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Review

Lithium-Ion Battery Management System for Electric Vehicles: Constraints, Challenges, and Recommendations

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Abstract: Flexible, manageable, and more efficient energy storage solutions have increased the demand for electric vehicles. A powerful battery pack would power the driving motor of electric vehicles. The battery power density, longevity, adaptable electrochemical behavior, and temperature tolerance must be understood. Battery management systems are essential in electric vehicles and renewable energy storage systems. This article addresses concerns, difficulties, and solutions related to batteries. The battery management system covers voltage and current monitoring; charge and discharge estimation, protection, and equalization; thermal management; and battery data actuation and storage. Furthermore, this study characterized the various cell balancing circuit types, their components, current and voltage stresses, control reliability, power loss, efficiency, size and cost, and their benefits and drawbacks. Secondly, we review concerns and challenges in battery management systems. Furthermore, we identify problems and obstacles that need additional attention for optimal and sustainable battery management systems for electric vehicles and renewable energy storage systems. Our last topic will be on issues for further research.

Keywords: battery management system; cell balancing; charge estimations; BMS issues and challenges

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1. Introduction

The energy storage system (ESS) has become popular in many domains, such as electric vehicles (EV), renewable energy storage, micro/smart-grid applications, etc. Modern EV generations are a reliable substitute for an internal combustion engine (ICE). ICE-based trucks, ships, cargo, and aircraft consume one-third of fossil fuel. ICE and industries are the two primary sources and are the leading causes of the emission of carbon dioxide (CO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen oxides (NO) [1]. These gases cause air pollution that is responsible for the greenhouse effect. In EV, the EES runs the EV motor and machines: air conditioner, navigation lights, etc. The EV is well known as a zero-carbon-emission vehicle, whence the release of SO_2, CO_2, NO, and CO have not been prominent during driving; it would be helpful to consider the environmental challenges and fossil fuel utilization [1,2].

Typically, EVs are fully/partially powered by storage energy (SE) in road-/highway-, rail-, air-, and sea-based vehicles. Nowadays, high-tech vehicles like private cars and city buses are currently being upgraded with ES. The cumulative EV market now stresses sustainable battery development, power-system involvement, tax revenue, cost, e-commerce accessibility, and the edge among the common choices for automation mobility [1,3]. Recently, EVs have been progressively becoming popular in global markets such as China and Europe. Increasing the use of EVs instead of ICE vehicles can alleviate problems, such as global warming and greenhouse gases, that pose a threat to the environment. Numerous countries and companies are inspiring their people to use EVs in ways that are more prudent and convenient for EV implementation and management. EVs are considered an ESS transmitted in a smart/micro-grid system that uses synchronized charging energies to equipoise unbalanced solar power and wind generation. Currently, EV's ESS scales capacity from 17 kW to 200 kW, which is unbelievable because EVs can receive the electricity during the pick-up load period. It makes a fantastic way for the renewable energies' electrical structure to link to the grid, vehicle-to-grid (V2G), and grid-to-vehicle (G2V) [4–6]. In EVs, several energy storage devices (ESD) have been introduced, i.e., the super-capacitor (SC), battery, and fuel cell. Batteries are well-known electrochemical storage devices that supply electricity. In energy combustion, SC is an electromagnetic storage system wherein electrodes and electrolytes store static energy, and liquid hydrogen (H_2) is utilized in fuel cells. Autonomous ESD cells have 1.5 V to 5.5 V, which are connected in series, parallel, or series–parallel combinations in the ESD modules to accomplish the essential power of EV demands. ESD is the electrochemical store, and its chemical reaction happens during the discharging and charging time. The ESD output voltage and capacity rely upon the deterioration of the chemical reaction, which is caused by the shortening of the lifespan and cyclic life. The cell has been aligned askew with internal resistance, the thermal difference, and self-discharge in the ESD pack because of cell formation and overcharge/discharge. Different cells' voltage and power reduction in the ESD packs can cause an explosion during charging [7–10].

The storage energy powers EV accessories, the lighting system, the motor, and various operational mechanisms. The rechargeable ESDs, e.g., Li-ion battery (LIB), lead-acid battery, SCs, and nickel and zinc batteries, are used in EVs. The technological development of ESDs has caused an intense increase in ESD demand in the field of portable electrical apparatuses. However, lead-acid batteries have recently had an extensive worldwide market in solar ESSs, whereas the LIB has future demand in bulk ESS. Different types of ESDs are considered based on specific requirements in EVs [4,11,12]. In EV systems, ESD specifications account for individual cell safety, especially energy storage capacity. The cell voltage of an ESD becomes imbalanced due to the under/overcharge, the cell's internal chemical properties, and temperature profile [1,13]. The ESD lifetime can be increased by reducing the temperature hazards and balancing the cell voltage.

The battery management system (BMS), which is compulsory for an ESS, plays a vital role in EVs, as shown in Figure 1. The BMS ensures the ESD's lifelong service, safety, and balanced facility for EV driving. The BMS is an extensive structure containing inclusive mechanisms and performance assessment for numerous ESD types, cell monitoring, power, thermal management, charging/discharging procedures, health status, data acquirement, cell protection, and lifetime.

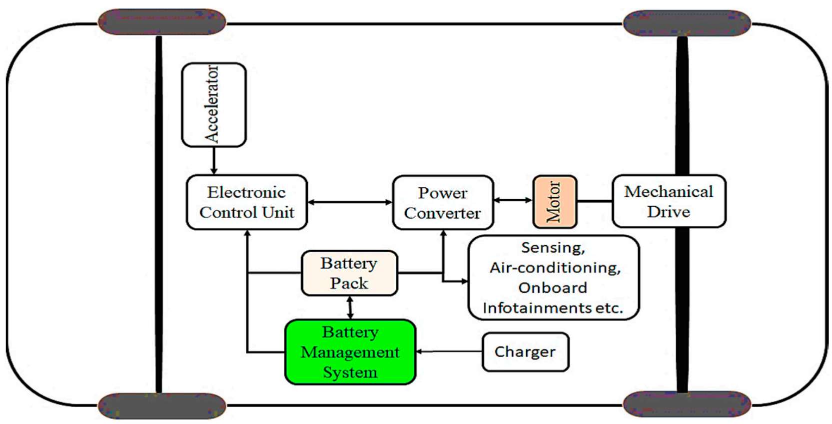

Figure 1. BMS operation inside the EV.

Cell voltage imbalance occurred during the charging/discharging time for internal electrochemical reactions in ESD. In BMS, cell voltage balancing is the leading work to improve cell life span and safety [1,4,14]. Researchers and scientists are working on BMSs to develop highly efficient cell voltage/charge balancing systems to balance the cell voltage/charge, protect the cell from hazardous explosions, and improve its reliability.

Motivation and objectives: Much research has been conducted on the BMS working environments for EV systems. The BMS study field creates more attention and increases the research scope at the academic or industrial level. The significance of BMS research is illustrated in Figure 2, where we present the number of publications since 2010. Shen and Gao [15] analyzed BMSs based on modeling efforts. Lelie et al. reviewed BMS hardware concepts [16]. In [17,18], there is a discussion of battery modeling and state-of-charge estimations. Lin, Jiayuan, et al., reviewed battery thermal management systems LIB [19], and See, K.W. et al., reviewed safety issues on BMSs on a large scale LIB [20]. Tran, Manh-Kien, et al., reviewed cloud-based smart BMSs for LIB [21]. However, most of the study focused on BMS-specific parameters (i.e., battery modeling, state-of-charge estimation, voltage balancing, heat, safety, etc.), for which some points are still lacking. Considering these lacking points, the primary objective of this study is to present a brief survey and to summarize the existing BMSs, descriptions, issues, challenges, and recommendations based on various researchers' efforts. This study started with background on ESSs, BMSs, and EV-applicable batteries. Then a brief overview of BMSs, their issues, and challenges are presented. Finally, the perspective of BMS improvement for the future is presented. Figure 3 illustrates the taxonomy of an overview of the study.

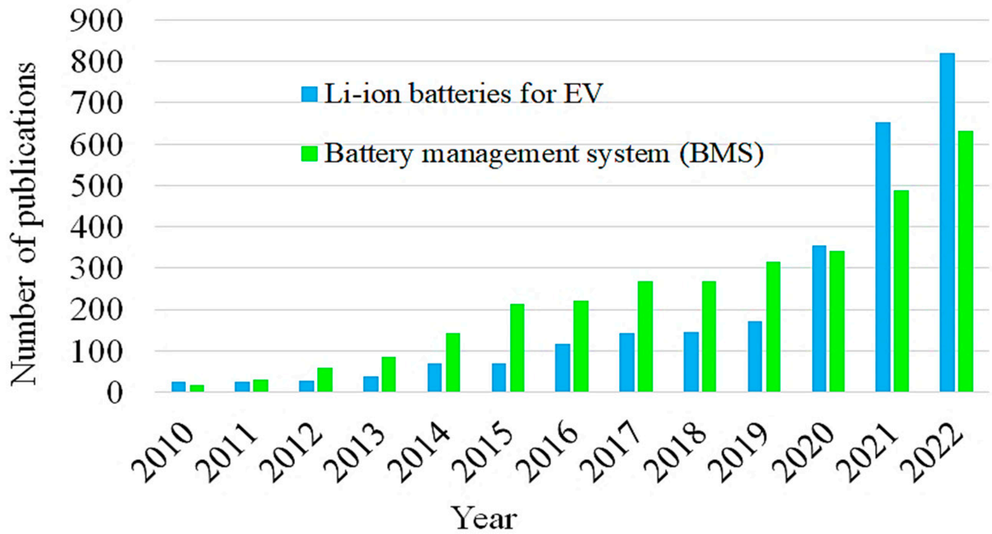

Figure 2. Number of reviewed published articles on BMSs (data sources: Scopus; keywords: Li-ion battery for EV and battery management system; access date: 25 November 2022). https://www.sciencedirect.com/search?qs=Li-ion%20batteries%20for%20EV.

The survey method is described in Section 2. Section 3 presents a short review of the battery. The battery management system is described in Section 4. BMS issues and challenges are presented in Section 5, and Section 6 presents BMS recommendations. Finally, the conclusion is presented in Section 7.

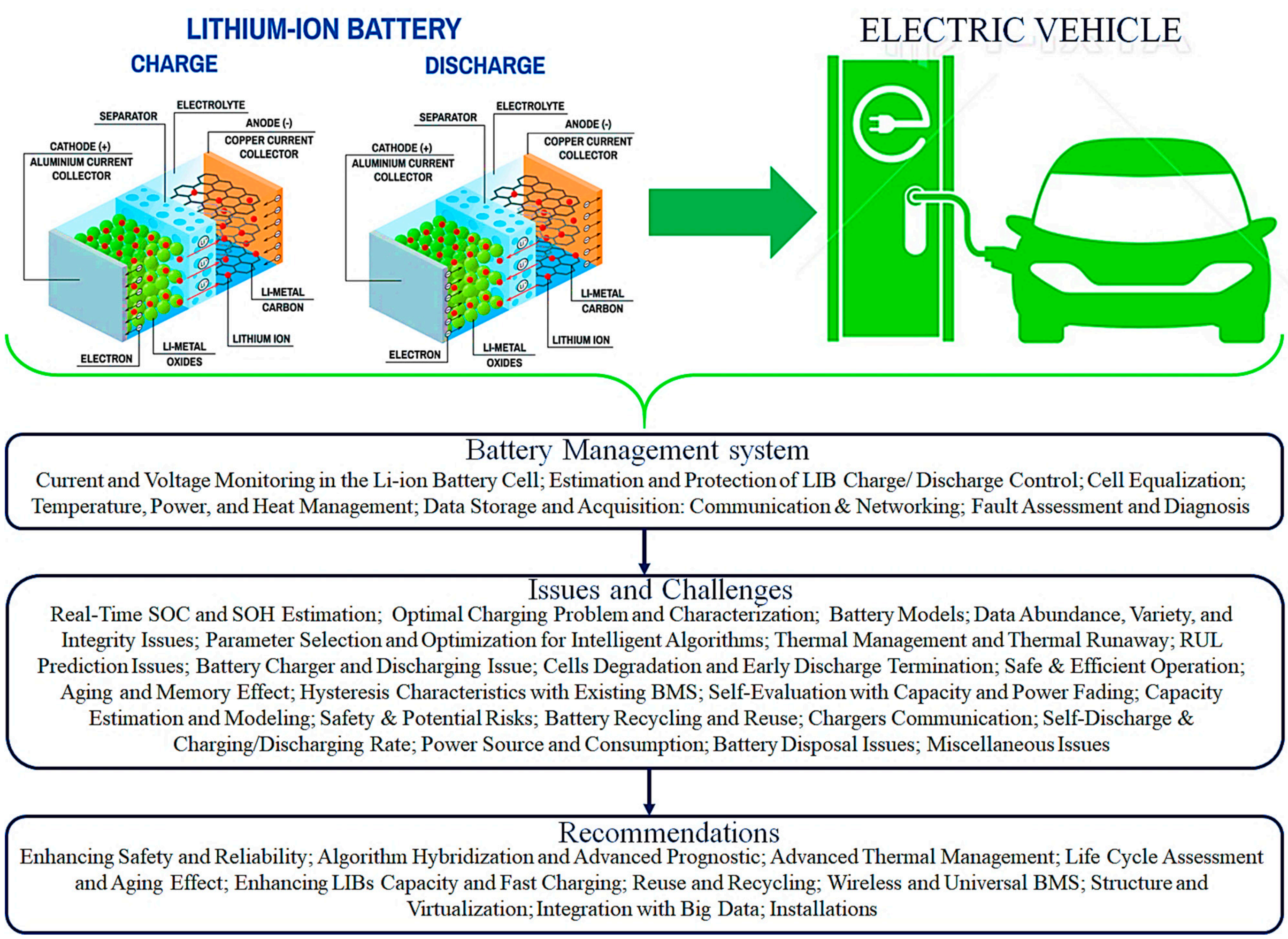

Figure 3. Overview of study.

2. Survey Methods

This survey aims to illustrate a straightforward discussion, critical analysis, and suggestions for BMSs. Therefore, the authors have gathered the most relevant and recent information containing key technologies, drawbacks, and research gaps. This survey determines the number of published articles based on four screening and assessment stages. The initial phase of the systematic literature review is the screening and assessment of BMSs in various databases, i.e., Google Scholar, ResearchGate, IEEE Xplore, ScienceDirect, and MDPI. Subsequently, we found 386 articles for analysis. Secondly, we searched our papers based on crucial work and selected 215 articles for analysis. In the third stage, we selected 155 articles to read the abstract, introductions, and conclusion. Fourthly, we selected 65 articles to read whole sections and content based on journal impact, citations, and the review process. Finally, we considered and established 91 articles to use as references and developed this review.

The result of the survey is divided into four steps. Firstly, the EV-related battery is discussed. Secondly, various aspects of BMSs have been clarified. Thirdly, the issues and challenges of the BMS for EV systems have been investigated and discussed. Finally, future directions for further improvement of BMSs have been presented. The survey structure has been completed in two steps that are as shown in Figure 4.

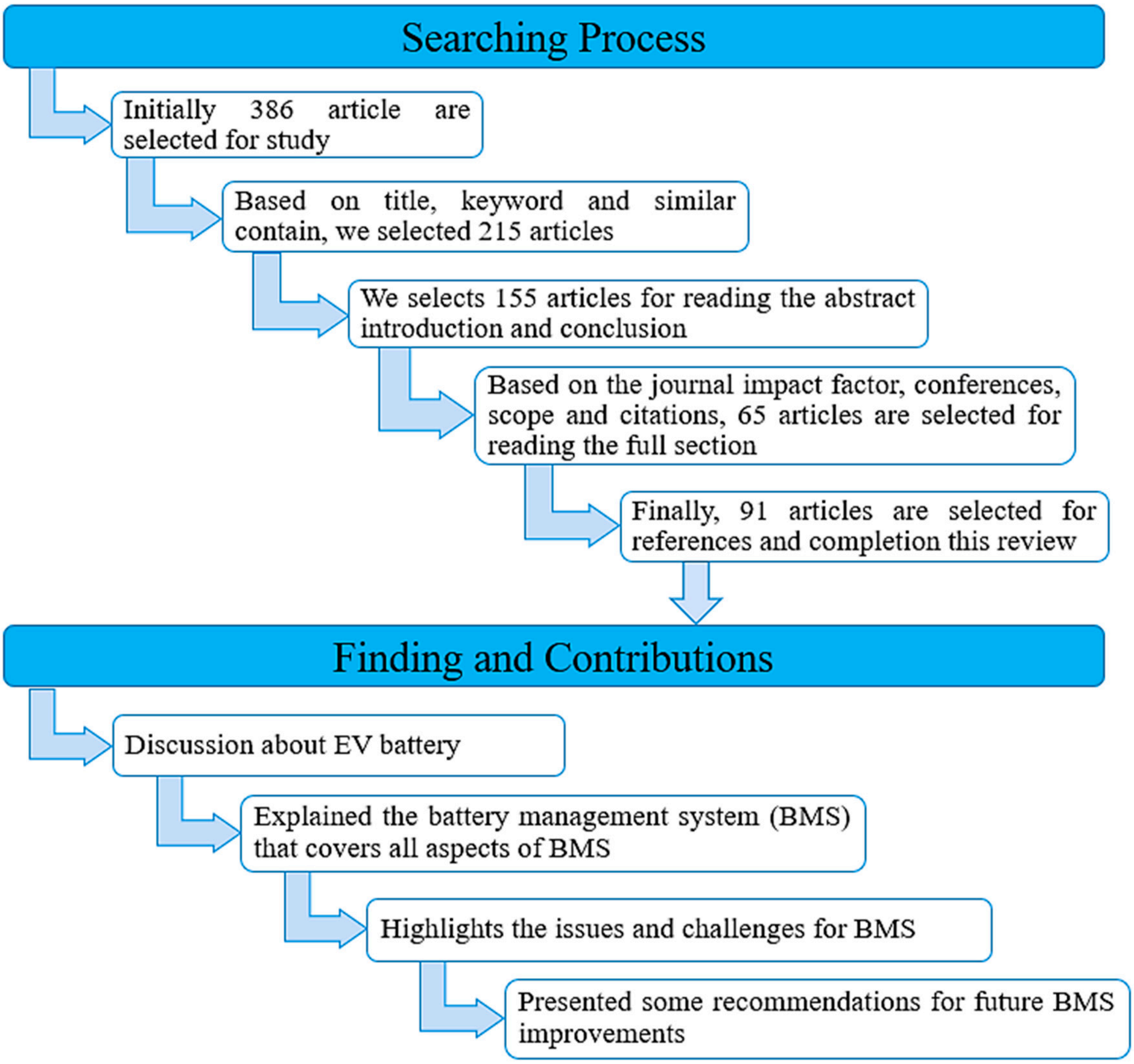

Figure 4. Schematic design of the reviewing methodology.

3. Battery

A battery is an electrochemical ESD that delivers electric power. EVs employ secondary electrochemical batteries, which have greater power and energy. The technological advancement of batteries has significantly impacted the automation/EV sector [22–24]. Researchers have been consistently working on the EV battery system to provide greater specific power and energy density batteries. Batteries with high specific energy and power density, extended life term, and high-temperature tolerance are utilized in EVs. In EVs, various rechargeable batteries are used, such as nickel-based batteries, LIBs, and sodium–sulfur-based batteries [19,25]. LIBs have 0.3 MJ/kg energy density (more than 100 times less than gasoline, which has 48 MJ/kg energy density), but it is a suitable alternative for EV application. At present, LIBs are the most applied EV system.

LIBs are usually utilized in consumer devices, EVs, and grid storage. Positive electrode materials include lithium metal oxide ($LiCoO_2$, $LiNiO_2$, $LiMn_2O_4$) and lithium iron phosphate ($LiFePO_4$). Graphite is often used in negative electrodes. The electrolyte is a non-aqueous lithium salt. Electrical insulation uses a LiPF6 separator. LB offers high energy density, specific energy, long lifespan, high cycle efficiency, quick reaction time, and low individual discharge rates [26–28]. Li-ion batteries' high price and safety hazards when overcharged restrict their usage in the power sector.

4. Battery Management System

LIBs are becoming highly powerful and deliver EV driving power as an alternative to ICE vehicles and in clean transport worldwide. HEV and BEV systems will positively affect the universal economy and the environment. In EV technologies, devices are required to develop their competency during operational hours and safe operation, as well as to secure the ESS. The BMS manages the ES, transmission, control, and management facilities related to EV, along with the charge equalizer, battery cell voltage control, input/output voltage controls, protection, and diagnosing and assessing errors [14,25,29]. Some BMS specifications and functions are present in Figure 5. The BMS also manages the battery charging characteristics and status. The BMS controls the battery's charge and discharge and the load demand of the battery pack. The BMS calculates the lithium's cell voltage levels and saves the cells from over/undercharging. To improve battery performance and lifetime, the BMS should conduct cell balancing techniques using the charge/voltage equalization. The BMS observes the cell operating temperature at some stages, manages a power converter, and operates the battery cell in a way that keeps it healthy and safely functional despite heat. The cell protection mechanism protects the cell from short circuit, overload, current/voltage stress, etc., over time [30–32]. In the EV system, the BMS analyzes and measures the energy-storage distribution processes and defects. The specifications are current and voltage monitoring in the LIB cell; the estimation and protection of LIB charge/discharge control; cell equalization; temperature, power, and heat management; data storage and acquisition; communication and networking, and fault assessment and diagnosis.

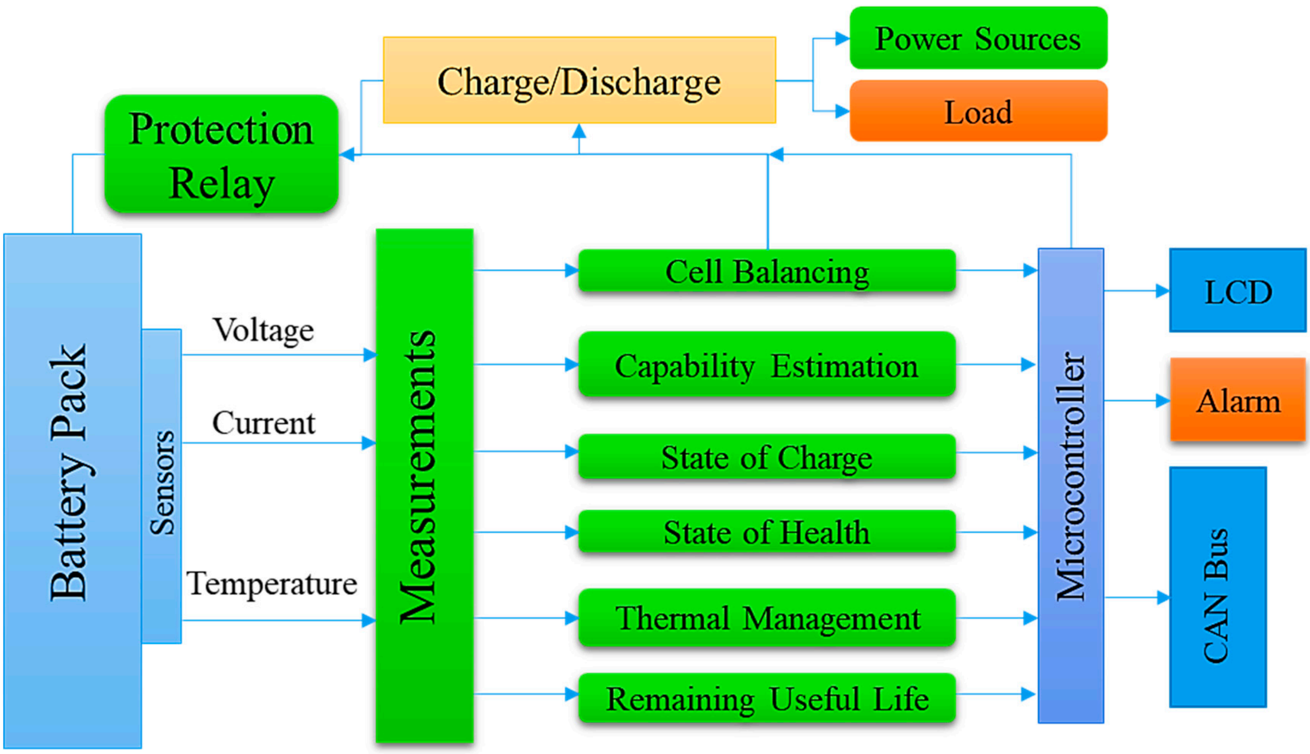

Figure 5. Battery management system, adapted from [1].

4.1. Current and Voltage Monitoring in the Li-Ion Battery Cell

EVs are compactly connected through LIB packs. The battery cells' nature can be different during run times. Constant cell monitoring is essential to determine the state of the cells. The cell monitoring results guide the device's operating efficiency in energy management, power delivery, and safety. It manages cell monitoring under discharge and charge conditions, overcharge and undercharge protection, temperature and heat monitoring, fault detection, the data-acquisition interface, connectivity, and assessment, among other things [33–36]. LIBs deliver constant voltage and current during the discharge time. The unstable cell current and voltage delivery cause cell damage or explosion. During operation, the cell voltage/current levels are required to be regulated to protect the cell from undercharging/overcharging. In addition, the battery pack's voltage and current condition are displayed for further assistance.

4.2. Estimation and Protection of LIB Charge/Discharge Control

LIBs' efficiency and development depend on the charge's state and the discharge situations. The optimal conditions for LIB competency enhance battery energy formation and a flexible life cycle. The conventional charge and discharge panels reduce the memory effect and lengthen the battery's discharge duration. LIBs are discharged by CC–CV (constant current and constant voltage) load, the DCM (discontinuous current mode), and PI (proportionally integrated) controller operations, including the state of feature (SOF), the state of charge (SOC), the state of health (SOH), and remaining useful life (RUL) [37–39]. The SOC indicates the charging–discharging and depth condition of LIBs. The SOC will be measured and examined with several methods, i.e., open-circuit voltage (OCV), Coulomb counting (CC), electromotive Force (EMF), internal resistance, electrochemical impedance spectroscopy, model-based SOC estimation, unscented Kalman filter, extended Kalman filter, Kalman filter (KF), sigma point Kalman filter, H∞ filter, particle filter recursive least square, fuzzy logic (FL), neural network (NN), support vector machine (SVM), sliding mode observer, genetic algorithm, non-linear observers, proportional-integral observer, bi-linear interpolation, hybrid method, and impulse response. A battery's state of health (SOH) is determined by its power density, internal impedance, and self-discharge rate. The SOH demonstrates the overall battery performance. The open-loop technique is used to evaluate the SOH. It depends on the durability model, which accepts the mechanism of lithium-ion loss, side reactions, capacity, internal resistance, and the close-loop battery model for parameter detection.

The SOH will be measured and examined with a process, i.e., CC, OCV, impedance spectroscopy, KF, particle filter, least square, FL, NN, SVM, sample entropy, and probability density function [40–44]. The SOF identifies the actual condition of the battery by determining the output ratio of the battery's existing efficiency in EV systems. The charge/discharge profile of the battery can be calculated, determining SOH, SOC, SOF, and operating temperature. The RUL can measure the SOH of the battery. There has been little work done on the estimation of the RUL. Herein, we present some RUL measured and examined with a process, i.e., adaptive filter technique, intelligent techniques, stochastic technique, Bayesian, naïve Bayes, artificial NN, SVM, particles swim optimization, etc. In EVs, LIB cells are used as ESS, connected in serial and parallel combinations on the battery pack. The stored energy of the ESS is used to drive the motor and other systems in the EV and is charged by the power supply from the outside [1,40,45–47]. A sequential charge–discharge cycle causes pressure and charge imbalance between battery cells due to the diversity of their physical properties. Unbalanced charging profiles are a discrepancy in surviving systems due to temperature effects, manufacturing defects, and cell aging, which reduce ESS's overall efficiency and reliability. Over-discharge can degrade the battery's chemical components and shorten its lifespan. In addition, overcharging might result in cell explosion [4,48]. The BMS can halt the charge and discharge of the battery when it is not in use state or delivering electricity. Therefore, it is essential to protect batteries and extend their storage capacity to their operating rating.

4.3. Cell Equalization

Battery ESSs (BESSs) are increasingly used in EV applications due to their many advantageous characteristics, such as rapid demand response, great flexibility in the installation location, and brief building time [49]. Therefore, BESS contributes positively to the electrical power system, such as voltage and frequency management, black-start capability, standing reserve, renewable energy integration, peak shaving, load leveling, and power quality enhancement. BESS cells are integrated in series/parallel in the strings to achieve the requisite power. So, cells' SOC imbalance is typical in BESS due to an internal or external cause and effect. The manufacturing defect, self-discharge rate, internal impedance, and charge storage volume is the reason for cell imbalances. The unequal distribution is an external reason for temperature increase in a BESS, driven by various self-discharge in the state of the charge and discharge cycles in an unequal cell string [50–53]. Different cell-balancing topologies have been proposed in the last few decades. Those are categorized into two main categories: active balancing and passive balancing, based on their ES elements, utilization, and energy balancing methods illustrated in Figure 6.

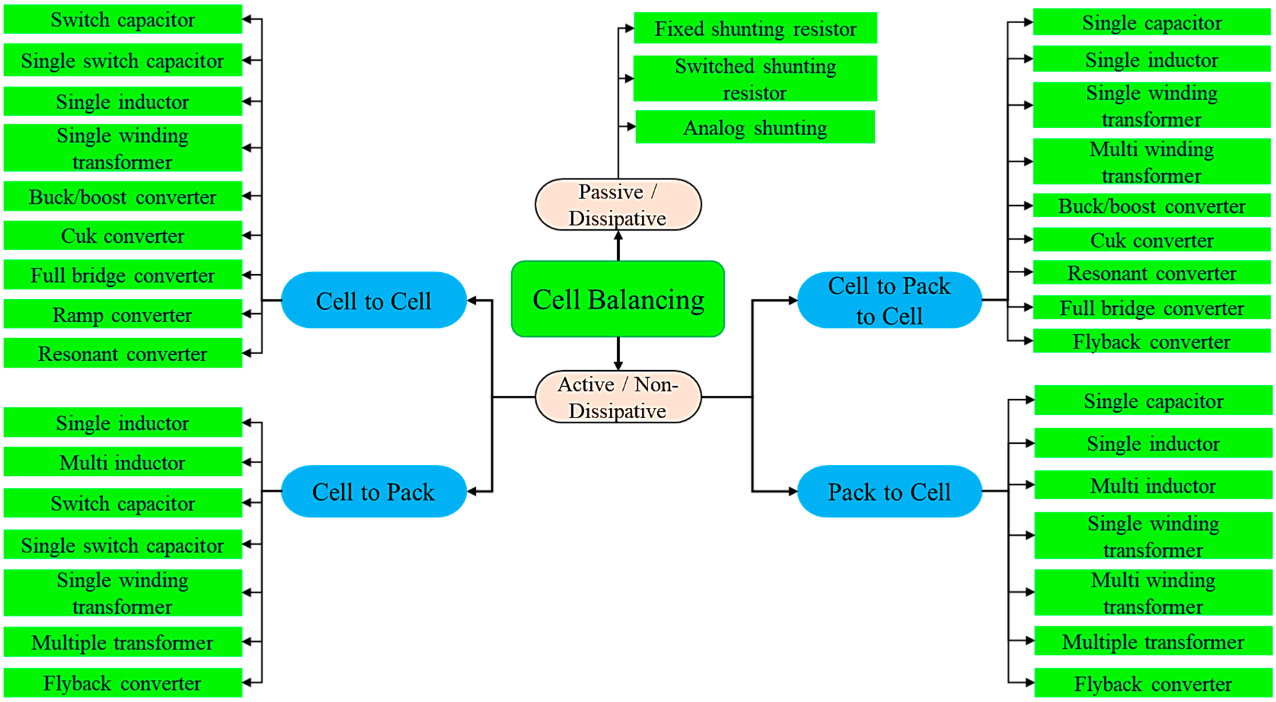

Figure 6. Cell balancing topology.

4.3.1. Passive Cell Balancing

Balancing passive cells requires shunt resistors to reduce excess energy in the form of heat. In dissipative cell balance, the topology reduces extra power until the lower and higher cells' powers are equivalent. This topology offers low cost, simplicity, and a compact size. The disadvantages include heat dissipation, energy loss, and lengthy cell balancing. Shunting resistors are used to balance passive cells [54,55].

4.3.2. Active Cell Balancing

Active cell balancing seems to outperform passive cell balancing. It transfers extra energy between BESS cells using capacitors, converters, transformers, and inductors instead of shunt resistors. Excessive energy cells move the higher energy to lower energy cells based on their energy carrier. Accordingly, cell balance is acquired without energy waste. As an effect, the topology can be utilized regardless of the chemical properties of all cells for the technology. High efficiency and high balancing speed are major benefits, though they come with implementation complexity and high cost. Based on the active elements, active cell balancing is classified into three different categories: capacitors, converters, or inductors and transformers [50,56,57].

- **Cell balancing based on capacitor:** Capacitors aid in achieving cell balance by shifting energy between nearby cells. The primary disadvantages are energy loss during capacitor charging and delayed balancing. Switched capacitors are used in single-tiered, double-tiered, and multiple capacitors [4,58].
- **Cell balancing based on a transformer or inductor:** Transformers or inductors are used to achieve cell equilibrium through the energy transferred from a cell module to another cell module or from cell to cell, where it can achieve cell equilibrium very quickly. However, the disadvantage of this method is the need to include filter capacitors across each cell due to the high cost and frequency of the transformer. The approach variations include a single-winding transformer, multi, multiple winding, and a single/multi-inductor [59,60].
- **Cell balancing based on a converter**: Convertor-based cell balancing has recently gained popularity owing to its unique ability to regulate the whole balancing process. But high cost and complexity remain essential issues. A standard/modified DC–DC converter, such as a buck, boost, or buck–boost converter, flyback converter, resonant converter, full-bridge and cuk converter, or a PWM converter, is used for balancing [61,62].
- **Comparative Analysis:** The balancing speed, charge/discharge capabilities, and primary components needed for balancing and cell application are compared. Table 1 compares them. As little resistance is used for successive mode operation, passive cell balancing is appropriate for applications that consume limited power. Furthermore, passive cell balancing is cheap. Nevertheless, active cell balancing saves more energy and can manage more power than passive cell balancing. If appropriately used, full-bridge converters may solve two primary obstacles that BESSs face (DC/AC power and cell balancing system). Another advantage is its fast balancing speed. During charging/discharging, the cell with lower/higher energy precedes the cell with higher/lower energy. More details of active and passive charge balancing circuits are discussed in [63].

Table 1. Comparison of the charge balancing topologies [4,53,63].

Balancing Techniques, Methods, and Types	No. of Elements for Balancing (n Cells)	Balancing Time, Control Complicity	Power Loss, Efficiency	Voltage and Current Stress	Size and Cost	Benefits	Drawbacks
Fixed Shunt, Passive and Fixed	n resistors	Slow, Very Simple	Very High, Poor	Zero/Zero	Very Small, Very Cheap	Very simple control system, very small size and cheap	Long balance time, high power loss, require thermal management, poor efficiency
Switch Shunt, Passive and Only Charging	n switches, n resistors	Slow, Simple	Very High, Low	High/High	Very Small, Very Cheap	Simple control system, vary cheap and small in size, suitable to apply in HEV but face some limitations for applying in EV	Long balance time, high power loss, require thermal management, poor efficiency
Analog Shunt, Passive, and Only Charging	n switches, n Op-amps, 3n resistors, n capacitors	Slow, Simple	High, Low	High/High	Very Small, Cheap	Simple control system, very small and cheap	High power loss, require thermal management, poor efficiency
Single-Switch Capacitor, Active and Charge/Discharge	n + 5 switches, 1 capacitor	Medium, Complex	Minor, Better	Low/Low	Small, Medium	Bidirectional, simple control, good efficiency, suitable for application in HEV and EV	Control system is complex, and minor power loss
Switch Capacitor, Active and Charge/Discharge	2n switches, n − 1 capacitor	Medium, Medium	Minor, Better	Low/Low	Medium, Medium	Bidirectional, simple control, low current and voltage stress	Many switches needed, medium equalization speed
Double-Tiered Switch capacitor, Active and Charge/Discharge	2n switches, 2n − 3 capacitor	Medium, Complex	Minor, Better	Low/Low	Medium, Medium	Bidirectional, good efficiency, fast balancing compared with switch capacitor	Many switches needed, medium equalization speed
Modularized Switch Capacitor, Active and Charge/Discharge	M(n + 2) switches, M(n − 1) capacitor	Medium, Complex	Minor, Better	Low/Low	Medium, Medium	Bidirectional, low current and voltage stress, applied in high power application	Requires many switches, complex control system, large size and costly

Table 1. *Cont.*

Balancing Techniques, Methods, and Types	No. of Elements for Balancing (n Cells)	Balancing Time, Control Complicity	Power Loss, Efficiency	Voltage and Current Stress	Size and Cost	Benefits	Drawbacks
Single Inductor, Active and Charge/Discharge	2n − 2 switches, 1 inductor, 2n − 2 diodes	High, Complex	Low, High	Low/Low	Medium, Medium	Bidirectional, low power loss, current and voltage stress is low	Requires many switches and diodes, complex control
Multi Inductor, Active, and Charge/Discharge	n + 1 switches, n − 1 inductors	High, Complex	Low, High	Low/Low	Large, Medium	Bidirectional, low power loss, current and voltage stress is low, fast balancing compared with a single inductor and switch capacitor	Requires many switches and current filter capacitor, complex control
Single Winding Transformer, Active and Charge/Discharge	n + 6 switches, 1 diode, 2 indicators, 1 transformer	Medium, Complex	Low, Better	Medium/ Medium	Large, Costly	Bidirectional, medium balancing speed, low magnetizing loss	Requires many switches and components for balancing and complex control system
Multi-winding Transformer, Active and Charge/Discharge	2 switches, n diode, 1 winding transformer, n + 1 inductors	Medium, Complex	Low, Better	Medium/Low	Large, Costly	Bidirectional, medium balancing speed, suitable for use in HEV and EV application	Many switches and components are required for balancing and a sophisticated control system, as well as a high magnetic loss and a high dimension.
Modularized Winding Transformer, Active and Charge/Discharge	M(n + 2) switches, Mn diodes, M(n + 2) indicators, M − 1 transformers	Medium, Complex	Very Low, Better	Low/Low	Large, Costly	Suitable for application in high-power ES systems and used in HEV and EV	Several switches and components are required for balance, and a complicated control system, large size and costly
Fly-Back Converter, Active and Charge/Discharge	2n switches, 2n inductors, n winding transformers	Medium, Medium	Low, Good	Low/Low	Large, Costly	Bidirectional, medium balancing speed, low power loss, current, and voltage stress	Several switches and components are required for balance, and a complicated control system, large size and costly
Boost Converter, Active, and Charge/Discharge	n + 1 switches, 1 diode, n + 1 indicators 1 capacitor	High, Complex	Minor, Better	Low/Low	Medium, Medium	Bidirectional, high balancing speed, low current and voltage stress, minor power loss	Requires intelligent and appropriate voltage sensing, complex control system, costly
Buck–Boost Converter, Active and Charge/Discharge	2n − 2 switches, n − 1 inductors	Vary High, Complex	Minor, Better	Low/Low	Medium, Medium	Bidirectional, very high balancing speed, low current and voltage stress, minor power loss	Requires intelligent and appropriate voltage sensing, complex control system
Ramp Converter, Active and Charge/Discharge	n switches, n diodes, n/2 inductors, n capacitors	Medium, Complex	Low, Good	Medium/ Medium	Large, Costly	Bidirectional, less power loss, soft switching, good efficient	Several switches and components are required for balance, and a complicated control system, costly
Cuk Converter, Active and Charge/Discharge	2n − 2 switches, 2n − 2 inductors, N − 1 capacitors	High, Complex	Low, Better	Low/Low	Medium, Medium	Bidirectional, high balancing efficiency, low current and voltage stress, suitable for HEV and EV	Several switches and components are required for balance, and a complicated control system, large size and costly
Resonant Converter, Active and Charge/Discharge	2n − 2 switches, n − 1 indicators, n − 1 capacitors	High, Complex	Very Low, Better	Low/Low	Medium, Costly	Bidirectional, high balancing efficiency, less power loss, low current and voltage stress, suitable for HEV and EV	Requires intelligent and appropriate voltage sensing, complex control system
Full-Bridge Converter, Active and Charge/Discharge	2n + 2 switches, 2 capacitors	Medium, Complex	Low, Better	High/High	Large, Costly	Bidirectional, high balancing efficiency, power loss is negligible	Complex control system, costly
PWM Controller, Active and Charge/Discharge	n switches, 2 resistors 2 diodes, n − 1 inductors	Medium, Complex	Low, Better	High/High	Large, Costly	Bidirectional, medium balancing efficiency,	Several switches and components are required for balance, and a complicated control system, high current and voltage stress
Complete Shunting Balancing, Active and Charge	2n switches, n diodes	Medium, Medium	Minor, Good	Low/Low	Small, Cheap	Medium balancing efficiency, small size, and cheap	Work only in charging mode

4.4. Temperature, Power, and Heat Management

Balanced and efficient power distribution is the recent challenge on EVs, whereas minimal power loss and abuse take advantage. Without power management, the overall system performance is reduced. Besides that, different types of electronic equipment, irregular operation in equipment and machinery, and unreliable power supply are the reasons for the lower effectiveness of the BESS. Managing the stabilized power supply and power control during the charging time of EVs using a management system and power control is an intelligent and highly beneficial method. Considering SOC, SOH, and aging, optimal power regulation and management are required to maximize system protection, longevity, and efficiency. It decreases power loss and maintenance of the automated control and administration of EV systems. An ESS's temperature control component keeps the LIB within thermal range. It regulates heating and cooling. To prevent explosions, the EV battery's temperature is constantly monitored. The LIB pack must be compatible with the EV. The BMS controls onboard cooling and heating systems [64–66].

A LIB comprises an electrode, electrolyte, and separator covered by a shell. For safe operation and better performance, a LIB's functional temperature range is 15 °C to 45 °C. Below 15 °C, a LIB may not function well and electrochemical reactions do not execute well. In low temperatures, during the charging period, lithium dendrites can damage the film; therefore, a short circuit occurs in the LIB. Additionally, LIB voltage increases until it reaches the cut-off voltage and faces capacitive loss. Furthermore, a high temperature (>40 °C) is challenging for a LIB's smooth operation [67,68]. Due to a high temperature, with a LIB's electrochemical properties misbalancing, an explosion occurs. An explosion occurs when the LIB becomes hot, and the internal chemical releases CO, C_2H_2, and H_2S. Furthermore, a short circuit occurs in the internal LIB power circuit structure. Several thermal management methods are present in Figure 7, and more details are present in [69,70].

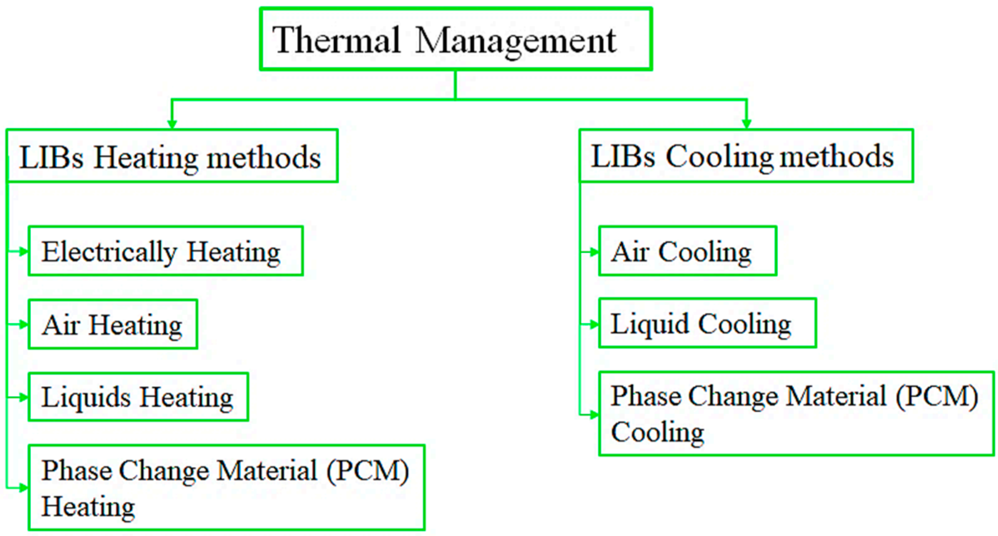

Figure 7. Taxonomy of thermal management system.

4.5. Data Storage and Acquisition: Communication and Networking

Electric vehicle (EV) systems incorporate a vehicle's subsystems and networks. EV performance requires the electronic tracking, configuration, and modification of the BMS. It may also identify EV charging stations and anticipate driving range. The BMS maintains battery data from the EV storage system, like voltage and SOC from the LIB, reading temperature, charge and discharge of the battery, and program control. The BMS transmits and processes the stored data of cell equations, fault diagnostics, heat management, and monitoring through the controller. The EV's central controller is connected to several control units that calculate the BMS operation and provide identical decision output. The data-acquiring systems include assembling the ESS features and measuring the condition using the BMS. Additionally, this acquisition-system processing equipment comprises instruments and applications [71,72].

The LIB data acquisition system is compatible with, e.g., pressure, gas, or other digital and analog sensors. The inner-core status of cells must be known to develop precise cell models, comprehend the purpose of developing accurate cell models, and understand cell performance inside a module. Inadequate temperature management systems can cause unbalanced aging and rapid cell degeneration. An internal array of seven thermistors was built to provide the core temperature by combining these readings with cell current via a bus bar, attached sensors, and voltage sensor measurements. Creating smart cells also incorporates power line communication (PLC) circuitry [73]. The MODBUS TCP protocol permits a WIFI link between the EV and the computer by allowing all signals to be wirelessly delivered from the EV and received in a computer. The signals collected from the acquisition prototype were utilized to assess both the correctness of its operation, validating it using a "NI myDAQ,", and the modification in the period of the measured quantities to determine the behavior correctness of its operation, validating it using a "NI myDAQ" and the change in a period of the estimated quantities of the batteries during their discharge process [74]. Data storage and acquisition make it possible to identify LIB's optimal operating and preventive maintenance conditions.

4.6. Fault Assessment and Diagnosis

Some potential complications in an ESS include overpowering flow, lower charge, voltage stress, and very high and low temperatures. The BMS also knows about system-maintenance defects, power errors, code errors, preparing deficiencies, availability, and break problems. Additionally, based on the indicative developments, the BMS must interpret and determine the deceptions and make suitable decisions. Innovations, framework knowledge, tight supervision, group exchanges, documents, and others are required for advanced measurement. LIBs are evaluated using signal control strategies, research models, and knowledge. A fault evaluation is used to simplify the project and expand the condition of the LIBs in ES [75,76].

There is a sophisticated nonlinear time-varying arrangement with several inconsistencies in the LIB. Rapidly, LIB fault diagnosis without visible problems is becoming challenging using the fault diagnosis approach. Voltage fluctuation is a typical fault response in reality. Therefore, voltage inconsistency monitoring is crucial for the LIBs in EVs to operate safely and dependably. For the LIBs in EVs to operate safely and dependably, voltage inconsistency monitoring is therefore vital. The entropy approach does not depend on a precise analysis model and professional knowledge. Additionally, it ignores the system structure and complex fault mechanisms. Therefore, it has resulted in widespread concern [77], and more details on fault diagnosis are present in [78]. BMS collects battery data, power input/performance, user interfaces, sensors, and ES frameworks. Thus, improving EV application by executing BMD to extend ESD life and ensure power, efficiency, and precise energy assessment is critical.

5. Issues and Challenges

LIBs have several features: high capacity, high power and energy density, high-temperature tolerance and cyclic life, long duty cycle, fast charging, and less effective memory. However, there are some issues, so it is required to indicate appropriate solutions for safety excitabilities, recycling and environmental impacts, custom and expansive characteristics, and the discharging- and charging-period memory effect for a wide range of sequential uses. These issues are also applicable to other electrochemical batteries for EV applications. The following are summaries of the main problems.

5.1. Real-Time SOC and SOH Estimation

SOC estimation is challenging due to the highly non-linear properties of EVs. However, it has flaws like early SOC faults, current measurement and integration faults, and battery capacity uncertainties. Furthermore, the battery needs to rest; measuring open-circuit voltage is impossible in real-time. There is a technique for estimating parameter errors, voltage and current measurement errors, aging, and temperature. It takes longer and costs more money to use electrochemical impedance spectroscopy (EIS). Various SOC and SOH estimation methods (Figure 8) determine EV batteries' SOC and SOH [40,79]. However, real-time determining the SOC in practical situations is difficult with the present methods. A low-cost BMS with little memory but high speed is the most challenging to estimate SOC. Current methods for real-time SOH estimation do not include minority battery health. Presently, model-based techniques have some drawbacks and cannot correctly predict health states [80,81]. Different training and machine learning methodologies are also problematic when using data-driven approaches. As a result, the owner has two choices: replace the battery before it completely fails, increase the risk of a financial burden and environmental waste for the owner, or wait for the storm to fall.

5.2. Optimal Charging Problem and Characterization

The current charging technique takes a long time to charge an EV's batteries with a battery pack, which is less efficient and less safe. The CC trickle is the most common technique for charging methods. However, as it uses low currents, charging takes a longer time. Increasing the charging current reduces charging time but raises the OCV of streamers above the safe threshold and generates heat. There are significant drawbacks to traditional battery charging methods. Therefore, balancing the charging efficiency, heat, battery lifespan, and degradation is challenging. There are several concerns with the real-time estimations of SOC and SOH in a BMS since they are time-demanding and inaccurate. Simple OCV–SOC models for real-time SOC assessments are less accurate and accumulate errors from other estimated parameters. These OCV models encompass the predicted SOC range based on battery usage and the entire SOC range, mainly obtained with a complete charge/discharge profile. It is challenging to characterize SOH in real time [82,83].

5.3. Battery Models

BMS batteries are typically characterized using physical (equivalent, electrochemical) and data-driven (hybrid) techniques. Testing in different environments is impossible due to the need for precise conditions. Data-driven algorithms' performance and computational complexity highly depend on test data and training procedures. It has resulted in several clever techniques/algorithms [84,85].

5.4. Data Abundance, Variety, and Integrity Issues

The accuracy of clever algorithms in battery models mainly depends on the amount and diversity of data available. However, gathering a considerable amount of different data takes a long time, increasing computing complexity and increasing the risk of over-fitting. The data bank's fixed charge/discharge pattern and laboratory temperature settings ensure data integrity. Moreover, laboratory battery test benches suffer from poor accuracy, high noise, and EMI. Thus, the BMS must be evaluated in various real-world scenarios.

5.5. Parameter Selection and Optimization for Intelligent Algorithms

Framework, training methodologies, input features, and hyperparameter change all influence the performance of intelligent algorithms. Designing the appropriate structure and choosing the correct hyperparameters for intelligent algorithms is problematic, resulting in data under- and overfitting. The current trial-and-error methods for selecting hyper settings are time-consuming and exhausting for humans. Optimization is required for both intelligent approaches and various control schemes. However, optimization algorithms differ between convergence rates, execution times, and compliance rates.

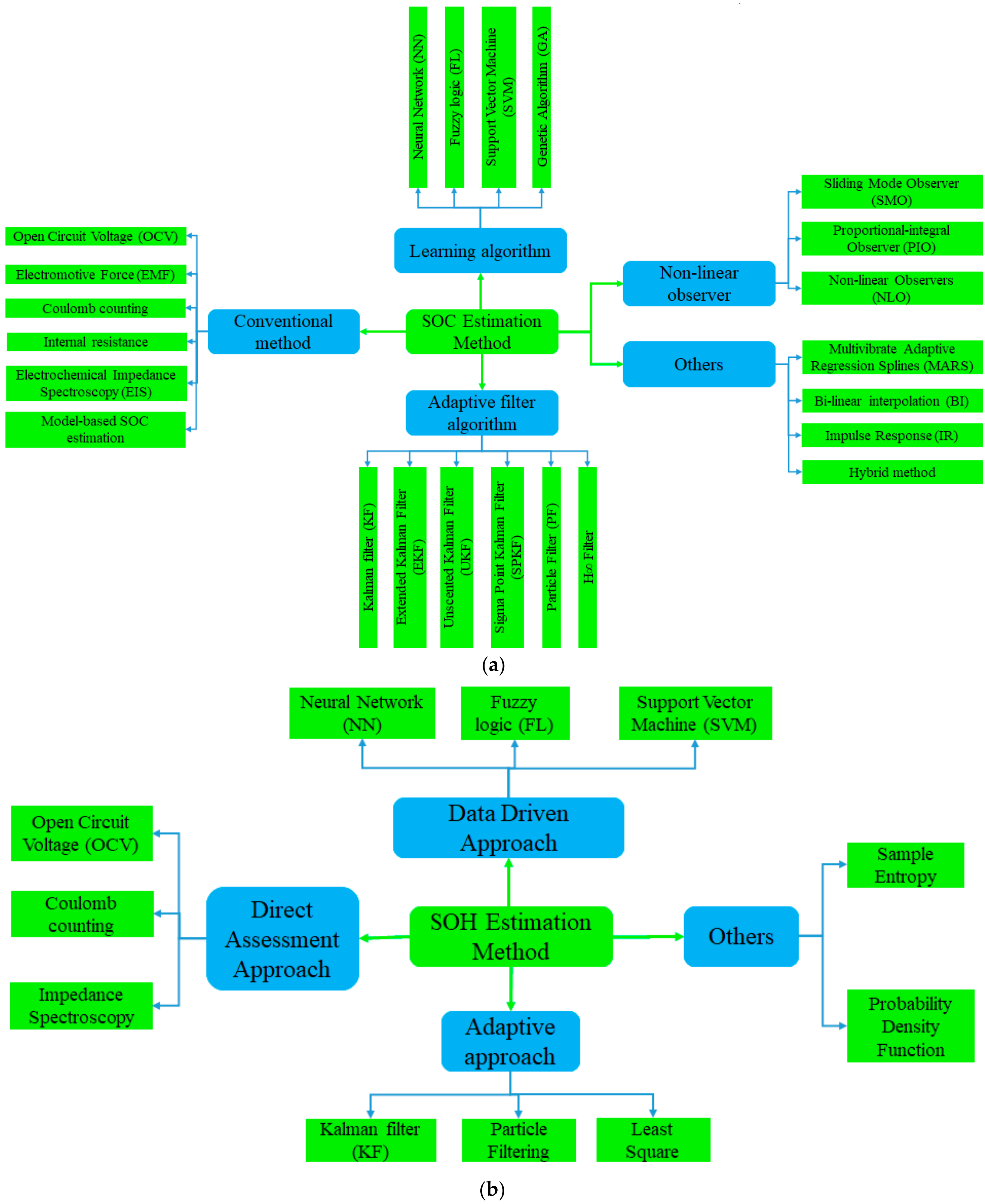

Figure 8. Taxonomy of SOC and SOH estimation method, (**a**) SOC estimation; (**b**) SOH estimation.

5.6. Thermal Management and Thermal Runaway

To obtain precise SOC and RUL measurements and prevent system failures, BMS relies on collecting local and distributed temperature data. However, a smart BMS relies on accurate, low-cost temperature sensors and has a wide temperature range, especially monitoring inside temperatures. Overcharging one cell to a voltage more significant than the industry norm (4.35 V) and increasing the frequency at which it is charged and discharged contribute to the irreversible chemical process. Potential side effects include lithium plating, overcharging, short-circuiting, and heat buildup. Accelerated charging raises the risk of thermal runaway, resulting in an explosion [86–88].

5.7. RUL Prediction Issues

It is challenging to predict RUL via BMS effectively due to modeling insufficiencies, system noise, and reduced sensor fidelity, among other issues. Because of the many unknowns involving RUL prediction using aging mechanisms, this method can only be used for a select few battery types. Health indicator inaccuracy makes it difficult to accurately predict RUL using data-driven strategies, while computational difficulties complicate attempts to use hybrid approaches [79,89].

5.8. Battery Charger and Discharging Issue

Another problem for BMS is the lack of universal battery chargers. Custom battery chargers tend to be more compact and intended for domestic use, leading to increased electrical clutter and environmental waste. As a result of the wide variety of batteries in use, battery charger designers must handle this issue. Working with damaged or old batteries necessitates using safe–discharge batteries, which can be dangerous. Batteries in brine produce hydrogen and oxygen gases that must be vented to avoid detonation. Using resistors to release batteries requires a low current to prevent overheating [90,91].

5.9. Cells Degradation and Early Discharge Termination

If all battery cells in a pack begin with the same SOC, having a lower capacity than other serially connected cells results in cell imbalance. The collection will achieve a specific voltage. However, each cell's voltage will vary. If the lower cell's capacity is less than 10%, the voltage rises to a dangerous level, causing cell breakdown or safety issues. Thus, cell breakdown processes are auto-accelerating, making BMS management difficult. Early discharge termination reduces battery capacity if cells in a pack reach a lower voltage threshold. This voltage is below the pack's threshold. Low cells are bypassed to extend the discharge time of the battery. However, efficient forgetting costs a BMS. Excessive charging can also cause detonation [91,92].

5.10. Safe and Efficient Operation

Operations can be extended due to a loss of LIB capacity. A serially connected battery that exceeds the 4.35 V limit may cause a charging interruption to prevent overloading. Undercharged batteries have a shorter life span. Batteries lack a safe working range due to constantly changing internal and external factors [93]. This may cause significant concerns with cell reliability and stability. Furthermore, maintaining a proficient operational condition is difficult, especially for BMS peripheral control units, as several circumstances impact battery electrochemical properties.

5.11. Aging and Memory Effect

A battery ages due to internal resistance and capacitance fading. High temperatures also speed up the aging process. It is impossible to tell when a battery is getting old until it suddenly stops working. A model that considers cell aging factors is required to solve this problem. The memory effect occurs after repeated charge–discharge cycles: less memory capacity and possible cell imbalances [94,95].

5.12. Hysteresis Characteristics with Existing BMS

It is difficult to accurately measure the SOC because the SOC–OCV curve changes with charging and discharging. These four factors work together to create the characteristic hysteresis of electrical circuits. Different BMSs use various cell balancing and communication systems. As a result, software and hardware are not interchangeable between different BMSs. Recycling old battery packs in other BMSs is impossible because the current BMS is not universal in many other characteristics, such as battery selection, algorithm selection, and restrictions on battery packs.

5.13. Self-Evaluation with Capacity and Power Fading

BMS is difficult to evaluate due to numerous complex factors such as power and capacity fading, heat impact on various inputs, and LIB relaxation impact. This necessitates studying BMS assessment and validation under different failure scenarios. Real-world temperature changes, both gradual and rapid, cause the further development of real-time self-evaluation. The battery's active components change during discharge, generating a more significant reduction in capacity. Power output can be impacted by improving the internal impedance and voltage drop. The SOC error is inflated because of both occurrences.

5.14. Capacity Estimation and Modeling

The capacity of a battery can currently be estimated via a full discharge test, and the equation capacity = RI/dt can be found online. Longer integration times increase capacity, while a steady discharge rate allows maximum power. The battery discharge rate is not continuous. Therefore, the battery will not always be completely depleted. Similar questions remain for battery modeling under varied situations or with a combination of parameters rather than just one.

5.15. Safety and Potential Risks

During cycling, each cell responds differently, resulting in a safety issue. Temperature fluctuations and other external environmental influences degrade the LIBs' performance. Leakage, insulation breaks, and short circuits can result from battery degeneration. Suppose LIBs are opened in the open air or exposed to water. In that case, new hazards may arise, such as spontaneous combustion and explosions, exothermic interactions of lithium ions with oxygen, exothermic reactions creating exothermic reactions, hydrogen gas, etc. These reactions can be deadly. Batteries are also harmful because of the proximity of highly reactive substances. If overheating or overcharging occurs, fires or explosions are a risk. The cathode can dissolve if the maximum voltage is exceeded, increasing heat and short-circuit dangers. The electrolyte can also decompose at excessively high voltages, which is exceptionally harmful [96,97].

5.16. Battery Recycling and Reuse

Another issue that requires attention is the recycling of batteries. A system for collecting and recycling batteries is needed to keep up with the growing amount of spent LIBs. In addition, this will lessen environmental issues and boost the possibilities for recycling. However, there is not a well-defined procedure with the fewest negative consequences on the environment. An additional problem for BMSs is the reuse of batteries. Battery characterizations performed in laboratories, which are only valid once, are extensively relied upon by BMS algorithms. The batteries' electrochemical properties change with time as they are used and exposed to different environmental circumstances. Therefore, it is unsafe to assume that old batteries have the same characteristics as new ones. Metals like copper, aluminum, and cobalt are also found in batteries. Due to the accelerated mining of the metals utilized in batteries and a rise in their prices, it would be good if we could use these batteries again [98,99]. Nowadays, bulk retired batteries are used for renewal ESS and applications worldwide. The BMS is essential to second life-cycle battery-safe operation [93].

5.17. Chargers Communication

The BMS must connect with the vehicle's internal components, charger, and external devices to function correctly. Internal communication is handled through various controlled area network buses. The system management bus (SMBus) communicates with the charger and supplies it with information on the battery's current state and previous usage. However, due to the vast number of manufacturers and battery types, it is challenging to design a consistent connection with the charger.

5.18. Self-Discharge and Charging/Discharging Rate

Battery self-discharge can cause errors in SOC estimation. Temperature, diffusion process effects, cycle times, and storage time can cause self-discharge. Evaluating SOC depends on charging and discharging rates. The deeper the engagement, the more critical it is to keep the battery within safe parameters.

5.19. Power Source and Consumption

Since EVs have no other means of generating electricity except batteries, the BMS must draw its power from the battery it is tasked with safeguarding and maintaining. As a result, the BMS becomes more challenging to design. When an automobile operates, idling, or charging, its BMS consumes power. For this reason, if the car is left uncharged for an extended period, the BMS must consume very little energy to prevent battery depletion. Even with well-known automobiles like Tesla, this issue is still fairly prevalent.

5.20. Battery Disposal Issues

It is necessary to properly dispose of some types of spent batteries because they are considered hazardous trash. Explosions, environmental problems, and safety difficulties can result if these LIBs are not correctly disposed of. Clean-up costs are also a possibility. Battery disposal is a complicated process that includes regulatory concerns, transportation, treatment, and disposal costs.

5.21. Miscellaneous Issues

Data logging features are critical for generating a database of driving patterns and other helpful information for EVs, and BMS has many other challenges. On the other hand, the BMS circuitry is complicated, costly, heavy, uses a lot of power, and makes it difficult to regulate pressure. There is a limited amount of data logging functions available in a BMS. Advances in electric vehicle technology necessitate a sophisticated BMS. Energy computation and safety systems are affected by LIB pack SOC imbalances. Less effort has been made to evaluate and compare the performance of various types of prognosis, making prognostics less efficient than diagnostics. In reverse, utilizing separate battery modules from multiple manufacturers, a tiny battery testing system is required to test the batteries. Next, we will discuss various solutions to our current issues/challenges.

6. Recommendations

Based on issues and challenges, sustainable EV-applicable future research and development scopes are recommended and highlighted. The future LIB manufacturing and technological advancement have been obtained as follows:

6.1. Enhancing Safety and Reliability

Current models limit battery status predictions, cell balancing, and optimal charging (electric/thermal and data-driven). Improved efficiencies and lower costs for batteries are required. A change in current affects the SOC and SOE, while capacity changes affect the SOH and RUL. Multi-scale and co-estimation procedures utilizing various spatial and temporal scales should be developed to estimate battery conditions accurately. BMS's computing time will be reduced as a result.

Additionally, optimizing data-driven control strategies with multiple scales and dimensions may be more effective for jointly estimating numerous scale states. The most common dangers associated with LIBs include high-voltage exposure, fires, combustibility, arcing, and the toxicity of vented gas, among other things. Batteries' safety and reliability can be improved by using interlock circuits and insulation monitoring, which keep the PCBs inside the batteries and the connectors at appropriate distances. Optocouplers are worse in terms of performance and reliability in galvanic signal isolation. Hence, digital isolator ICs should be utilized instead, reducing the risk of a fire by putting sensors inside the battery pack. Contactors and fuses should be employed when separating the battery pack from the system. The electrical behavior of the battery should be used to prevent software and sensor mistakes. Safety and reliability must be balanced so that no one safety action can lead to another hazard. Current interrupt devices and techniques with positive temperature coefficients will help keep LIBs safe. A low-cost alternative to increasing BMS security could be gas sensors. A strict standard of safety must be adhered to by all BMS units to comply with the ISO26262 standard [91].

6.2. Algorithm Hybridization and Advanced Prognostic

Recent research has revealed that optimizing hybridized intelligent algorithms offers advantages over optimizing single intelligent algorithms. However, complexity and undesirable outcomes have both increased. The development of efficient hybrid algorithms requires further investigation. Temperature, charge/discharge rate, DOD, vibrations, and other variables should be monitored using advanced prognostics and health management (PHM) techniques, so that a BMS can make better decisions and improve the system's overall safety, reliability, and lifespan.

6.3. Advanced Thermal Management

A reliable BMS should use intelligent methods for estimating the battery state and for troubleshooting. Time and training accuracy issues plague deep learning algorithms. Research on parameters and activity algorithms is required to speed up the training process. Improved battery temperature control is needed. Sensor-less temperature sensing and electrochemical impedance spectroscopy should be encouraged to improve accuracy and safety. Newer technology should also be used to determine the interior temperature. External battery thermal management technology includes air/liquid and material cooling.

6.4. Life Cycle Assessment and Aging Effect

New materials and their effect on battery lifespan patterns need further study. LIBs should not be made with materials that are rare, expensive, toxic, or difficult to recycle. Through model simulations, it is possible to increase the battery pack's life by using new materials without harming the battery's performance at a steady state. The battery makers will be more interested, and the recycling load and disposal infrastructure will be reduced. For a BMS to forecast SOH effectively, it is critical to understand the impact of aging on LIB parameters. The aging dynamics of batteries are complex, intertwined, and similar, making it difficult to assess their age. This effect causes the development of new approaches.

6.5. Enhancing LIBs Capacity and Fast Charging

Many hidden factors affect a LIB's capacity, including vibrations, ambient elements, operational conditions, and technical differences. It is impossible to forecast the degeneration due to all this correctly. To extend the useful life of LIBs, new technologies must be created. To improve battery efficiency and the accuracy of predictions, it is necessary to employ new methods of abnormality detection and diverse driving styles. The rise of electric vehicles causes rapid charging. There must be a far more advanced battery management system to prevent overcharging or overheating in fast-charging batteries. A charging strategy that is efficient, safe, and based on optimal solutions should be the goal of BMS's charging system.

6.6. Reuse and Recycling

There should also be research on battery reuse to conserve excess energy. These strategies need to be effective while also being kind to the environment. It will also help preserve the Earth's limited supply of lithium-ion batteries. Recycled batteries still contain valuable power. There are 6831 cells in a Tesla Roadster's battery, and if no one recycles them, there will be a lot of waste. Government and non-governmental organizations should work together to develop new technologies to discover the most cost-effective and beneficial methods of recovering this valuable energy and resources from old batteries. The disposal of used LIBs is regulated differently in different countries. Universal and consistent rules must be established, however, to deal with this problem without harming the environment and to enhance the work of scientists and industry alike.

6.7. Wireless and Universal BMS

To establish a universal and open-source BMS, adaptive techniques must be developed. Various BMS manufacturers can work together to improve and develop hardware and software, enhancing BMS's overall efficiency. It will also make BMSs more cost-effective and satisfy future needs by allowing the easy integration of third-party functionalities. Improved performance and cultural shifts necessitate a wireless BMS. This will lower the cost, weight, and size of the BMS by eliminating the enormous amount of wiring in the current BMS. Any component that needs to be repaired or replaced is more complex or takes longer due to the present wiring. Two benefits of wireless battery management systems are improved vehicle efficiency and reduced operating costs.

6.8. Structure and Virtualization

In an accident, the battery's two electrodes must be separated by insulation. Using fire retardants with a higher flashpoint than electrolytes will help. Using the wrong fuel, oxidizer, or control unit can cause a fire or other anomaly in the battery. Rather than the BMS master control unit, the vehicle's control unit should be replaced with a virtual computer. The overall BMS system will save money, time, and space because only the agent modules will be responsible for monitoring and measuring. PikeOS from SYSGO, for example, can monitor this virtual machine in real-time.

6.9. Integration with Big Data

Using cloud computing, cloud storage, and big data platforms can improve the accuracy of intelligent algorithms. Cloud-based BMS systems and digital twins could help with data logging and computational issues. With thoughtful approaches, it is possible to train in real time and more precisely and accurately.

6.10. Installations Recommendations

There must be rigorous adherence to the equipment rating and labeling instructions. In case of a replacement, be sure the new equipment is compatible with the old. Verification by a third party is highly advised to ensure product safety and ward off the manufacturer's or designer's mistakes. Removing the entire battery bank is always preferable to removing just a few batteries. Keeping a safety logbook and doing frequent safety checks of the BMS are necessary to meet any new regulations or to make adjustments. Perfection in hardware or software manipulation is required for a tamper-proof BMS. The BMS must shut down/disconnect and reset the load/charger if it detects abnormal behavior or readings.

7. Conclusions

Battery management is a critical concern for EV adoption due to battery life cycle, safety, cost, and temperature difficulties. In contrast to other works that analyze only one or two aspects of battery management, this work examines all facets. This study discusses various BMS topologies, features/functions, requirements, and comparisons. For the BMS, six points were highlighted, especially focused on battery cell charge balancing techniques. BMS's main challenges are real-time SOC and SOH estimation, optimal charging problems, thermal management and runaway, and battery recycling and reuse. This paper suggests future BMS trends such as hybridized intelligent algorithms, universal BMS, efficient prototype design, enhanced predictive methods, and BMS virtualization. This review shows that BMSs still face several obstacles, even when applying various suitable algorithms and complex approaches/models. Future EVs' BMS must execute numerous advanced activities in real time to handle the complicated nature of batteries, cope with severe conditions, and meet future EVs' needs. This research shows that EV adoption will be challenging unless current issues are solved and better BMSs are built. A complete discussion, analysis, and suggestions are provided, which will be helpful to vehicle engineers and EV producers.

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References

1. Hasan, M.K.; Mahmud, M.; Habib, A.A.; Motakabber, S.; Islam, S. Review of electric vehicle energy storage and management system: Standards, issues, and challenges. *J. Energy Storage* **2021**, *41*, 102940. [CrossRef]
2. Gholami, K.; Azizivahed, A.; Arefi, A. Risk-oriented energy management strategy for electric vehicle fleets in hybrid AC-DC microgrids. *J. Energy Storage* **2022**, *50*, 104258. [CrossRef]
3. Barbosa, W.; Prado, T.; Batista, C.; Câmara, J.C.; Cerqueira, R.; Coelho, R.; Guarieiro, L. Electric Vehicles: Bibliometric Analysis of the Current State of the Art and Perspectives. *Energies* **2022**, *15*, 395. [CrossRef]
4. Habib, A.A.; Hasan, M.K.; Mahmud, M.; Motakabber, S.; Ibrahimya, M.I.; Islam, S. A review: Energy storage system and balancing circuits for electric vehicle application. *IET Power Electron.* **2021**, *14*, 1–13. [CrossRef]
5. Ravi, S.S.; Aziz, M. Utilization of Electric Vehicles for Vehicle-to-Grid Services: Progress and Perspectives. *Energies* **2022**, *15*, 589. [CrossRef]
6. Ouramdane, O.; Elbouchikhi, E.; Amirat, Y.; Gooya, E.S. Optimal Sizing and Energy Management of Microgrids with Vehicle-to-Grid Technology: A Critical Review and Future Trends. *Energies* **2021**, *14*, 4166. [CrossRef]
7. Sehil, K.; Alamri, B.; Alqarni, M.; Sallama, A.; Darwish, M. Empirical Analysis of High Voltage Battery Pack Cells for Electric Racing Vehicles. *Energies* **2021**, *14*, 1556. [CrossRef]
8. Chen, M.; Zhang, Y.; Xing, G.; Chou, S.-L.; Tang, Y. Electrochemical energy storage devices working in extreme conditions. *Energy Environ. Sci.* **2021**, *14*, 3323–3351. [CrossRef]
9. Iqbal, M.Z.; Aziz, U. Supercapattery: Merging of battery-supercapacitor electrodes for hybrid energy storage devices. *J. Energy Storage* **2022**, *46*, 103823. [CrossRef]
10. Olabi, A.; Wilberforce, T.; Sayed, E.T.; Abo-Khalil, A.G.; Maghrabie, H.M.; Elsaid, K.; Abdelkareem, M.A. Battery energy storage systems and SWOT (strengths, weakness, opportunities, and threats) analysis of batteries in power transmission. *Energy* **2022**, *254*, 123987. [CrossRef]
11. Galkin, I.A.; Blinov, A.; Vorobyov, M.; Bubovich, A.; Saltanovs, R.; Peftitsis, D. Interface Converters for Residential Battery Energy Storage Systems: Practices, Difficulties and Prospects. *Energies* **2021**, *14*, 3365. [CrossRef]
12. Sumdani, M.G.; Islam, M.R.; Yahaya, A.N.A.; Safie, S.I. Recent advancements in synthesis, properties, and applications of conductive polymers for electrochemical energy storage devices: A review. *Polym. Eng. Sci.* **2022**, *62*, 269–303. [CrossRef]
13. Azad, F.S.; Habib, A.A.; Rahman, A.; Ahmed, I. Active cell balancing of Li-Ion batteries using single capacitor and single LC series resonant circuit. *Bull. Electr. Eng. Inform.* **2020**, *9*, 1318–1325. [CrossRef]
14. Lee, J.; Kim, J.-M.; Yi, J.; Won, C.-Y. Battery management system algorithm for energy storage systems considering battery efficiency. *Electronics* **2021**, *10*, 1859. [CrossRef]
15. Shen, M.; Gao, Q. A review on battery management system from the modeling efforts to its multiapplication and integration. *Int. J. Energy Res.* **2019**, *43*, 5042–5075. [CrossRef]
16. Lelie, M.; Braun, T.; Knips, M.; Nordmann, H.; Ringbeck, F.; Zappen, H.; Sauer, D.U. Battery management system hardware concepts: An overview. *Appl. Sci.* **2018**, *8*, 534. [CrossRef]

17. Ali, M.U.; Zafar, A.; Nengroo, S.H.; Hussain, S.; Junaid Alvi, M.; Kim, H.-J. Towards a smarter battery management system for electric vehicle applications: A critical review of lithium-ion battery state of charge estimation. *Energies* **2019**, *12*, 446. [CrossRef]
18. Wang, Y.; Tian, J.; Sun, Z.; Wang, L.; Xu, R.; Li, M.; Chen, Z. A comprehensive review of battery modeling and state estimation approaches for advanced battery management systems. *Renew. Sustain. Energy Rev.* **2020**, *131*, 110015. [CrossRef]
19. Lin, J.; Liu, X.; Li, S.; Zhang, C.; Yang, S. A review on recent progress, challenges and perspective of battery thermal management system. *Int. J. Heat Mass Transf.* **2021**, *167*, 120834. [CrossRef]
20. See, K.; Wang, G.; Zhang, Y.; Wang, Y.; Meng, L.; Gu, X.; Zhang, N.; Lim, K.; Zhao, L.; Xie, B. Critical review and functional safety of a battery management system for large-scale lithium-ion battery pack technologies. *Int. J. Coal Sci. Technol.* **2022**, *9*, 1–17. [CrossRef]
21. Tran, M.-K.; Panchal, S.; Khang, T.D.; Panchal, K.; Fraser, R.; Fowler, M. Concept review of a cloud-based smart battery management system for lithium-ion batteries: Feasibility, logistics, and functionality. *Batteries* **2022**, *8*, 19. [CrossRef] [PubMed]
22. Habib, A.A.; Motakabber, S.; Ibrahimy, M.I. A comparative study of electrochemical battery for electric vehicles applications. In Proceedings of the 2019 IEEE International Conference on Power, Electrical, and Electronics and Industrial Applications (PEEIACON), Dhaka, Bangladesh, 29 November–1 December 2019; pp. 43–47.
23. Li, S.; Fan, Z. Encapsulation methods of sulfur particles for lithium-sulfur batteries: A review. *Energy Storage Mater.* **2021**, *34*, 107–127. [CrossRef]
24. Li, S.; Leng, D.; Li, W.; Qie, L.; Dong, Z.; Cheng, Z.; Fan, Z. Recent progress in developing Li_2S cathodes for Li–S batteries. *Energy Storage Mater.* **2020**, *27*, 279–296. [CrossRef]
25. Ramkumar, M.S.; Reddy, C.; Ramakrishnan, A.; Raja, K.; Pushpa, S.; Jose, S.; Jayakumar, M. Review on Li-Ion Battery with Battery Management System in Electrical Vehicle. *Adv. Mater. Sci. Eng.* **2022**, *2022*, 3379574. [CrossRef]
26. Miao, Y.; Hynan, P.; Von Jouanne, A.; Yokochi, A. Current Li-ion battery technologies in electric vehicles and opportunities for advancements. *Energies* **2019**, *12*, 1074. [CrossRef]
27. Camargos, P.H.; dos Santos, P.H.; dos Santos, I.R.; Ribeiro, G.S.; Caetano, R.E. Perspectives on Li-ion battery categories for electric vehicle applications: A review of state of the art. *Int. J. Energy Res.* **2022**, *46*, 19258–19268. [CrossRef]
28. Pražanová, A.; Knap, V.; Stroe, D.-I. Literature Review, Recycling of Lithium-Ion Batteries from Electric Vehicles, Part I: Recycling Technology. *Energies* **2022**, *15*, 1086. [CrossRef]
29. Zau, A.T.P.; Lencwe, M.J.; Chowdhury, S.D.; Olwal, T.O. A Battery Management Strategy in a Lead-Acid and Lithium-Ion Hybrid Battery Energy Storage System for Conventional Transport Vehicles. *Energies* **2022**, *15*, 2577. [CrossRef]
30. Okay, K.; Eray, S.; Eray, A. Development of prototype battery management system for PV system. *Renew. Energy* **2022**, *181*, 1294–1304. [CrossRef]
31. Surya, S.; Williamson, S.S. A Comprehensive Study on DC–DC and DC–AC Converters in Electric and Hybrid Electric Vehicles. In *E-Mobility*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 59–81.
32. Bashir, H.; Yaqoob, A.; Jawaid, I.; Khalid, W.; Javed, M.Y.; Sultan, W. A Review of Battery Management System and Modern State Estimation Approaches in Lithiumion Batteries for Electric Vehicle. In Proceedings of the 2022 5th International Conference on Energy Conservation and Efficiency (ICECE), Lahore, Pakistan, 16–17 March 2022; pp. 1–8.
33. Gabbar, H.A.; Othman, A.M.; Abdussami, M.R. Review of battery management systems (BMS) development and industrial standards. *Technologies* **2021**, *9*, 28. [CrossRef]
34. Chen, H.-C.; Li, S.-S.; Wu, S.-L.; Lee, C.-Y. Design of a Modular Battery Management System for Electric Motorcycle. *Energies* **2021**, *14*, 3532. [CrossRef]
35. Kirchev, A.; Brun-Buisson, D.; Gau, V. Li-Ion Cell Safety Monitoring Using Mechanical Parameters: Part I. Normal Battery Operation. *J. Electrochem. Soc.* **2022**, *169*, 010515. [CrossRef]
36. Gao, Y.; Liu, C.; Chen, S.; Zhang, X.; Fan, G.; Zhu, C. Development and parameterization of a control-oriented electrochemical model of lithium-ion batteries for battery-management-systems applications. *Appl. Energy* **2022**, *309*, 118521. [CrossRef]
37. Mahmud, M.; Islam, M.R.; Motakabber, S.; Satter, M.D.A.; Afroz, K.E.; Habib, A.A. Control Speed of BLDC Motor using PID. In Proceedings of the 2022 IEEE 18th International Colloquium on Signal Processing & Applications (CSPA), Selangor, Malaysia, 12 May 2022; pp. 150–154.
38. Kong, D.; Wang, S.; Ping, P. State-of-health estimation and remaining useful life for lithium-ion battery based on deep learning with Bayesian hyperparameter optimization. *Int. J. Energy Res.* **2022**, *46*, 6081–6098. [CrossRef]
39. Ge, M.-F.; Liu, Y.; Jiang, X.; Liu, J. A review on state of health estimations and remaining useful life prognostics of lithium-ion batteries. *Measurement* **2021**, *174*, 109057. [CrossRef]
40. Hannan, M.A.; Lipu, M.H.; Hussain, A.; Mohamed, A. A review of lithium-ion battery state of charge estimation and management system in electric vehicle applications: Challenges and recommendations. *Renew. Sustain. Energy Rev.* **2017**, *78*, 834–854. [CrossRef]
41. Mahmud, M.; Motakabber, S.; Alam, A.Z.; Nordin, A.N.; Habib, A.A. Modeling and Performance Analysis of an Adaptive PID Speed Controller for the BLDC Motor. *Int. J. Adv. Comput. Sci. Appl.* **2020**, *11*, 272–276. [CrossRef]
42. Adaikkappan, M.; Sathiyamoorthy, N. Modeling, state of charge estimation, and charging of lithium-ion battery in electric vehicle: A review. *Int. J. Energy Res.* **2022**, *46*, 2141–2165. [CrossRef]

43. Liu, Y.; He, Y.; Bian, H.; Guo, W.; Zhang, X. A review of lithium-ion battery state of charge estimation based on deep learning: Directions for improvement and future trends. *J. Energy Storage* **2022**, *52*, 104664. [CrossRef]
44. Cui, Z.; Wang, L.; Li, Q.; Wang, K. A comprehensive review on the state of charge estimation for lithium-ion battery based on neural network. *Int. J. Energy Res.* **2022**, *46*, 5423–5440. [CrossRef]
45. Cui, Z.; Dai, J.; Sun, J.; Li, D.; Wang, L.; Wang, K. Hybrid methods using neural network and Kalman filter for the state of charge estimation of lithium-ion battery. *Math. Probl. Eng.* **2022**, *2022*, 9616124. [CrossRef]
46. Akbar, K.; Zou, Y.; Awais, Q.; Baig, M.J.A.; Jamil, M. A Machine Learning-Based Robust State of Health (SOH) Prediction Model for Electric Vehicle Batteries. *Electronics* **2022**, *11*, 1216. [CrossRef]
47. Shu, X.; Shen, S.; Shen, J.; Zhang, Y.; Li, G.; Chen, Z.; Liu, Y. State of health prediction of lithium-ion batteries based on machine learning: Advances and perspectives. *Iscience* **2021**, *24*, 103265. [CrossRef]
48. Vichard, L.; Ravey, A.; Venet, P.; Harel, F.; Pelissier, S.; Hissel, D. A method to estimate battery SOH indicators based on vehicle operating data only. *Energy* **2021**, *225*, 120235. [CrossRef]
49. Habib, A.A.; Motakabber, S.; Ibrahimy, M.I.; Hasan, M.K. Active voltage balancing circuit using single switched-capacitor and series LC resonant energy carrier. *Electron. Lett.* **2020**, *56*, 1036–1039. [CrossRef]
50. Samanta, A.; Chowdhuri, S. Active cell balancing of lithium-ion battery pack using dual DC-DC converter and auxiliary lead-acid battery. *J. Energy Storage* **2021**, *33*, 102109. [CrossRef]
51. Riczu, C.; Bauman, J. Implementation and System-Level Modeling of a Hardware Efficient Cell Balancing Circuit for Electric Vehicle Range Extension. *IEEE Trans. Ind. Appl.* **2021**, *57*, 2883–2895. [CrossRef]
52. Wu, K.-K.; Wang, H.-Y.; Chen, C.; Tao, T.; Zhang, H.; Wu, K.; Liu, Y.-X. Battery voltage transfer method for multi-cells Li-ion battery pack protection chips. *Analog Integr. Circuits Signal Process.* **2022**, *111*, 13–24. [CrossRef]
53. Hasan, M.K.; Habib, A.; Islam, S.; Ghani, A.T.A.; Hossain, E. Resonant energy carrier base active charge-balancing algorithm. *Electronics* **2020**, *9*, 2166. [CrossRef]
54. Thiruvonasundari, D.; Deepa, K. Optimized passive cell balancing for fast charging in electric vehicle. *IETE J. Res.* **2021**, 1–9. [CrossRef]
55. Duraisamy, T.; Kaliyaperumal, D. Adaptive passive balancing in battery management system for e-mobility. *Int. J. Energy Res.* **2021**, *45*, 10752–10764. [CrossRef]
56. Hoekstra, F.S.; Bergveld, H.J.; Donkers, M. Optimal Control of Active Cell Balancing: Extending the Range and Useful Lifetime of a Battery Pack. *IEEE Trans. Control Syst. Technol.* **2022**, *30*. [CrossRef]
57. Qu, F.; Luo, Q.; Liang, H.; Mou, D.; Sun, P.; Du, X. Systematic Overview of Active Battery Equalization Structures: Mathematical Modeling and Performance Evaluation. *IEEE Trans. Energy Convers.* **2022**, *37*, 1685–1703. [CrossRef]
58. Hein, T.; Ziegler, A.; Oeser, D.; Ackva, A. A capacity-based equalization method for aged lithium-ion batteries in electric vehicles. *Electr. Power Syst. Res.* **2021**, *191*, 106898. [CrossRef]
59. Park, Y.-H.; Kim, R.-Y.; Choi, Y.-J. An Active Cascaded Battery Voltage Balancing Circuit Based on Multi-Winding Transformer with Small Magnetizing Inductance. *Energies* **2021**, *14*, 1302. [CrossRef]
60. Noh, G.; Lee, J.; Ha, J.-I. Design and Analysis of Single-Inductor Power Converter for Both Battery Balancing and Voltage Regulation. *IEEE Trans. Ind. Electron.* **2021**, *69*, 2874–2884. [CrossRef]
61. Eroğlu, F.; Kurtoğlu, M.; Vural, A.M. Bidirectional DC–DC converter based multilevel battery storage systems for electric vehicle and large-scale grid applications: A critical review considering different topologies, state-of-charge balancing and future trends. *IET Renew. Power Gener.* **2021**, *15*, 915–938. [CrossRef]
62. Turksoy, A.; Teke, A.; Alkaya, A. A comprehensive overview of the dc-dc converter-based battery charge balancing methods in electric vehicles. *Renew. Sustain. Energy Rev.* **2020**, *133*, 110274. [CrossRef]
63. Habib, A.A.; Hasan, M.K.; Islam, S.; Sharma, R.; Hassan, R.; Nafi, N.; Yadav, K.; Alotaibi, S.D. Energy-efficient system and charge balancing topology for electric vehicle application. *Sustain. Energy Technol. Assess.* **2022**, *53*, 102516.
64. Akinlabi, A.H.; Solyali, D. Configuration, design, and optimization of air-cooled battery thermal management system for electric vehicles: A review. *Renew. Sustain. Energy Rev.* **2020**, *125*, 109815. [CrossRef]
65. Karimi, D. Modular Methodology for Developing Comprehensive Active and Passive Thermal Management Systems for Electric Vehicle. *Vrije Univ. Bruss. Bruss. Belg.* **2022**.
66. Song, L.; Zheng, Y.; Xiao, Z.; Wang, C.; Long, T. Review on Thermal Runaway of Lithium-Ion Batteries for Electric Vehicles. *J. Electron. Mater.* **2022**, *51*, 30–46. [CrossRef]
67. Kummitha, O.R. Thermal cooling of li-ion cylindrical cells battery module with baffles arrangement for airflow cooling numerical analysis. *J. Energy Storage* **2023**, *59*, 106474. [CrossRef]
68. Yang, C.; Xi, H.; Wang, M. Structure optimization of air cooling battery thermal management system based on lithium-ion battery. *J. Energy Storage* **2023**, *59*, 106538. [CrossRef]
69. Zhang, X.; Li, Z.; Luo, L.; Fan, Y.; Du, Z. A review on thermal management of lithium-ion batteries for electric vehicles. *Energy* **2022**, *238*, 121652. [CrossRef]
70. Jiang, Z.; Li, H.; Qu, Z.; Zhang, J. Recent progress in lithium-ion battery thermal management for a wide range of temperature and abuse conditions. *Int. J. Hydrog. Energy* **2022**, *47*, 9428–9459. [CrossRef]

71. Lee, H.-J.; Kim, K.-T.; Park, J.-H.; Bere, G.; Ochoa, J.J.; Kim, T. Convolutional neural network-based false battery data detection and classification for battery energy storage systems. *IEEE Trans. Energy Convers.* **2021**, *36*, 3108–3117. [CrossRef]
72. Zhang, L.; Gao, T.; Cai, G.; Hai, K.L. Research on electric vehicle charging safety warning model based on back propagation neural network optimized by improved gray wolf algorithm. *J. Energy Storage* **2022**, *49*, 104092. [CrossRef]
73. Vincent, T.A.; Gulsoy, B.; Sansom, J.E.; Marco, J. In-situ instrumentation of cells and power line communication data acquisition towards smart cell development. *J. Energy Storage* **2022**, *50*, 104218. [CrossRef]
74. Encalada-Palacios, F.; Salamea-Palacios, C. Lithium-ion cell data acquisition prototype of a personal mobility electric vehicle. In Proceedings of the 2022 International Conference on Electrical, Computer and Energy Technologies (ICECET), Prague, Czech Republic, 20–22 July 2022; pp. 1–6.
75. Cong, X.; Zhang, C.; Jiang, J.; Zhang, W.; Jiang, Y.; Zhang, L. A Comprehensive Signal-Based Fault Diagnosis Method for Lithium-Ion Batteries in Electric Vehicles. *Energies* **2021**, *14*, 1221. [CrossRef]
76. Jiang, J.; Li, T.; Chang, C.; Yang, C.; Liao, L. Fault diagnosis method for lithium-ion batteries in electric vehicles based on isolated forest algorithm. *J. Energy Storage* **2022**, *50*, 104177. [CrossRef]
77. Lin, M.; Xie, H.; Shan, M. A Hybrid Multiscale Permutation Entropy-Based Fault Diagnosis and Inconsistency Evaluation Approach for Lithium Battery of E-Vehicles. *IEEE Access* **2022**, *10*, 104757–104768. [CrossRef]
78. Lan, J.; Wei, R.; Huang, S.; Li, D.; Zhao, C.; Yin, L.; Wang, J. In-depth bibliometric analysis on research trends in fault diagnosis of lithium-ion batteries. *J. Energy Storage* **2022**, *54*, 105275. [CrossRef]
79. Lipu, M.H.; Hannan, M.; Hussain, A.; Hoque, M.; Ker, P.J.; Saad, M.M.; Ayob, A. A review of state of health and remaining useful life estimation methods for lithium-ion battery in electric vehicles: Challenges and recommendations. *J. Clean. Prod.* **2018**, *205*, 115–133. [CrossRef]
80. Mc Carthy, K.; Gullapalli, H.; Kennedy, T. Real-time internal temperature estimation of commercial Li-ion batteries using online impedance measurements. *J. Power Sources* **2022**, *519*, 230786. [CrossRef]
81. Locorotondo, E.; Cultrera, V.; Pugi, L.; Berzi, L.; Pierini, M.; Lutzemberger, G. Development of a battery real-time state of health diagnosis based on fast impedance measurements. *J. Energy Storage* **2021**, *38*, 102566. [CrossRef]
82. Uiterkamp, M.H.S.; Gerards, M.E.; Hurink, J.L. Online electric vehicle charging with discrete charging rates. *Sustain. Energy Grids Netw.* **2021**, *25*, 100423. [CrossRef]
83. Yao, C.; Chen, S.; Yang, Z. Joint routing and charging problem of multiple electric vehicles: A fast optimization algorithm. *IEEE Trans. Intell. Transp. Syst.* **2021**, *23*, 8184–8193. [CrossRef]
84. Zhou, W.; Zheng, Y.; Pan, Z.; Lu, Q. Review on the battery model and SOC estimation method. *Processes* **2021**, *9*, 1685. [CrossRef]
85. Estaller, J.; Kersten, A.; Kuder, M.; Thiringer, T.; Eckerle, R.; Weyh, T. Overview of Battery Impedance Modeling Including Detailed State-of-the-Art Cylindrical 18650 Lithium-Ion Battery Cell Comparisons. *Energies* **2022**, *15*, 3822. [CrossRef]
86. Hannan, M.; Al-Shetwi, A.; Begum, R.; Young, S.; Hoque, M.; Ker, P.; Mansur, M.; Alzaareer, K. The value of thermal management control strategies for battery energy storage in grid decarbonization: Issues and recommendations. *J. Clean. Prod.* **2020**, *276*, 124223. [CrossRef]
87. Sun, Z.; Guo, Y.; Zhang, C.; Xu, H.; Zhou, Q.; Wang, C. A Novel Hybrid Battery Thermal Management System for Prevention of Thermal Runaway Propagation. *IEEE Trans. Transp. Electrif.* **2022**, *207*, 118198. [CrossRef]
88. Huang, Q.; Li, X.; Zhang, G.; Weng, J.; Wang, Y.; Deng, J. Innovative thermal management and thermal runaway suppression for battery module with flame retardant flexible composite phase change material. *J. Clean. Prod.* **2022**, *330*, 129718. [CrossRef]
89. Ansari, S.; Ayob, A.; Lipu, M.H.; Hussain, A.; Saad, M.H.M. Particle swarm optimized data-driven model for remaining useful life prediction of lithium-ion batteries by systematic sampling. *J. Energy Storage* **2022**, *56*, 106050. [CrossRef]
90. Aghajan-Eshkevari, S.; Azad, S.; Nazari-Heris, M.; Ameli, M.T.; Asadi, S. Charging and discharging of electric vehicles in power systems: An updated and detailed review of methods, control structures, objectives, and optimization methodologies. *Sustainability* **2022**, *14*, 2137. [CrossRef]
91. Uzair, M.; Abbas, G.; Hosain, S. Characteristics of Battery Management Systems of Electric Vehicles with Consideration of the Active and Passive Cell Balancing Process. *World Electr. Veh. J.* **2021**, *12*, 120. [CrossRef]
92. Shamim, N.; Viswanathan, V.V.; Thomsen, E.C.; Li, G.; Reed, D.M.; Sprenkle, V.L. Valve Regulated Lead Acid Battery Evaluation under Peak Shaving and Frequency Regulation Duty Cycles. *Energies* **2022**, *15*, 3389. [CrossRef]
93. Habib, A.A.; Hasan, M.K.; Islam, S.; Ahmed, M.M.; Aman, A.H.M.; Bagwari, A.; Khan, S. Voltage equalization circuit for retired batteries for energy storage applications. *Energy Rep.* **2022**, *8*, 367–374. [CrossRef]
94. Barcellona, S.; Colnago, S.; Dotelli, G.; Latorrata, S.; Piegari, L. Aging effect on the variation of Li-ion battery resistance as function of temperature and state of charge. *J. Energy Storage* **2022**, *50*, 104658. [CrossRef]
95. Zhang, L.; Yang, Z.; Hu, F.; Feng, X.; Li, D.; Chen, Y. Reversible Al-Site Switching and Consequent Memory Effect of Al-Doped $Li_4Ti_5O_{12}$ in Li-Ion Batteries. *ACS Appl. Mater. Interfaces* **2020**, *12*, 17415–17423. [CrossRef]
96. Christensen, P.A.; Anderson, P.A.; Harper, G.D.; Lambert, S.M.; Mrozik, W.; Rajaeifar, M.A.; Wise, M.S.; Heidrich, O. Risk management over the life cycle of lithium-ion batteries in electric vehicles. *Renew. Sustain. Energy Rev.* **2021**, *148*, 111240. [CrossRef]
97. Chen, Y.; Kang, Y.; Zhao, Y.; Wang, L.; Liu, J.; Li, Y.; Liang, Z.; He, X.; Li, X.; Tavajohi, N. A review of lithium-ion battery safety concerns: The issues, strategies, and testing standards. *J. Energy Chem.* **2021**, *59*, 83–99. [CrossRef]

98. Fujita, T.; Chen, H.; Wang, K.-T.; He, C.-L.; Wang, Y.-B.; Dodbiba, G.; Wei, Y.-Z. Reduction, reuse and recycle of spent Li-ion batteries for automobiles: A review. *Int. J. Miner. Metall. Mater.* **2021**, *28*, 179–192. [CrossRef]
99. Natarajan, S.; Akshay, M.; Aravindan, V. Recycling/Reuse of Current Collectors from Spent Lithium-Ion Batteries: Benefits and Issues. *Adv. Sustain. Syst.* **2022**, *6*, 2100432. [CrossRef]