a continuous development in energy and strength of lithium-ion batteries, resulting inside the opening of latest development throughout all industries [24]. The features of excessive strength density, low self-discharge, and reduced price cause them to an excellent alternative for electric vehicle batteries. In conjunction with all of the advantages to be had from those batteries, safety problems related with those batteries want to be considered for adoption of electric vehicle. Battery management device in electric vehicles is a mainly designed electronic circuit that ensures the safety and stability of these battery packs [25].

A battery percent in an electric vehicle is a combination of a couple of modules of cells, and every module is a set of each cell. Its miles are hard to manage overall performance of a battery percent because every cell in every module can get charged and discharged at varying value. In addition, each cell has a specific operational nation due to the distinction in temperature, state of health, and country of price.

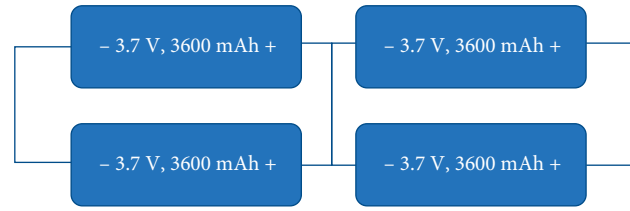

Figure 6: Serial-parallel arrangement.

Therefore, for a green and safe operation, each battery cell wishes to be monitored independently [26].

In PHEVs, the chargers are connected directly. This process affects the performance of battery and life time of the battery and also affects the efficiency of the vehicle. For this reason, the BMS is very important in PHEV.

In HEV, the batteries depend upon the braking system to charge the battery. This process indirectly affects the battery performance because the unstable process of charging affects the battery lifetime and performance of the battery.

Most electrical vehicles use a cooling loop. This loop sometimes contains associated ethylene glycol fluid. The fluid is circulated through the batteries and a few of the electronics, exploitation an electrical pump. This loop contains a radiator to unharness heat to the surface air.

3.1. Battery Management System. BMS is a protection device. It is used to protect the batteries from EV. BMS is a main control unit for battery operations.

Initially, the capacity of battery parameters is fixed and makes sure the operating values because these values are compared with current process value [27].

BMS consists of many important parameters as follows:

(1) State of change
(2) State of health
(3) Thermal management
(4) Control unit
(5) Cell monitoring

Figure 7 shows the function of BMS in EV. The overall process in the battery management system is as follows.

The overall monitoring process of cell performance is called cell monitoring.

Here, over charging and over discharging of battery and life time of batteries are measured [28].

If any fault (or) irregular actions occurred, the safety signals generated control the fault process.

(1) State of Charge. The state of charge is one of important parameters in batteries. Generally, SOC is defined as the radio between current storage capacity to total storage capacity of batteries [29].

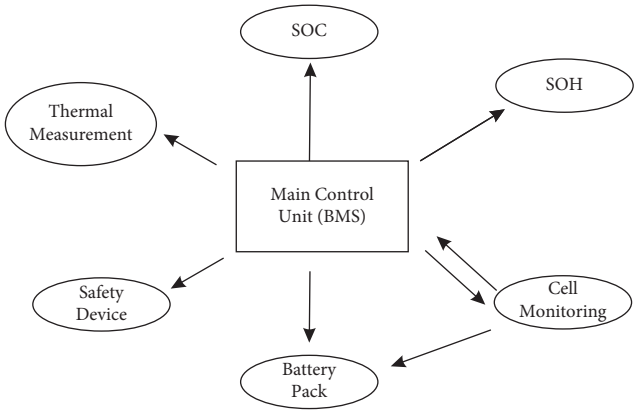

Figure 7: Function of BMS in EV cell monitoring.

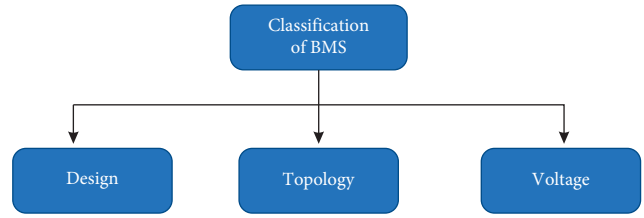

Figure 8: Classification of BMS.

Figure 9: Function of low voltage BMS.

Figure 10: Function of high voltage BMS.

When charging process is doing, the capacity of batteries measured continuously. It the amount of charging is reached to battery capacity; the charging is stopped.

(2) State of Health. The state of health is defined as ratio between the remaining charging in the battery, divided by the maximum charge that can be delivered by the battery [30].

(3) Thermal Management. It is used to measure the temperature of battery pack during the process of charging, discharging, and running of EV.

The higher temperature increase, fault operation of components which increase, failed of components.

To avoid this, thermal management systems are used for measuring temperature level in battery pack.

Its temperature is increased, and the control signal is given to coolant circuit and activates cooling process for controlling the temperature level. [31].

3.2. Classification of BMS. Figure 8 represents the classification of BMS. The classification depending on different categories is explained.

3.2.1. Depends on Design. In the design wise, the BMS is classified as follows:

(1) Production circuit model

(2) BMS

(1) Production Circuit Model. The primary protection circuits control all of the fundamental safety features: overvoltage, underneath-voltage, overcurrent, and on occasion over and under temperature. Additionally, maximum of the world class designs that we produce additionally include a secondary safety circuit which will safe gaurd the battery cells as the primary protection unit [32].

The protection circuits are contained which is usually referred to as the protection circuit module (PCM).

The PCM is a part of the battery management machine (BMS) which manages the electronics of a rechargeable battery % by tracking its nation, reporting that data, balancing the cells together with protecting the battery, and controlling its surroundings.

Battery safety circuits for the maximum annoying packages are operated commonly by means of Integrated Circuits (ICs) typically using MOSFETS to replace lithium cells inside and outside of circuit. The over-present-day protection is commonly supplied while the IC detects the top present-day limit of the battery being reached which interrupts the circuit [33].

(2) Battery Management System. BMS is an extra sophisticated and intelligent shielding circuit. It includes extra modules like manipulate circuitry, control, and display modules. These modules other than controlling offer actual time records of the battery percent. It consists of a number of 2-wheeler, 3-wheeler, public and personal motors, stationary applications, and so on.

3.2.2. Depends on Topology. Depending on the topology, the BMS is classified as

(1) Centralized BMS

(2) Modular BMS

(3) Distributed BMS

(1) Centralized BMS. In centralized BMS, there is a single board comprising a centralized controller and a smart circuit for all the operations and internal communication. The centralized controller performs the functions of monitoring, maintaining battery voltages, temperature, and cell balancing by means of an instantaneous reference to each cell of the battery. The total board is commonly powered from battery output. The wire harness collected records related to battery state of health and state of charge are communicated internally and externally by the smart circuit board [34].

Table 1: Comparison of Li-ion battery.

S. No.	Types of batteries	Life cycle	Temperature	Heavy weight	Easy access	Energy efficient
1	Lithium-ion	High	Yes	Yes	Yes	Good
2	Nickel-metal	Low	No	Yes	No	Good
3	Ultra capacitor	Low	Yes	Yes	No	Good
4	Lead acid	High	No	Yes	Yes	Good

(2) Decentralized BMS. Decentralized BMS does not contain any main controller for all units. They have various topologies for controlling the BMS components.

In decentralized BMS, the cell tracking and smart circuit board is part of different meeting units. There are approaches, specifically modular and master slave, for implementation of this type of BMS. This topology ensures excessive reliability in comparison to centralized BMS.

(3) Modular BMS. BMS consists of two modules: one is multiple modules and another one is identical module. These two modules are connected through the number of wires.

(1) Multiple modules

(2) Identical module

The multiple modules are connected to all the components and control and monitor the performance of all components.

The identical module collects the information from all components and report to multiple modules. The multiple modules give control signal for controlling process depending on output from the identical module.

So, each module has interconnections through wires.

(4) Distributed BMS. A distributed BMS is slightly different from other topologies. While the electronics are grouped and housed independently from the cells in other topologies, a distributed BMS has the electronics contained on cell boards that are placed directly on the cells being measured.

Many number of wires are being used in EVs for Battery Management System (BMS) for communication purposes between BMS Controller to dispatches [35].

3.2.3. Based on the Voltage. In BMS, battery pack is very important because battery is the main energy system in EV. This battery packs are classified into two ways:

(1) Low voltage

(2) High voltage

(1) Low Voltage BMS. Low voltage BMS supports 12 to 16 faucets depending on the required module and 8 temperature sensors. The number of cells is added through the cell interface. Figure 9 proposes the functionality of the low voltage BMS.

(2) High Voltage BMS. HV-BMS has more advantages compared with LV-BMS. Here, the HV-BMS increases safety and reliability of battery. It prevented the damages for individual cells and batteries and increased the efficiency and lifetime of battery [36].

Figure 10 shows the function of high voltage BMS. The high voltage rating in BMS performance is explained.

4. Advantage of BMS

(i) A BMS increases the life time of battery cells in EV

(ii) Easily measures the cells voltage

(iii) Finds any fluctuation and other disturbance very easily

(iv) Easily controls the performance of battery cells

(v) Controls the usage of energy from battery pack

(vi) Increases the reliability and stability

(vii) Increases the performance of EV

(viii) Reduces the usage of fossil fuels

(ix) Controls the charging and discharging produced depending on battery capacity

(x) Maintenance is low compare than fuel vehicle.

5. Disadvantages of BMS

(i) Battery charging time is long

(ii) Charging stations are not familiar to all places

(iii) In high loaded vehicles, the battery size is large

(iv) It required all time electric power for charging purpose

5.1. Comparision of Li-Ion Batteries with Other Batteries. Table 1 shows the comparison of Li-ion battery. The advantage of Li-ion battery with other batteries is explained.

In just five times, the capacity of lithium-ion batteries reduces to 70–90. This short lifetime indicates that there will be a farther boost to demand for lithium-ion batteries to replace those in heavily used battery-powered products similar as electric vehicles.

6. Conclusion

In Li-ion batteries, BMS, to improve the monitoring sensor signals. These signals are used for measuring the real time value of SOC, SOH, and temperature rating. These values help to increase the performance and improve the process of BMS in EV. When charging and discharging processes are controlled, the usage of energy in the battery is also controlled. This process improves the life time of the battery and efficiency of the EV. Nowadays, the controlling process is improved in two ways; it is improving hardware components

and another one is improving the algorithm coding method. The Li-ion batteries have followings merits:

(i) The Li-ion batteries have higher energy density.

(ii) It had lower self-discharge time compared with another rechargeable cell.

(iii) It does not require maintenance component during the performance.

(iv) The nominal voltage rating of Li-ion batteries is 3.7 V. It is higher than other battery cell voltage ratings.

(v) Different types of Li-ion batteries are available, and we choose the best one with respect to requirement.

Data Availability

All the data supporting the results of this study are included within this article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] A Internationale Pour L'′Evaluation Du Rendement Scolaire, *Global EV outlook 2016: Beyond one million electric cars*, OECD Publishing, Paris, France, 2016.

[2] A. Mahmoudzadeh Andwari, A. Pesiridis, S. Rajoo, R. Martinez-Botas, and V. Esfahanian, "A review of battery electric vehicle technology and readiness levels," *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 414–430, 2017.

[3] X. Hu, C. Zou, C. Zhang, and Y. Li, "Technological developments in batteries: a survey of principal roles, types, and management needs," *IEEE Power and Energy Magazine*, vol. 15, no. 5, pp. 20–31, 2017.

[4] K. Liu, K. Li, Q. Peng, and C. Zhang, "A brief review on key technologies in the battery management system of electric vehicles," *Frontiers of Mechanical Engineering*, vol. 14, no. 1, pp. 47–64, 2018.

[5] S. Nejad, D. T. Gladwin, and D. A. Stone, "A systematic review of lumped-parameter equivalent circuit models for real-time estimation of lithium-ion battery states," *Journal of Power Sources*, vol. 316, pp. 183–196, 2016.

[6] J. Meng, G. Luo, M. Ricco, M. Swierczynski, D.-I. Stroe, and R. Teodorescu, "Overview of lithium-ion battery modeling methods for state-of-charge estimation in electrical vehicles," *Applied Sciences*, vol. 8, no. 5, p. 659, 2018.

[7] S. Barcellona and L. Piegari, "Lithium ion battery models and parameter identification techniques," *Energies*, vol. 10, no. 12, 2007.

[8] D. Datong Liu, W. Wei Xie, H. Haitao Liao, and Y. Yu Peng, "An integrated probabilistic approach to lithium-ion battery remaining useful life estimation," *IEEE Transactions on Instrumentation and Measurement*, vol. 64, no. 3, pp. 660–670, 2015.

[9] D. Wang, F. Yang, K.-L. Tsui, Q. Zhou, and S. J. Bae, "Remaining useful life prediction of lithium-ion batteries based on spherical cubature particle filter," *IEEE Transactions on Instrumentation and Measurement*, vol. 65, no. 6, pp. 1282–1291, 2016.

[10] J. Xie, J. Ma, and K. Bai, "Enhanced Coulomb counting method for state-of-charge estimation of lithium-ion batteries based on peukert's law and coulombic efficiency," *Journal of Power Electronics*, vol. 18, no. 3, pp. 910–922, 2018.

[11] J. G. Zhu, Z. C. Sun, X. Z. Wei, and H. F. Dai, "A new lithium-ion battery internal temperature on-line estimate method based on electrochemical impedance spectroscopy measurement," *Journal of Power Sources*, vol. 274, pp. 990–1004, 2015.

[12] M. Galeotti, L. Cinà, C. Giammanco, S. Cordiner, and A. Di Carlo, "Performance analysis and soh (state of health) evaluation of lithium polymer batteries through electrochemical impedance spectroscopy," *Energy*, vol. 89, pp. 678–686, 2015.

[13] X. Dang, L. Yan, K. Xu, X. Wu, H. Jiang, and H. Sun, "Open-circuit voltage-based state of charge estimation of lithium-ion battery using dual neural network fusion battery model," *Electrochimica Acta*, vol. 188, pp. 356–366, 2016.

[14] Q. Yu, R. Xiong, C. Lin, W. Shen, and J. Deng, "Lithium-ion battery parameters and state-of-charge joint estimation based on h infinity and unscented kalman filters," *IEEE Transactions on Vehicular Technology*, vol. 66, 2017.

[15] M. Ye, H. Guo, and B. Cao, "A model-based adaptive state of charge estimator for a lithium-ion battery using an improved adaptive particle filter," *Applied Energy*, vol. 190, pp. 740–748, 2017.

[16] L. Zheng, L. Zhang, J. Zhu, G. Wang, and J. Jiang, "Co-estimation of state-of-charge, capacity and resistance for lithium-ion batteries based on a high-fidelity electrochemical model," *Applied Energy*, vol. 180, pp. 424–434, 2016.

[17] L. Zhi, Z. Peng, W. Zhifu, S. Qiang, and R. Yinan, "State of charge estimation for li-ion battery based on extended kalman filter," *Energy Procedia*, vol. 105, pp. 3515–3520, 2017.

[18] D. Zhou, K. Zhang, A. Ravey, F. Gao, and A. Miraoui, "Online estimation of lithium polymer batteries state-of-charge using particle filter-based data fusion with multimodels approach," *IEEE Transactions on Industry Applications*, vol. 52, no. 3, pp. 2582–2595, 2016.

[19] A. Ali and D. Söffker, "Towards optimal power management of hybrid electric vehicles in real-time: a review on methods, challenges, and state-of-the-art solutions," *Energies*, vol. 11, no. 3, p. 476, 2018.

[20] S. Zhang, R. Xiong, and F. Sun, "Model predictive control for power management in a plug-in hybrid electric vehicle with a hybrid energy storage system," *Applied Energy*, vol. 185, pp. 1654–1662, 2017.

[21] A. C. Luna, N. L. Diaz, M. Graells, J. C. Vasquez, and J. M. Guerrero, "Mixed-integer-linear-programming-based energy management system for hybrid PV-Wind-Battery microgrids: modeling, design, and experimental verification," *IEEE Transactions on Power Electronics*, vol. 32, no. 4, pp. 2769–2783, 2017.

[22] B. Sakhdari and N. L. Azad, "An optimal energy management system for battery electric vehicles," *IFAC-PapersOnLine*, vol. 48, no. 15, pp. 86–92, 2015.

[23] S. Aghajani and M. Kalantar, "A cooperative game theoretic analysis of electric vehicles parking lot in smart grid," *Energy*, vol. 137, pp. 129–139, 2017.

[24] C. Chellaswamy and R. Ramesh, "Future renewable energy option for recharging full electric vehicles," *Renewable and Sustainable Energy Reviews*, vol. 76, pp. 824–838, 2017.

[25] L. Li, L. Zhou, C. Yang, R. Xiong, S. You, and Z. Han, "A novel combinatorial optimization algorithm for energy management strategy of plug-in hybrid electric vehicle," *Journal of the Franklin Institute*, vol. 354, no. 15, pp. 6588–6609, 2017.

[26] L. Wenxia, S. Niu, H. Xu, and X. Li, "A new method to plan the capacity and location of battery swapping station for electric vehicles considering demand side management," *Sustainability*, vol. 8, pp. 1–17, 2016.

[27] W. A. Appiah, J. Park, S. Byun, M.-H. Ryou, and Y. M. Lee, "A mathematical model for cyclic aging of spinel LiMn2O4/graphite lithium-ion cells," *Journal of the Electrochemical Society*, vol. 163, no. 13, pp. A2757–A2767, 2016.

[28] R. S. Raghavan, A. M. Kumar, and R. Narayanrao, "Intercalation induced surface cracking in electrode particles," *ZAMM - Journal of Applied Mathematics and Mechanics/Zeitschrift für Angewandte Mathematik und Mechanik*, vol. 95, no. 8, pp. 845–858, 2015.

[29] J. Xu, R. D. Deshpande, J. Pan et al., "Electrode side reactions, capacity loss and mechanical degradation in lithium-ion batteries," *Journal of the Electrochemical Society*, vol. 162, no. 10, pp. A2026–A2035, 2015.

[30] B. Yan, C. Lim, Z. Song, and L. Zhu, "Analysis of polarization in realistic li ion battery electrode microstructure using numerical simulation," *Electrochimica Acta*, vol. 185, pp. 125–141, 2015.

[31] F. Sun, H. Markötter, I. Manke, A. Hilger, N. Kardjilov, and J. Banhart, "Three-dimensional visualization of gas evolution and channel formation inside a lithium-ion battery," *ACS Applied Materials & Interfaces*, vol. 8, no. 11, pp. 7156–7164, 2016.

[32] S. Waluś, C. Barchasz, R. Bouchet et al., "Lithium/sulfur batteries upon cycling: structural modifications and species quantification by in situ and operando x-ray diffraction spectroscopy," *Advanced Energy Materials*, vol. 5, no. 16, Article ID 1500165, 2015.

[33] A. W. Brownrigg, G. Mountjoy, A. V. Chadwick et al., "In situ Fe K-edge X-ray absorption spectroscopy study during cycling of Li2FeSiO4 and Li2.2Fe0.9SiO4 Li ion battery materials," *Journal of Materials Chemistry*, vol. 3, no. 14, pp. 7314–7322, 2015.

[34] S. Y. Luchkin, K. Romanyuk, M. Ivanov, and A. L. Kholkin, "Li transport in fresh and aged LiMn2O4 cathodes via electrochemical strain microscopy," *Journal of Applied Physics*, vol. 118, no. 7, Article ID 072016, 2015.

[35] E. Ventosa and W. Schuhmann, "Scanning electrochemical microscopy of li-ion batteries," *Physical Chemistry Chemical Physics*, vol. 17, no. 43, pp. 28441–28450, 2015.

[36] L. Cabo-Fernandez, F. Mueller, S. Passerini, and L. J. Hardwick, "In situ Raman spectroscopy of carbon-coated ZnFe2O4 anode material in Li-ion batteries - investigation of SEI growth," *Chemical Communications*, vol. 52, no. 20, pp. 3970–3973, 2016.