Review on Battery Management System for Electric Vehicle Application

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Abstract. Among various energy sources for an electric vehicle, battery occupies its prominent place for its high energy density and high power density. Among various battery chemistries, a Li-ion battery has become the strong contender in electric vehicle industry. The battery cells are either connected in series or parallel for a battery pack to achieve higher voltage and current for electric vehicle application.The battery management system act as a brain of the battery operated electric vehicle. The modeling of the battery pack system is the necessary phenomena for any proposed battery management system. The series connected cells in the battery pack should maintain the same potential of individual cell at ideal, charging and discharging conditions. If the potential of the series connected cells are mismatched then the charging and discharging of the battery pack is affected. This invokes the problem of cell unbalancing due to both extrinsic and intrinsic parameters. The problem could be overcome by using cell to cell balancing, cell – module balancing with the board classification of active and passive balancing. By implementing the proper cell balancing methodology the equalization time of the battery pack is lowered and the aging of the battery pack is improved. The survey explains the battery parameters, role of battery management system and various methods of cell balancing for an electric vehicle application.

Keywords: Battery, Management System, Electric, Vehicle.

1 Introduction

In recent days, the fuel cost and environmental impact flicker the interest to the electric vehicles in the transportation sector. The electric vehicle travels for nearly few years ago.In 18th century, the electric vehicle plays a major contribution to the road vehicle. During this Edison period, the DC revolves the world. But, later due to invention of low cost and high resources fuel, the internal combustion (IC) engine revolves the transportation industry. The low cost and high availability of resources paves the way for internal combustion engine in the 19th century. To attain the sustainable energy, in 20th century, the world slowly shows the interest towards the electric vehicle. The main drawback of the 19th century is, theIC Engine vehicles are increase in the cost of fuel and environmental impact such as air pollution.Thus, the air pollution is reduced to three times compare to the conventional energy resources. The operational efficiency is increased above 80 % for battery operated electric vehicle and thereby the cost of the energy spent is also lower. The energy efficiency is also increased to higher rate from 60 – 80 % compared to the conventional IC combustion engine with 20 % [1-

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2] .To promote the Electric vehicle to the user the Government of India also initiates a few schemes like NEMMP, FAME I, FAME II with incentives to the customer. The National Electric Mobility Mission Plan (NEMMP) -2020 was introduced on 2013 to provide fuel protection by developing the electric, plug-in-hybrid and hybrid vehicles in India. FAME refers to Faster Adoption and Manufacturing of Electric Vehicles. The phase I of FAME was launched under NEMMP in 2011 to reduce the CO_2 emission of the country and promotes timely incentives to industry and purchase of electric vehicles.The phase II of FAME was initiated in 2019 for three years to promote large number of policies and schemes with incentives for the user and the industry. According to the survey, the total no. of vehicles sold was about 83558 and the TamilNadu sold about 12855 dated on 12-07-2021 9.00 a.m. [3-4].There are different type's energy storage components in the power system distribution side as renewable energy source. As batteries power the modern lives of consumers, it is playing a major role in electric vehicle application. Based on the performance parameters of battery such as high energy density and high power density, it becomes the master of all energy storage devices especially for electric vehicle application. The high specific energy source of battery is used for long range driving application and the power density is used for acceleration of the electric vehicle. To manage the battery parameters of Lithium-ion battery it is necessary to understand the working of a battery, way of charging and state-of-charge (SOC). The figure 1.1 shows the Li-ion pouch cells with arrangement as battery pack is used for electric vehicle application.

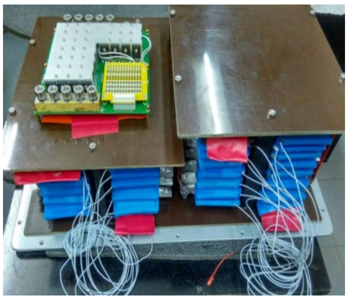

Figure. No. 1.1 Lithium-ion battery

Section 2 explains the characteristics and working of a battery. Section 3 shows the types of battery modeling with its charging characteristics. Section 4 analyzes the role of battery management system for EV application. Section 5 implies the role and basic functions of battery management systems and section 6 reviews the causes and types of cell balancing in BMS. Section 7 clearly shows the software to simulate and other performance parameters of the battery management system. Section 8 spots the research areas for the electric vehicle application and the role of smart in electric vehicle application. Section 9 shows the conclusion of the review paper presented.

Types of Electric Vehicle

There are different types of electric vehicle are hybrid electric vehicle, plug-in hybrid electric vehicle, Fuel cell Electric Vehicle and battery operated electric vehicle. The driving range of the vehicle varies according to the type. The Table 1.1 describes the types of vehicle used for road transportation.

Table. No. 1.1 Types of Vehicles for Transportation

Vehicle Type	Driv-ing Range	Cost	Environ-mental Impact	Effici-ency	Size	Weig-ht	Cha-rge
Plug-in-Hybrid	300	High	Medium	Medium	High	Medium	High
Hybrid Electric Vehicle	300	Low	Medium	Medium	High	Low	Low
Fuel Cell Operated Electric Vehicle	300	High	Low	Very High	Medium	High	Very Low
Battery-Operated Electric Vehicle	300	Medi-um	Low	High	Medium	High	Very High

Based on the above tabulation it is inferred that the battery operated electric vehicle shows the better driving range, medium cost, less impact on environment, higher efficiency with less size and weight [5]. The main drawback of the battery operated electric vehicle is the charging time of the battery. Thus, the primary and secondary goal of any electric vehicle is safety and cost is tabulated in table 1.2.The different types of energy storage based electric vehicle are as follows.It includes Battery, Fuel Cell, Capacitor based storage and MEMS based storage.From these types, the battery occupies its position because of its high energy and high power density.

Table. No. 1.2 Energy Storage Devices

Parameters	Fuel Cell	Battery	Ultra Capacitors
Safety	Unsafe	Safe	Unsafe
Fuel Charge	Low time to charge	High time to charge	High time to charge

Lifetime	Medium life	Medium Life	Low
Environme-ntal Impact	Less environmental impact	High environmental impact	Less environmental impact
Energy Density	Very High	Very High	Low
Power Density	Medium	Very High	Very High
Cost	High	Medium	High
Size and Weight	High	Medium	High

From the table 1.2, the battery operated electric vehicle shows the high safety, low impact to environment, low cost and safety to both the system and the user. The specific energy density and power density of the battery is higher compared to other energy storage devices and also paves the way to shift to battery operated electric vehicle [6].

Section 2
Battery

This section explains the basic characteristics and the working of the battery.

Characteristics of Battery

In general, charging is the process which forms due to friction, induction and conduction. In battery operated electric vehicle, the process of charging involves conduction. The electrochemical process is happening across negative and positive electrode of battery and it is separated by a separator[7-8]. The current collector is located across the end of the both electrodes. The main parts of the battery cell are shown in the figure 2.1.

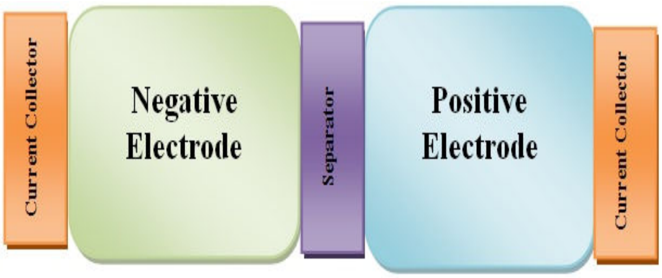

Figure No. 2.1. Lithium-ion Battery Characteristics

The operational characteristics of a battery are designed by the following components such as

1) Positive Electrode
2) Negative Electrode
3) Electrolyte
4) Separator and
5) Current Collector

The electrode act as a conductive medium for transfer of ions from internal to external circuit. The electrolyte will act as a solvent medium between anode and cathode containing acid, base or salt responsible for ionic conductivity. It also helps in internal ion charge transfer between the electrodes.

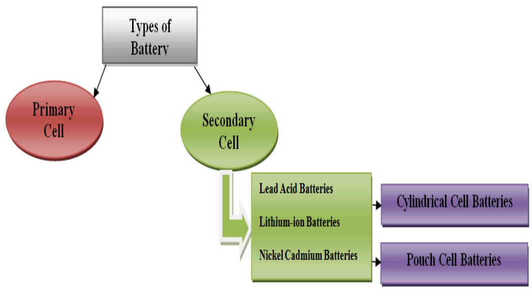

Figure No. 2.2. Types of Battery Cell

To avoid self discharge in a battery, the electrolyte acts as electronic insulator between the electrodes. To prevent the battery from overheating, short circuit, ion transportation and self dis-charge, a separator is used and this is usually made up of polymer and fiber materials with good mechanical properties and chemical stability. The current collector is used to convert the output of the electrodes to external circuit. Thus, an electrochemical cell is smallest unit consist of anode and cathode separated by a separator to deliver an output voltage and current for different application. Based on the construction of battery cells, it is classified as cylindrical and pouch cells. Based on the storage capacity, it is classified as primary cell and secondary cell as shown in the figure 2.2. The primary cell is a battery which cannot be recharged after the use and it can be used only once. The primary reason for this electrochemical reaction is the formation of oxidized layer in the cell. The secondary ells are generally rechargeable and used large number of times based on the performance.

The operating cell voltage of a single cell lead acid and single cell lithium ion is around 12 V and 3.3 to 3.6 V. Thus, the rating of the single is limited due to electrochemical nature and to provide safety and reliable operation of the battery pack. Since damage in one cell could affect the entire system and also have greater impact in economy of the battery operated electric vehicle. When two or more cell connected in series the voltage rating of the battery is added. Similarly, when two or more cell connected in parallel the current rating of the battery is added. Thus a electrochemical cell stores energy that can be released to do electrical output work and batteries are connected in series and parallel according to the user application. The series and parallel combination battery cell si shown in the figure 2.3 and figure 2.4.

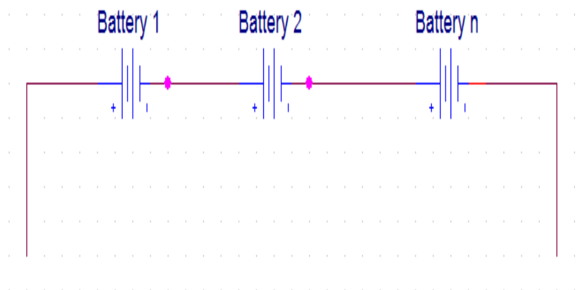

Figure No. 2.3. Series Connected Battery Cell

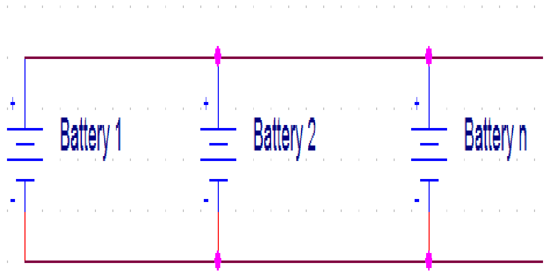

Figure No. 2.4. Parallel Connected Battery Cell

The most important function of a battery is
1) Charging
2) Discharging

These both charging and discharging happens during the process of reduction and oxidation. The general oxidation and reduction reactions for a Lithium-ion Battery would be as given in equations 3.1 and 3.2

$X^{+}\overrightarrow{oxidation}X + e$…..(2.1)

$M^{+} + e\overrightarrow{reduction}M$…..(2.2)

In general, the oxidation reaction takes place at the anode and reduction reaction at the cathode respectively.

Charging Cycle:

The principle of charging a battery during the charging cycle is shown in the figure 2.5.

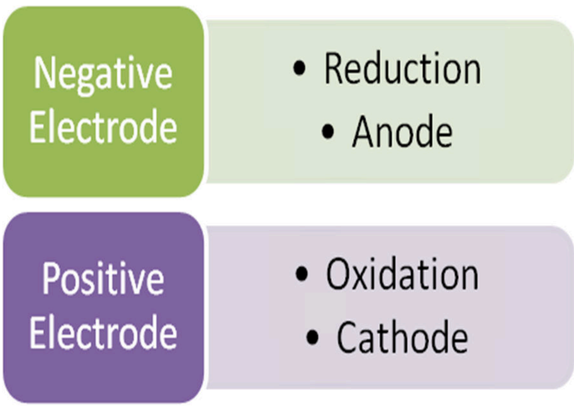

Figure No. 2.5. Charging Cycle of Battery

From this figure, it clear that negative electrode performs reduction and the positive electrode performs oxidation for charging process.

Discharging cycle:

The principle of dis-charging a battery during the dis-charging cycle is shown in the figure 2.6.

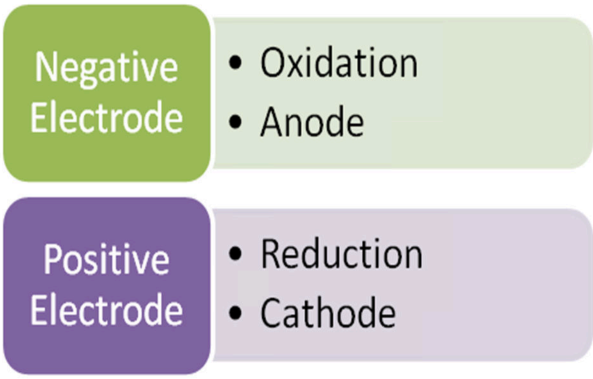

Figure No. 2.6. Discharging Cycle of Battery

From the above two figures, it is clear that negative electrode undergoes oxidation and the positive electrode undergoes reduction for discharging process.

The advantages of battery operated electric vehicle are

1. Cost
2. Size
3. Maintenance
4. Large Capacity
5. Compact Volume
6. High Starting Torque
7. Low Noise
8. Safety

The main drawback of the battery is

1. Complex control algorithm
2. Protection
3. Longer Charging Time
4. Peak power Demand on the grid system

The different types of battery chemistry include Lead acid, Li-ion etc for any electric vehicle application.The table 2.1 shows the recent battery chemistries employed in industries for electric vehicle application. The NMC based Li-ion chemistry cells are widely used for electric vehicle application because of its better performance characteristics such as specific energy, energy efficiency, cycle life, temperature range, cost and safety compared to the other battery chemistries in industries.The commonly used Lithium-ion chemistry is shown in the table 2.1 [14].

Table. No. 2.1 Battery Chemistry and its Properties

Chemistry	Cathode	Anode	Electrolyte	Specific Energy Wh/	Rate of Charge	Rate of Dis-Charge	Energy Efficiency	Cycle Life	Temperature Range	Safety	Cost

				kg								
Lithium Cobalt Oxide($LiCoO_2$) LCO/Graphite	cobalt oxide	graphite carbon	-	150-300	0.5 C	1C	70	1000	Cell <55 º C	Good	$120
Lithium nickel cobalt aluminum oxide NCA / Graphite	cobalt aluminum oxide	graphite carbon	-	150-300	0.5 C	1C	70	1000	Cell <55 º C	Good	$120
Nickel-manganese-cobalt (NMC) / graphite	**Nickel - manganese-cobalt**	**graphite (with sillica in anode)**	**-**	**150-330**	**1 C**	**1C (2C to 3C also possible)**	**90**	**2000 / 8000 (si in anode)**	**Cell <55 º C**	**Best**	**$145**
Lithium Iron Phosphate - LFP /Graphite	Carbon-coated aluminium	graphite or hard carbon with intercalated metallic lithium	ethylene carbonate–dimethyl carbonate lithium perchlorate	90-50	1 C	2C (3C also possible)	75	2500 / 4000 (si in anode)	Safer	Good	$225
Nickel-manganese-cobalt NMC/	-	graphite carbon	-	60-100	4C	4C	85	10000	Safest	Good	$400

lithium-titanate-oxide LTO											
LFP/LTO(Nb doped Niobium doped lithium titanate)		graphite carbon with Niobium doped	-	50-80	5C	10C	85	20000	Safest	Good	Very High

Section 3

Modeling of Battery

To build a battery pack for any application, it is necessary to model a battery or a single cell. Battery Modeling is the fundamental way to represent the battery. There are different methods and approaches to design a battery model in real time. The methods are classified based on the following parameters such as the difference in the perspective of modeling, level of modeling, approaches of modeling and the time scale of the model. The board classification of battery modeling includes as shown in the figure 3.1.

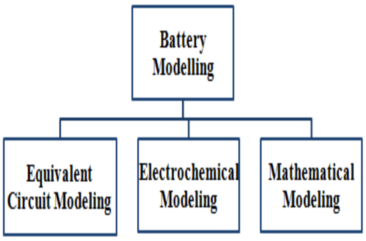

Figure No.3.1. Types of Battery Modeling

The equivalent circuit of the battery is represented using a resistor in series with the parallel combination of Resistor and capacitor. The simple equivalent circuit of a battery is shown in the figure 3.2. The internal resistance refers to the separator responsible for Li-ion movement between the cathode and the anode [9-10]. The RC refers to the time constant with the voltage relaxation parameter of the battery.

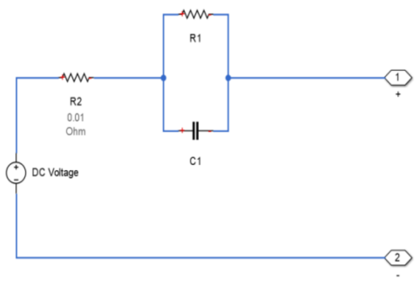

Figure No. 3.2. Equivalent Battery Circuit

The prominent battery chemistries are lead-acid, Ni-Cd, Ni-Zn, Zn-air, Ni-MH, Na-s, Lithium polymer and Lithium ion batteries. The each battery chemistry has its own advantages and disadvantages. For the analysis of the battery management it is necessary to create the battery pack system. There are different data sets available for the various methods. The data set refers to the various types of voltage, current, capacity, energy, temperature etc for different ideal, charging , discharging cycles. The methods include Equivalent circuit model, electrochemical model and neural networks. Each individual method has its own pros and cons. The electrochemical model is the method based on the chemistry of the cells. The data set for the method is difficult to interpret. It also mainly based the chemistry of the cell and it cannot to applicable to any type of cells. The equivalent circuit model is designed based on the available data set. The look up table framed is OCV-SOC look up table. From the graph, it shows that SOC from 25 % to 80 % is about the flatten curve with respect to the OCV where the accuracy will be low. The mathematical modeling of these cells is complicated and large no. of unknown parameters is taken into the consideration. The later comes the machine learning methods employing the neural network where the data set is the challenging data. This method is also applicable to any type of cells and determine the any performance parameters such SOC, SOH and SOL etc. Based on the above methods, the battery system is designed. Based on the designed battery system, the battery management system plays a vital role [11-13].

Types of Charging Process

In India, the charging scheme employed is AC level 1 and charge demo charging scheme named after the inventor for charging a electric vehicle. Charging of a typical electrical vehicle is broadly classified into AC charging, DC charging and Wireless charging [15-16]. The different types of charging schemes are shown in the figure 3.3.

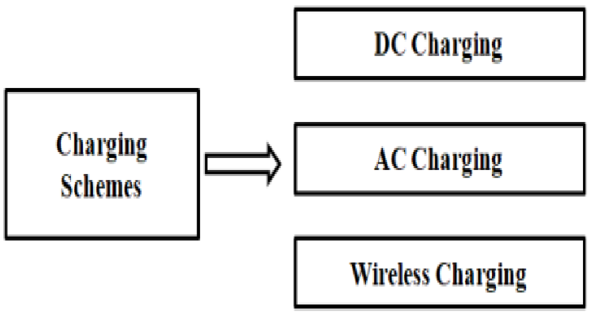

Figure No. 3.3 Different Charging Schemes

AC Charging

This type of charging is followed in India, since the alternating supply dominating the direct current.But, whereas depending on the AC supply shows the demand of supply in future [17]. The grid may get overloaded because of demand. In order to avoid such problem the smart grid comes into the existence with V1G and V2G network for better charging of electric vehicle. This kind of schemes is practiced by developed countries like UN,Germany etc.The level of AC charging is shown in the table 3.1.

The various charging techniques available for a battery are shown in the figure 3.4. The types of charging are listed below.

• Constant Current

• Constant Voltage
• Constant Current Constant Voltage (Series)
• Constant Current Constant Voltage (Parallel)
• Constant Current Constant Voltage (Vary)

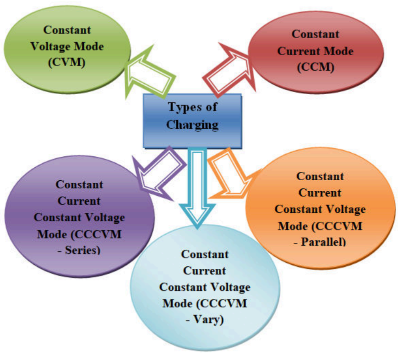

Figure No. 3.4. Types of Charging

Among several charging topology, the main charging scheme employed is constant current constant voltage mode (vary). In industry and real-time, this scheme is employed as charge demo scheme.

Table. No. 3.1 AC Charging System

	Voltage (V)	Current (A)	Power (kW)	Remarks	Charging Time
Level 1	120	12-16	Low	It uses On-board Charger	1-13 hours
Level 2	240	60	High	Directly connected to the grid	1-6 hours
Level 3	600	150	Very High	Wired permanently to the EV charging system	30 minutes

DC Charging:

The Dc charging is the fastest charging scheme employed in many countries recently [18]. The level of DC charging is listed in the table 3.2.

Table. No. 3.2 DCCharging System

	Voltage (V)		Current(A)		Power	Remarks
	Min	**Max**	**Min**	**Max**		
Level 1	200	450	10	80	Medium	Fast
Level 2	200	450	50	200	High	Faster
Level 3	200	600	100	400	Very High	Fastest

Wireless Charging:

The battery is charged without the wires. The losses in the system are greatly prevented and safety is also secured. But, the main drawback is the interference with other signals.

Inductive Charging System

The other methods in inductive charging system includeresonant inductive charging system and online- inductive charging system [19-20].

Capacitive Charging System

In capacitive method, the capacitor is used to store electrical energy in the capacitor through the transfer medium and helps in the charging of the battery cells connected in series.

Thus both capacitive and inductive based charging reduces the energy losses and increases the efficiency of the system. But, this topology does not provide a better economical response.

Permanent Magnet Charge Coupled System

It is similar to the inductive based charging with permanent magnet.

Section 4

Battery Management System - BMS

BMS refers to the battery management system. The role of BMS various according to the application of the user. The zero emissions and regenerative charging properties of the battery operated electric vehicle place an impact in global society.To improve and enhance the sales of the battery operated electric vehicle in the industry, the BMS act as the basic key to obtain the data, process the data and provide the corrective action for the required function. The primary role of battery is to drive the motor connected to the wheel. Thus, the chemical energy is converted to electric energy and transferred through kinetic energy and finally to convert into mechanical energy [21-23]. The auxiliary role of the battery in electric vehicle is to power the AC conditioner, cooling fan, charger point, Window opening and closing etc.Based on the Electric vehicle application, the main purpose of BMS for

1. Protection of Battery
2. Observing the Operating Voltage and Current
3. Thermal Management of battery pack
4. Cell Balancing of battery pack
5. Analysis of Performance parameters such as SOC, DOD, SOH , SOS, SOP
6. Analysis of fault condition

Thus, the battery operated electric vehicle with BMS act as a closed loop system. The performance parameters such as SoC (State-of-Charge), DoD (Depth-of-Discharge), SoH(State-of-Health) are determined by sensing voltage,current and temperature as the input arguments. There are different types of algorithms used for the above performance parameters. The determination of performance parameters are obtained based on the different approaches [24-28]. Based on the requirement the charging and discharging cycle of a battery is operated with high rate of accuracy.In case of any fault conditions, the BMS is capable of taking the precautionary action and primitive action. The fault condition may include short circuit faults, sudden rise in motor current, improper heat management, improper cell balancing etc. The performance parameters include SoS(State-of-Safety) Based on the controller output, the communication channel transfers the operation required to happen [29-33].Thus, the data acquisition system collects the data and protects the battery from any hazardous condition. The block diagram of the battery management system is shown in the figure 4.1.

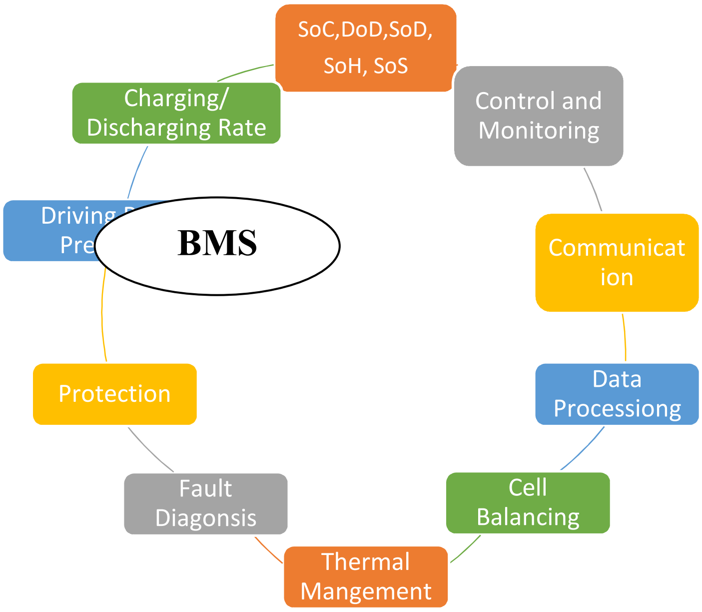

Figure No. 4.1. Block Diagram of Battery Management System

Thus, the BMS acts as predictive, processing and protective system for required application in the electric vehicle is shown in the figure 4.2.

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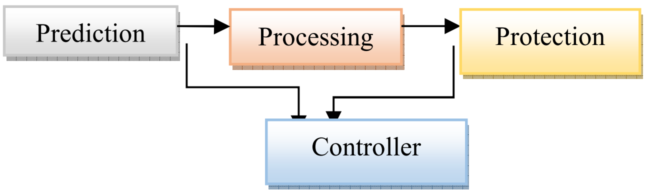


Figure No.4.2. Basic working of Battery Management System

Section 5

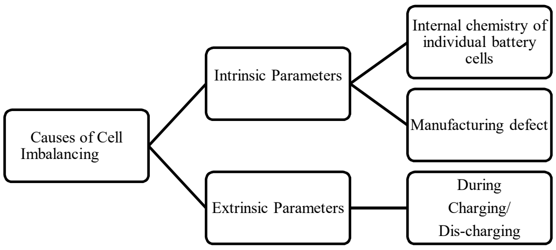
Cell Balancing

There are different issues that are taken into account for Electric vehicle application. According to the literature review, the most prominent issue encountered in the battery operated electric vehicle is cell balancing. The improper cell balancing in the battery pack also induces the thermal issues in the battery [34-37]. For a typical passive balancing the temperature rise may increase from 1-2 degree Celsius.The figure 5.1 shows the proper and improper balancing model for cell balancing in the battery pack.

Figure No. 5.1. Proper and Improper Cell Balancing

Causes of Battery Imbalance:

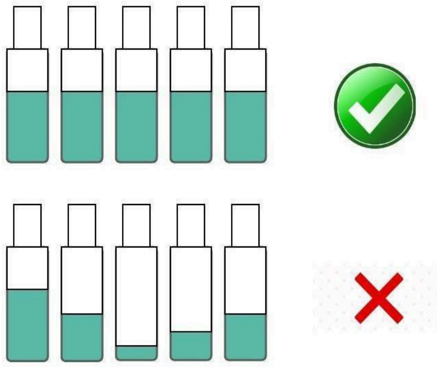
The main causes of the battery imbalance are listed in the figure 5.2 [38-39]. The intrinsic and extrinsic parameters are the major causes of cell unbalancing during ideal, charging and



discharging modes.

Figure No. 5.2. Causes of Cell Balancing

Classification Cell Balancing Types:



The three different conditions that is required for the analysis is ideal, charging and discharging mode. The charging of batteries varies with the topology connected and type of usage. In simple words, the cell imbalance varies with the topology and mode of usage. The balancing is broadly classified into Passive and active based the method of balancing. In addition to this, the cell balancing is also classified based the topology of the battery pack connection for various charging modes.

The different battery equalization controller topology used is shown in the figure 5.3[40].

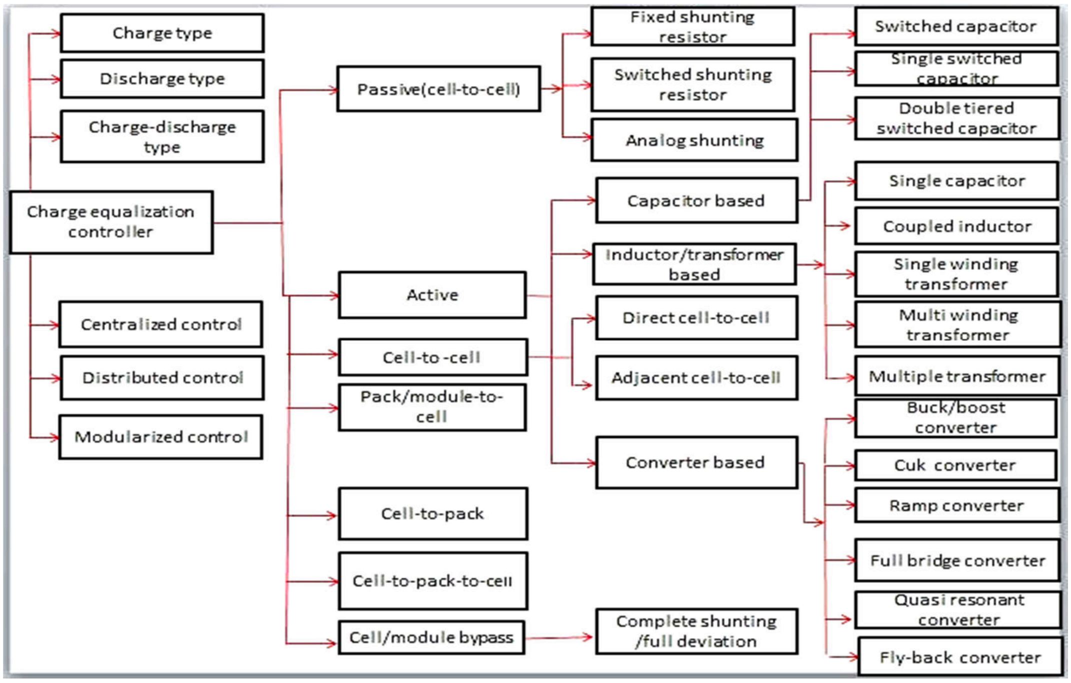


Figure No. 5.3.Battery Equalization Converter Topology

Based the structure,

The cell balancing techniques based on the configuration is listed in the table 5.1. The classification describes the equalization time, size, cost and efficiency of the topologies for the cell imbalance technique [41-43].

Table. No. 5.1 Cell Balancing Topologies

S. No.	Topology	Advantages	Disadvantages
1	Cell-By-pass	Higher Efficiency, Higher Speed, Lower Control Complexity, Smaller Size, Lower Switch Voltage Stress	Higher Current Stress across switches, Low Power Applications
2	Cell- to –Cell	Higher Efficiency, Lower Complexity, Lower Balancing Time, High Power Application	Higher Voltage Stress across switches, Larger Size, More Expensive, Higher Current Stress
3	Cell-to-Pack	High Power Applications, Lower Complexity, Faster Equalization, Lower Cost	Higher Switching Voltage / Current Stress, Difficult Modularity
4	Pack-to-Cell	Less Complexity, Easy Modularity, Fast Equalization Speed	Higher Switching Voltage / Current Stress, Larger Size, LowerEfficiency
5	Cell-to-Pack-to-cell	Very High Power Applications , Lower Complexity, Faster Equalization	High Switching Voltage / Current Stress, Difficult Modularity

Based on the Working of Equalizer Circuit,

Methods of Cell Balancing:

The basic solutions of cell balancing methods are achieved by equalizing the voltage and state of charge between the cells connected in battery pack [44-47]. Cell balancing based on the working of the balancing circuit , it is typically categorized in two types:

1. Active cell balancing
2. Passive cell balancing

The detailed description of the cell balancing techniques is shown in the figure 5.4 [48-51]. Thecell balancing is broadly classified into passive and active balancing. In passive balancing, shunting resistor and bypass resistor is used to balance the imbalanced cells. In active balancing, energy transfer occurs using R, L, C and converter methods. The hybrid combination is also allowed used to balance the cells between passive elements and active converter.

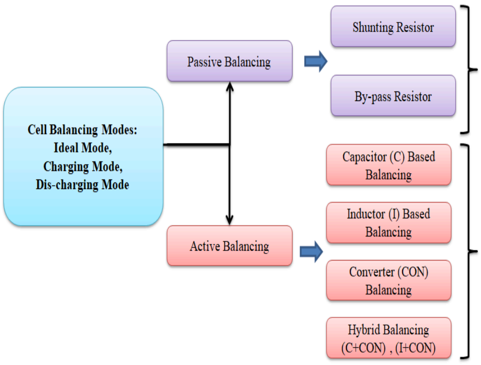


Figure No. 5.4. Cell Balancer Techniques with Different Modes

<u>Passive Balancing:</u>

The passive balancing technique is used to determine the lowest voltage and make other cells to discharge and balance at the same point [52-54]. The pictorial representation of passive balancing circuit is shown in figure 5.5.The common methods of cell balancing are as follows.

1. Fixed Resistor
2. Switched Resistor/ Bypass Resistor

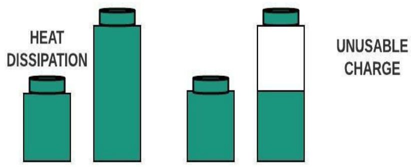


Figure No. 5.5. Passive Balancing Circuit

The algorithm used in the system for the passive balancing is explained using the flowchart as shown in the figure 5.6.

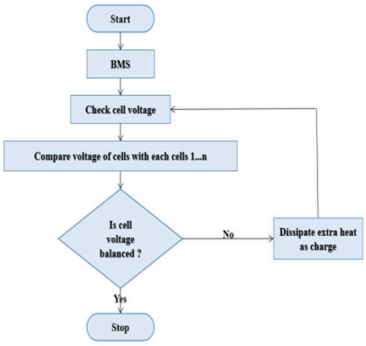


Figure No. 5.6.Algorithm for SOC and Voltage based passive cell balancing algorithm

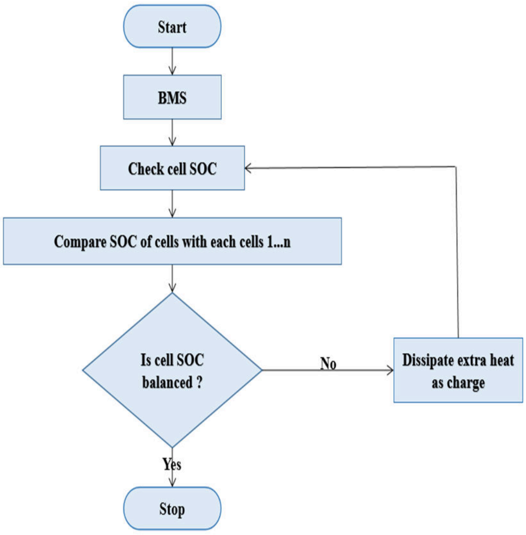
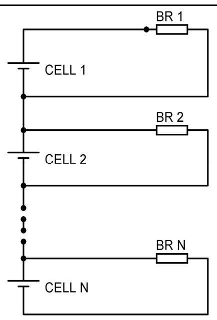
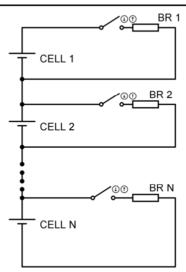
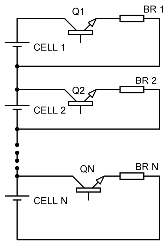
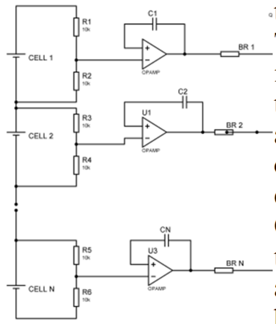


Figure No. 5.6.Algorithm for SOC and Voltage based passive cell balancing algorithm

The detailed explanation of the Passive Cell Balancing is tabulated in the table 5.2. The figure A to K shows the circuit diagram of various cell balancing method[52-55].

Cell Balancing Types	Circuit Diagram	Condition	Advant ages	Dis-advantages

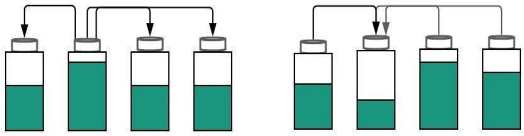
Fixed Resistor Method	 Figure No.: A Fixed Resistor Method	The cell 1 to cell N is connected in series to form battery pack for electric vehicle application. The BR1 refers to balancing resistor across the each cell. The resistors are fixed and have a fixed value of discharge current to the resistor. It is an open-loop system. The SOC and Voltage is not taken as the input to the system.	It is technically easy to implement at a low cost, design of the bypass resistor is simple and the complexity of the system design is lower.	Inefficient due to the efficiency of the system is very poor because fixed value of resistor does not allow a control algorithm. The system is in-efficient due to Heat loss. The system is not employed because of the manual intervention for the balancing of the battery cells.
Bypass resistor / Switched Shunting Resistor	 Figure No.: B Bypass Resistor Method	The cell 1 to cell n is connected in series to form battery pack for electric vehicle application. The BR 1 to BR N the balancing resistors is placed with a switch across the each cell. It is the good method of cell balancing for charging. The voltage of each cell in the battery pack is observed and obtainsthe lowest cell voltage. Then, forge the remaining cells to the lowest cell range by connecting by-pass resistors. The switch is turned ON and OFF using the control algorithm.	It is technically easy to implement at a low cost, design of the bypass resistor is simple and the complexity of the system design is lower. The switches used may be of MOSFET or any other devices that are available easy in the market.	But during discharging of the battery pack this may be not applicable, since the lowest voltage during discharging will lower to low value and cannot provide further discharging through the resistor. Discharging current has to be taken into the consideration.Inefficient due to Heat loss is a predominant problem as the resistor is used as a bypass element and switching loss using MOSFET

		This method is mainly applicable for charging systems.		switch.The complete discharge current through resistor flows via the MOSFET switch that is connected with Controller IC. Thus, the discharging current should be limited in the safer limit. This will increase the discharging time. Therefore, these systems have lower Charge-Discharge Rate.
Analog Shunting	 Figure No.: C Analog Switching using Transistor switch  Figure No.: D Analog Switching using OP-AMP	The CELL 1 to CELL N is connected in series to form a battery pack. The transistors Q1 to QN are connected as switch in the system. The transistor act as a switch to transfer the energy between the battery pack. Thus, the difference in energy between the cells is observed and the balancing occurs. The analog components such as OP-AMP and transistors are used as key element to balance the difference in cell voltage. The OPAMP can operate as a comparator, voltage follower and converters. The voltage reference is	The system is simple, economic, low power dissipation and low heat loss**.** The energy is saved because the switching occurs for the prescribed cells.	The circuit is complex to implement and the failure of analog components is difficult to troubleshoot. The system is efficient, but difficult to control. The accuracy of the analog circuit is not accurate and precise for this application because of the lower range application.

		set in the OP-AMP based circuits (shunt voltage regulator) and the reference voltage is received at the output[56]. [1]		

Active Balancing:

The active cell balancing is used to transfer the energy between the cells via inductor and capacitor [56-60]. The converters are used to provide the proper pulse width.The active balancing circuit shown in the figure 5.7.



CHARGING

DISCHARGING

Figure No. 5.7.Active Balancing Circuit

The active balancing algorithm is shown in the figure 5.8.

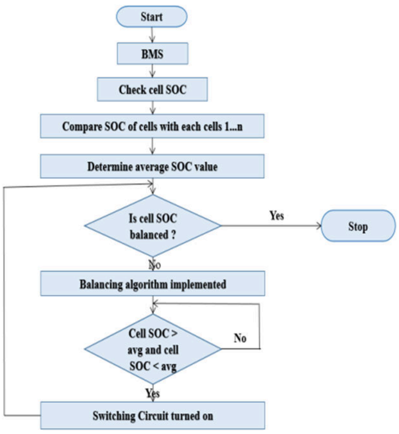


Figure No. 5.8. Algorithm for Active balancing in the Battery management system

The types of passive balancing are

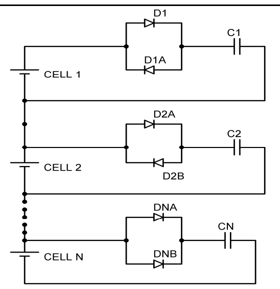
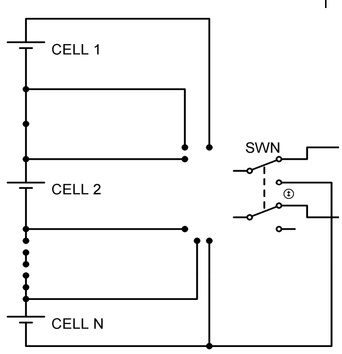
1. Fixed Capacitor Balancing
2. Charge Shuttling Capacitor
3. Single Switched Capacitor
4. Double tired switched capacitor bank
5. Modular switched capacitor bank
6. Single Inductor Balancing
7. Coupled Inductor Balanced
8. Single winding transformer based balancing
9. Multiple winding transformer balancing
10. Multi winding transformer based balancing
11. Modularized Multi winding transformerbased balancing
12. Boost Converter based balancing

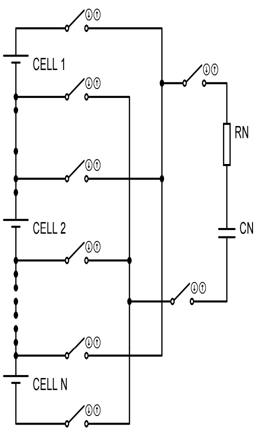
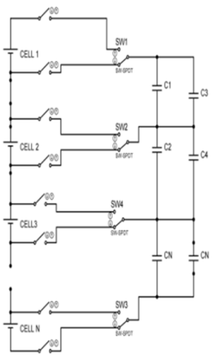
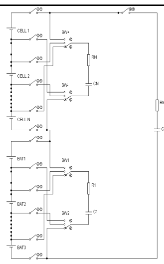
13. Buck-Boost converter based balancing
14. CUK Converterbased balancing
15. Ramp Converterbased balancing
16. Full Bridge converterbased balancing
17. Quasi resonant converterbased balancing
18. Unidirectional fly-back converterbased balancing
19. bidirectional fly-back converterbased balancing
20. Complete Shunting or Full deviation topologybased balancing
21. Push pull converterbased balancing

Active Cell Balancing

The detailed explanation of the Active Cell Balancing is tabulated in the table 5.3. The figure E to N shows the circuit diagram of various active cell balancing methods.

Table. No. 5.3 Active Cell Balancing Methods

Cell Balancing Type	**Circuit Diagram**	**Working**	**Advantages**	**Dis-advantages**
Energy Storage Element (Inductor, Capacitor)	 Figure No.: E Fixed Capacitor Balancing	The higher charge holding cell is sharing the charge with the low charge holding cell present in the battery pack [61]. The capacitors C1 to CN are connected across each cell. The diodes D1 and D1A are used as a switch for forward and reverse direction.	The energy transfer is possible using inductor and capacitor. The cost is minimized by using the passive elements.	The problem of interference occurs due to the usage of inductor and capacitor.
Charge Shuttles Firing Capacitor	 Figure No.: F Charge Shuttle Balancing	This is the most common method used in active cell balancing. The highest voltage cell transfers its energy to the lowest energy cell of the battery pack by proposing the algorithm in the system. The capacitor CN charges itself through the switch SWN from the highest voltage cell until the prescribed limit based on the algorithm [62]. Then, the switch is disconnected and	The system is highly efficient since there is no power loss in the circuit. The single capacitor is employed to balance a battery pack of battery cells. Thus, the cost of the system is low and low electromagneti	It is efficiently applicable only for adjacent cells where the system employs lesser switches and capacitors. It is costlier when no.of switches and capacitors are increased. The size and

		connected to the lowest voltage cell if required according to the algorithm. Thus, the charges get shuttled between the capacitor and the cells.	c interference to the system.	weight of active balancing is also big and heavier.
Single Switched Capacitor and Double-tried Switched Capacitor	 Figure No.: F Single Switched Capacitor Balancing	The single switched  ancing igher lower nsfer from lower a easy he sed to when ce [63]. Fi Sv The auxiliary capacitors are used for the cells. This is more efficient than single switched capacitor method [64]. The algorithm has been proposed based on the input received from the sensors. The capacitor tiers are employed for shuttling of cell energy between the battery cells.	The two tier capacitors employed can be used for any type of cells and battery bank. The no. of switches and capacitors used is less in single switched capacitor compared to double tired switched capacitor.	The size becomes more and then there is a complexity in system design. The cost of design and accurate switching makes the system complex. The no. of components used is higher in this method.
Modularized Cell Balancing	 Figure No.: H Modularized Capacitor Balancing	The modularized switched capacitor cell balancing circuit is widely employed in electric vehicle appalication to achiev e better equalization time and imptrove the performance of the battery life time [65]. The battery pack module is comprised of the capacitor via the switch. The balancing circuit	The efficiency of the modularized cell balancing is high. The entire battery is monitored and periodic set conditions are verified. The balancing time is improved and the auxiliary	The size becomes more and then there is a complexity in system design. The voltage residue error consideration needs to be improved.

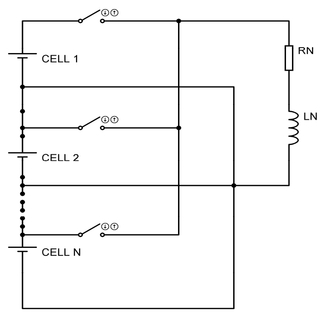
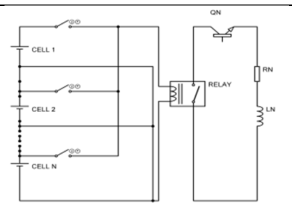
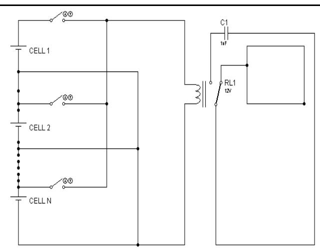
		balances the individual cells and later connected to the master balancing circuit of the battery pack. The balancing circuit works at better balancing time with lower voltage and current stress on the switches. The battery cells BAT1 to BAT3 is connected via the switches SW1 to SW2 to the resistor and capacitor R1 and C1.	capacitor is used for improving efficiency. The no. of components used is comparatively less in this system. This topology can be extended to series connected cells.	
Inductor based Balancing Single winding Balancing	 Figure No.: I Single Switched Inductive Balancing	The single winding transformer cell balancing circuit employs switched capacitor based balancing topology using switching configuration [66]. This is also called as switched transformer cell balancing circuit that passes the balancing current to flow from the higher energy cell to the lower energy cell pack through the transformer winding by operating the switches to transfer energy between the battery pack.The CELL 1 to CELL N is connected to inductor LN via switch to balance the battery cells.	The cell balancing happens at faster rate. The stored energy using inductor reduces the cell balancing time.	This balancing circuit is highly complex and the cost of the entire circuit is quite expensive.The configuration includes many switches and transformer windings .There may be problem of electromagnetic interference.
Multi-winding Balancing		A single transformer core is employed with a primary winding and multiple secondary winding on the secondary side for the multi-winding	The cell balancing happens at faster rate. This provides easy control unit and	The manufacturing of turn's ratio of inductor with parameter estimation is

	Figure No.: J Multi Switched Inductive Balancing	transformer methodology[67-68]. The switched mode power supply converters also come into the existence of the system. The CELL 1 to CELL N is connected via the relay to inductor LN based on transistor QN switching.	elimination of sensor interface.	highly complex. The leakage inductance of the winding differs and the balancing circuit may itself hinder the cell balancing time. The windings turns can be reduced to avoid these issues.
Converter Based Cell Balancing	 Figure No.: K Converter based Cell Balancing The different types of converter topology includes Boost Converter based balancing Buck-Boost converter based balancing CUK Converterbased balancing Ramp Converterbased balancing Full Bridge converterbased balancing Quasi resonant converterbased balancing Unidirectional fly-back converterbased balancing bidirectional fly-back converterbased balancing Complete Shunting or Full deviation topologybased balancing	In recent days, the converter based cell balancing is being proposed by many industries. The active charge balancing circuit is employed using the power converters. The configuration of the topology may include centralized, distributed and modularized for both charge and discharge conditions in electric vehicle applications [69-73]. This methodology creates interest and better performance related to the cell imbalance. The converter switching can happen via inductor or capacitor [74-81]. According to the transfer medium connected, the working differs. The cell with higher voltage is transferring the energy via the passive elements such inductor and	The cell balancing time is faster. It is economic to use. The efficiency of the converter based equalizing circuits is higher compared to other balancing methods. The constant output without any fluctuation is used to balance the cells. This improves the power quality in the system by reducing the ripple factor.	The complexity in circuit design. Skilled technicians are required. Improper design affects the performance of the battery. Heat sinks and other voltage and current protection circuits have to get employed for better performance. The switches losses should be minimized based on the design employed.

	Push pull converterbased balancingas mentioned above.	capacitor to the converter providing the constant output voltage.		

Comparison of Active and Passive cell balancing

In this comparison, the active and passive cell balancing are shown in the figure 5.9.

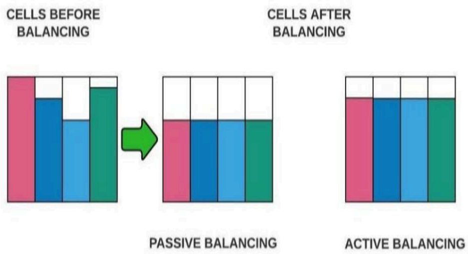


Figure No. 5.9.Cell Balancing Comparison

From this figure, the comparison clearly depicts the working of the passive and active balancing. This show for passive balancing the lowest cell level is reached and balanced. But in case of active balancing, the energy is transferred with the different cells and balancing is achieved. Thus the passive balancing is not more efficient in balancing the cells [82-83]. The energy is wasted as heat energy. In active balancing methods the efficiency can be improved.Generally, balancing take different methods of approach. The board classification is shown listed as

- Equivalent Circuit Method
- Model Based Method
- Circuit based Method

In this equivalent circuit method, the cell is modeled as a resistor and capacitor with the voltage source. The model based design to design the battery with different specification of the equivalent circuit method. The circuit based analysis is used directly with the battery. The error rate may be higher in case of circuit based method since accurate results cannot be analyzed.

Based on the methodology applied, there are different algorithms [84-87] such as

- Voltage based Algorithm (VBA)
- SOC based Algorithm (SBA)
- Outliner Detection Algorithm (ODA)
- OCV (Open-Circuit Voltage) based Algorithm (OCVA)

The table 5.4 shows the cost, equalization time, accuracy and complexity of the cell balancing methodologies.

Table. No. 5.4Algorithms Employed for Different Cell Balancing Methods

S. No.	Algorithm	Cost	Equalization Time	Accuracy	Complexity
1	VBA	Very Low	Good	Low	Very Low
2	SBA	Medium	Excellent	Good	Medium
3	ODA	Medium	Good	Good	Very High
4	OCVA	Low	Good	Medium	Very High

Section 6

Other Factors for BMS

Concern for Power Quality in Electric Vehicle:

By employing the power electronic based circuits in the charging system will affect the AC power systems. This has the major concern towards the power quality issues such as Voltage sag, Voltage Swell, harmonics and power demand by employing the ac charging system. The fault diagnosis(Battery Prognostics and Health Management) also plays a vital role in determine the performance and safety of the battery system [88-94].Even though different power quality mitigation techniques are found, there is a problem in the grid. The peak demand should not coincide with battery charging of an electric vehicle. The concern for the power quality issues have been increasing in recent times because of the solid state electronics role in power system. The power electronics converters have been employed for various applications such power conversion, protection scheme, cell balancing, mitigation methods to improve power quality etc.

Sensors used in Electric Vehicle:

There are different sensors used in electric vehicle. The energy management of theses sensors is taken into the account.In addition to that, the smart grid plays a major part in electric vehicle distribution. The energy management for electric vehicle is also a major concern. The research on energy management of electric vehicle is more important in customers view. The smart grid also plays a major role in energy management [95-96]. The studies show that the developed countries uses a common platform to charge the vehicle and provide incentives based on the usage in order to compensate the charge and discharge of the electric vehicle. The different types of sensors are used for different application. The board classifications of sensors in electric vehicle are

- Wired sensors
- Wireless Sensors
- MEMS based Sensors

The wired sensors may include current, pressure and flow etc. The wireless sensor may include temperature, voltage etc. The MEMS based sensors includes such as position sensors (encoders), pressure sensors, engine management system, Vehicle navigation sensors etc.

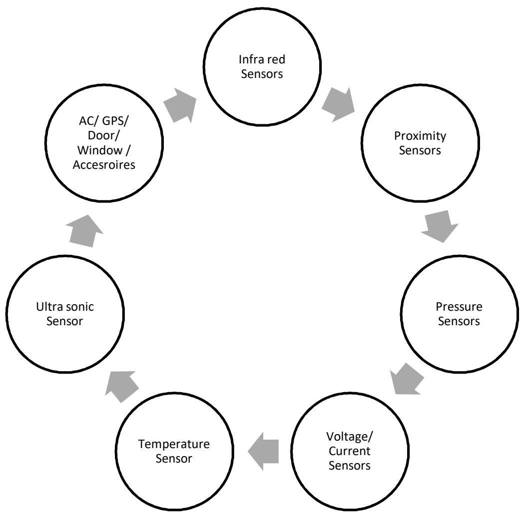


Figure No. 6.1.Sensors used in Electric Vehicle

The sensors mentioned in the figure 6.1 are used for various applications required in the vehicle. Even though, there are different sensors used in the vehicle the proper energy scheme employed in the vehicle could save the energy. Thus, the proper algorithm usage can improve the energy management of the vehicle.

Software Packages for Battery Management system:

The software packages used to simulate the battery management systems are Modelica (i.e. Einhorn et.al), MATLAB/SIMULINK, PROTEUS, and PSPICE. These packages are available in both open-source and proprietary version. The analysis of the battery management system with respect to voltage, current, temperature and other analysis are carried out easily. This also act as a root cause of real time hardware implementation of hardware circuits.

Research Scope

Based on the research views, the battery management system itself is under the scope of research. The Internet of Things (IoT) also paves the effective way to transfer energy from grid to electric vehicle and vice-versa [97-98].The parameters that are under the research progress are cell balancing, thermal management, Energy Management, Electromagnetic Interference, role of electric vehicle in smart grid and the power quality on the grid [99-102]. The model of grid to vehicle energy transfer is shown in the figure 8.1. the vehicle-to-grid configuration is employed either for domestic load application or act as distributed energy sources. This configuration enhances the safety, reliability, efficiency and stability of the grid system with good power quality. This also improves the power regulation, load balancing, power factor control and use renewable energy sources tracking.The figure 7.1 shows the vehicle to grid interactive system for smart grid application.

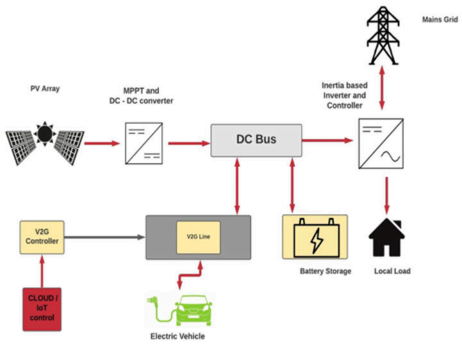


Figure 6.2Block diagram of Vehicle-to-Grid system

Section 7
Conclusion

The differenttypes of electric vehicle topologies are explained with power ranges. The battery management system act as the protective and regulating device for battery operated electric vehicle. The different BMS parameters such as SOC, DOD, SOH, SOP, SOS, thermal management and cell balancing is discussed. The detailed problem of cell balancing is analyzed with the causes working and a type of cell balancing topologies. The other impact factors for electric vehicle are also taken into the consideration for the efficient operation of the battery operated electric vehicle. Thus, the review covers the history of electric vehicle, polices followed in the country, working and chemistry of the battery cell, technology of employed in battery chemistry, battery pack design methodologies, role of battery management systems, cell balancing causes, effects and methods , fault conditions, sensors used in electric vehicle, vehicle to grid interaction in detail. Thus, the battery operated electric vehicle with battery management system is analyzed for different operating conditions.

References

[1] https://www.energy.gov/articles/history-electric-car

[2] A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development, Fuad Un-Noor and Sanjeevikumar Padmanaban , Energies 2017.

[3] https://fame2.heavyindustry.gov.in/

[4] https://www.iea.org/policies/7450-faster-adoption-and-manufacturing-of-hybrid-and-ev-fame-ii

[5] Recent Development on Electric Vehicles , K.W.E CHENG, 2009 3rd International Conference on Power Electronics Systems and Applications.

[6] A Review on Electric Vehicles: Technologies and Challenges , Julio A. Sanguesa1, Vicente Torres-Sanz , Smart Cities, 2021.

[7] Gregory Plett Algorithms for Battery Management Systems Specialization University of Colorado Boulder and University of Colorado System.

[8] Xavier, M.A., de Souza, A.K., Karami, K., Plett, G.L., Trimboli, M.S., “A Computational Framework for Lithium Ion Cell-Level Model Predictive Control Using a Physics-Based Reduced-Order Model,” IEEE Control Systems Letters, Vol. 5, No. 4, 2021, pp. 1387–92.

[9] Plett, G.L., “Battery management systems, Volume I: Battery modeling,” Artech House Publishers, 2015.

[10] Plett, G.L., “Battery management systems, Volume II: Equivalent-circuit methods,” Artech House Publishers, 2015.

[11] State of charge estimation for Li-ion batteries using neural network modeling and unscented Kalman filter-based error cancellation, Wei He, Nicholas Williard, Chaochao Chen, Michael Pecht Center for Advanced Life Cycle Engineering (CALCE), University of Maryland, College Park, MD 20742, USA

[12] State of charge estimation of lithium-ion batteries using the open-circuit voltage at various ambient temperatures Yinjiao Xing a,□, Wei He b, Michael Pecht b, Kwok Leung Tsui a a Department of Systems Engineering and Engineering Management, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon, Hong Kongb Center for Advanced Life Cycle Engineering (CALCE), University of Maryland, College Park, MD 20740, USA

[13] Cycle life testing and modeling of graphite/LiCoO2 cells under different state of charge ranges Saurabh Saxena*, Christopher Hendricks, Michael Pecht

[14] Center for Advanced Life Cycle Engineering, University of Maryland, Room 1103, Building 89, College Park, MD 20742, USA

[15] Effect of electrode physical and chemical properties on lithium-ion battery performance Victor Chabot, Siamak Farhad, Zhongwei Chen, Alan S. Fung, Aiping Yu, Feridun Hamdullahpur First published: 11 September 2013 https://doi.org/10.1002/er.3114. International Journal of energy research.

[16] energiesReviewSystem Planning of Grid-Connected Electric VehicleCharging Stations and Key Technologies: A ReviewChao-Tsung MaDepartment of Electrical Engineering, CEECS, National United University, Miaoli 36063, Taiwan; Energies 2019.

[17] Electric Vehicles Charging Technology Review and Optimal Size EstimationMorris Brenna1 · Federica Foiadelli1 · Carola Leone1 · Michela Longo1Received: 8 April 2020 / Revised: 7 July 2020 / Accepted: 17 September 2020 / Published online: 2 October 2020 © The Author(s) 2020, Journal of Electrical Engineering & Technology (2020) 15:2539–2552.

[18] Design and Implementation of AC Conductive Charging System for Electrical Vehicles, 2019 IEEE 2nd International Conference on Electronics Technology (ICET), Yu-En Wu, Department of Electronic Engineering, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan R.O.C.
[19] A study on the impacts of DC Fast Charging Stations on power distribution system, Yohanes Halim Febriwijaya School of Elecrical Engineering and Informatics, Institute of Technology Bandung, Bandung, Indonesia, Agus Purwadi, School of Elecrical Engineering and Informatics, Institute of Technology Bandung, Bandung, Indonesia, 2014 International Conference on Electrical Engineering and Computer Science (ICEECS).
[20] Wireless charging system using resonant coupling , 2017 International Conference on Inventive Systems and Control (ICISC), Gaurav Sharma, MAIT, New Delhi, India, Akhil Goel, MAIT, New Delhi, India.
[21] Review Paper on Wireless Power Transmission for Charging Mobile DevicesSuprabhat Das Department of Computer Science & Engineering, School of Engineering & Technology, Amity University, Kolkata 700135, India. International Journal of Engineering And Computer Science ISSN:2319-7242Volume 6 Issue 3 March 2017, Page No. 20751-20755.
[22] Batteries and battery management systems for electric vehicles , 2012 Design, Automation & Test in Europe Conference & Exhibition (DATE), M. Brandl , Austriamicrosystems AG, Unterpremstaetten, Austria, H. Gall, Austriamicrosystems AG, Unterpremstaetten, Austria.
[23] Battery Management System in Electric Vehicles , A. Hariprasad , Assistant Professor,Department of Electrical and Electronics Engineering, Vignan Institute of Technology and Science,Telangana.
[24] Technologies In Battery Management System-A ReviewHamsavarthini.Y, Kanthalakshmi.S, INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 9, ISSUE 01, JANUARY 2020.
[25] "Machine Learning-Based Lithium-Ion Battery Capacity Estimation Exploiting Multi-Channel Charging Profiles", Yohwan Choi, Seunghyoung Ryu , Kyungnam Park and Hongseok Kim, IEEE – 2019.
[26] "Lithium-ion battery modeling based on Big Data", Shuangqi Li, Jianwei Li, Hongwen He and Hanxiao Wang , Elseiver- 2018.
[27] "Digital twin for battery systems: Cloud battery management system with online state-of-charge and state-of-health estimation", Weihan Li, Monika Rentemeister, Julia Badedae, Dominik Josta, Dominik Schultef and Dirk Uwe Sauer , Springer - 2020.
[28] "Research and design of lithium battery management system for electric bicycle based on Internet of things technology", Yang Xu, Shen Jiang And Tong Xin Zhang, IEEE – 2019.
[29] "A review of lithium-ion battery state of charge estimation and management system in electric vehicle applications: Challenges and recommendations" , M.A.Hannan, M.S.H.Lipu , A.Hussain and A. Mohamed, Elsevier – 2017.
[30] A Li-ion Battery Management System Based on MCU and OZ8920, Xiaochao Xiaoa, Xiaojun Liua*, Libiao Qiaoa, Shuo LiaaSchool of Mechanical, Electrical & Information Engineering, Shandong University at Weihai, Weihai 264209, P. R. China. 2012 International Workshop on Information and Electronics Engineering (IWIEE 2012), 77-7058, 2011 Published by Elsevier Ltd.
[31] Review Paper on Electric Vehicle Charging and Battery Management System, KadlagSunildatSomnath, Mukesh Kumar Gupta - Elsevier-2019.
[32] "A Review on Electric Vehicles with perspective of Battery Management System" , Daisy Ranawat and M P R Prasad, IEEE – 2018.
[33] "A Review on Battery Management System for Electric Vehicles", Omkar S Chitnis, IJSER – 2019.
[34] "Battery Management Systems—Challenges and Some Solutions",Balakumar Balasingam , Mostafa Ahmed and Krishna Pattipati , MDPI, Energies 2020.
[35] "Comparative Analysis of Cell Balancing Topologies in Battery Management Systems" Abinash Khanal , Ashutosh Timilsina , Binay Paudyal and Saugat Ghimired-IOE Graduate Conference, 2019.

[36] “Energy storage system and balancing circuits for electric vehicle application” A. K. M. Ahasan Habib, Mohammad Kamrul Hasan,Md Mahmud, S.M.A. Motakabber,Muhammad I. Ibrahimya,Shayla Islam, IET-2020.
[37] “Review of Battery Cell Balancing Methodologies for optimizing battery pack performance in EV”, Zachary Bosire Omariba, Lijun Zhang, Dongbai Sun, IEEE-2019.
[38] “Charge equalization of Battery Power Modules in series”. Wei Hong,Kong-Soon Ng,Jin-Hsin Hu and Chin-Sien Moo. IEEE2010.
[39] “Balanced charging circuit for charge equalization”. Yao C.Hsieh, Chin S.Moo and IS.Tsai. IEEE2002.
[40] “Dynamic Charge Equalization for Series-connected Batteries”, Yao C. Hsieh, Chin S. Moo, I S. Tsai and Jung C. Cheng ,IEEE-2002.
[41] “Comparison and Evaluation of Charge Equalization Technique for Series Connected Batteries”, Kong Zhi-Guo, Zhu Chun-Bo, Lu Ren-Gui, Cheng Shu-Kang.
[42] “Battery charge equalization controller in electric vehicle applications: A review”, M.M. Hoquea, M.A. Hannan, A. Mohamed, A. Ayob, Elsevier -2016.
[43] Review of Battery Cell Balancing Methodologies for optimizing battery pack performance in EV, Zachary BosireOmariba, Lijun Zhang, Dongbai Sun, IEEE-2019.
[44] “Fast Equalization for Large Lithium Ion Batteries” , Thomas A.Stuart and Wei Zhu OVE et. Al , IEEE-2009.
[45] Z. G. Kong, C. B. Zhu, R. G. Lu, and S. K. Cheng, ‘Comparison and evaluation of charge equalization technique for series connected batteries’, PESC Rec. - IEEE Annu. Power Electron. Spec. Conf., pp. 1–6, 2006.
[46] Wei Hong, Kong-Soon Ng, Jin-Hsin Hu, and Chin-Sien Moo ,'Charge Equalization of Battery Power Modules in Series ',Dept. of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan.
[47] “Charge balancing of serially connected lithium-ion battery cells in electric vehicles”, M. Einhorn, W. Rößler, F. V. Conte, H. Popp & J. Fleig . Springer-2012.
[48] “Overview of Cell Balancing Methods for Li-ion Battery Technology”, Hemavathi S, CSIR-Central Electrochemical Research Institute (CECRI), CSIR -2015.
[49] “Cell Balancing Technology in Battery Packs”, Yang Xiaolu, Eden W. M. Ma, Michael Pecht, IEEE -2012.
[50] “Cell Balancing Management for Battery Pack”, Lin Hu, Meng-Lian Zhao*, Xiao-Bo Wu, Jia-Na Lou, IEEE -2010.
[51] Yao C. Hsieh, Chin S. Moo, and 1 S. Tsai, 'Balance Charging Circuit for Charge Equalization ', Power Electronics Laboratory Department of Electrical Engineering National Sun Yat-Sen University Kaohsiung, Taiwan.
[52] Comparative Analysis of Cell Balancing Topologies in Battery Management Systems. AbinashKhanal, AshutoshTimilsina ,BinayPaudyal and SaugatGhimired, IOE Graduate Conference - 2019.
[53] Yao C. Hsieh, Chin S. Moo, I S. Tsai and Jung C. Cheng ,'Dynamic Charge Equalization for Series-connected Batteries', Power Electronics Laboratory, Department of Electrical Engineering National Sun Yat-Sen University, Kaohsiung, Taiwan.
[54] “Passive and Active Battery Balancing comparison based on MATLAB Simulation” , Mohamed Daowd et. Al , IEEE-2011.
[55] “A Passive Battery Management System for Fast Balancing of Four LiFePO4 Cells”, Lucian Andrei Perisoara, Ionuț Constantin Guran, and Dumitrel Cătălin Costache. IEEE-2018.
[56] “Battery management system implementation with the passive control method using MOSFET as a load”, Sinan Kivrak, Tolga Ozer , Yuksel Oguz and Emre Burak Erken, SAGE Journal- 2019.
[57] “Real-time Battery Cell Voltage Measurement Method Using LC Series Circuit Type Cell Voltage Equalizer”, Daiki Satou , IEEE 2019.
[58] “Active cell balancing for electric vehicle battery management system”, Thiruvonasundari Duraisamy, Deepa kaliyaperumal, IJPEDS 2020.

[59] Active balancing charging module with continuous and controllable isolation for battery management system, JianOuyang, Ping Zhang, Shiyong Wang, Huiqi Li, IEEE-2012.

[60] “Charge Balancing of serially connected lithium-ion battery cells I electric vehicle” , M.Einhorn OVE et. Al , IEEE-2012.

[61] “Improved Performance of Serially Connected Li-Ion Batteries With Active Cell Balancing in Electric Vehicles”, Lin Hu, Meng-Lian Zhao*, Xiao-Bo Wu, Jia-Na Lou, IEEE -2010.

[62] “Capacitor Based Battery Balancing System”, Mohamed Daowd, Noshin Omar, Peter Van Den Bossche ,Joeri Van Mierlo. MPDI-2012.

[63] M. Daowd, M. Antoine, N. Omar, P. van den Bossche, and J. van Mierlo,‘Single switched capacitor battery balancing system enhancements’, Energies, vol. 6, no. 4, pp. 2149–2179, 2013.

[64] Capacitor Based Battery Balancing System”, Mohamed Daowd, Noshin Omar, Peter Van Den Bossche ,Joeri Van Mierlo, MPDI-2012.

[65] “Battery Cell Balancing Optimization for Battery Management System”, M.S. Yusof, S.F. Toha, N.A Kamisan, N.N.W.N. Hashim and M. A. Abdullah, IOP Science- 2016.

[66] “A comparative study of fault diagnostic methods for lithium-ion batteries based on a standardized fault feature comparison method”, Bin Duan, Qiang Liu , Yunlong Shang and Chenghui Zhang, Springer –2021.

[67] “Lithium-Ion Battery Health Prognosis Based on a Real Battery Management System Used in Electric Vehicles”, Rui Xiong, Yongzhi Zhang, Ju Wang, Hongwen He, Simin Peng, and Michael Pecht,IEEE-2019.

[68] “Double-Tiered Switched-Capacitor Battery Charge Equalization Technique “,Andrew C. Baughman and Mehdi Ferdowsi, IEEE-2008.

[69] A. C. Baughman and M. Ferdowsi, ‘Double-tiered switched-capacitor battery charge equalization.“A single-magnetic cell-to-cell battery equalization converter ” , Sang-Hyun Park et. Al , IEEE-2012.

[70] An Efficient Equalizing Method for Lithium-Ion Batteries Based on Coupled Inductor Balancing, Ali FarzanMoghaddam and Alex Van den Bossche,M PDI - 2019.

[71] “A Fast Multi-Switched Inductor Balancing System Based on a Fuzzy Logic Controller for Lithium-Ion Battery Packs in Electric Vehicles”, Xiudong Cui, Weixiang Shen ,Yunlei Zhang and CungangHu. ENERGIES-2017.

[72] A Modular Cell Balancer Based on Multi-Winding Transformer and Switched-Capacitor Circuits for a Series-Connected Battery String in Electric Vehicles, Thuc Minh Bui, Chang-Hwan Kim ,Kyu-Ho Kim and Sang Bong Rhee. MPDI-2018.

[73] A Low Cost and Fast Cell-to-Cell Balancing Circuit for Lithium-Ion Battery Strings, Van-Long Pham, Van-Tinh Duong and Woojin Choi, MDPI- Electronics, 2020.

[74] Development of Active Cell To Cell Battery Balancing System for Electric Vehicle Applications, EdiLeksono, IrsyadNashirulHaq, EndangJuliastuti, LaluGhifarulZakyFahran and FahriMuhamadNabhan, IEEE -2019.

[75] Novel Single Balancing Circuitry for Modular Cell for Electric Vehicle Applications, Ginu Ann George, M. V. Jayan, Fossy Mary Chacko, and A. Prince, Springer-2020.

[76] A Fast Multi-Switched Inductor Balancing System Based on a Fuzzy Logic Controller for Lithium-Ion Battery Packs in Electric Vehicles, Xiudong Cui, WeixiangShen, Yunlei Zhang and CungangHu, ENERGIES-2017.

[77] Li-Ren Yu*, Yao-Ching Hsieh*, Wei-Chen Liu, Chin-Sien Moo,'Balanced Discharging for Serial Battery Power Modules with Boost Converters',National Sun Yat-sen University/Department of Electrical Engineering, Kaohsiung City, Taiwan.

[78] Flyback Converter Balancing Technique for Lithium Based Batteries, Ali FarzanMoghaddam, Alex Van Den Bossche, IEEE (MOCAST) - 2019.

[79] “Battery Module Performance Improvement Using Active Cell Balancing System Based on Switched Capacitor Boost Converter”, Koko Friansa, Irsyad N. Haq,Edi Leksosno, Brian Yuliarto, Deddy Kurniadi,ICEVT-2017.

[80] “Active balancing charging module with continuous and controllable isolation for battery management system”, Jian Ouyang, Ping Zhang, Shiyong Wang, Huiqi Li,IEEE-2017.

[81] "Developing an active balancing model and its Battery Management System platform for lithium ion batteries", Bibiana Lorente Alvarez, Sergio Villar Garcia and Carles Ferrer Ramis, IEEE-2016.
[82] "Balanced Discharging for Serial Battery Power Modules with Boost Converters."Li-Ren Yu,Yao-Ching Hsieh,Wei-Chen Liu,Chin-Sien Moo.IEEE 2013.
[83] K. Friansa, I. N. Haq, E. Leksono, N. Tapran, D. Kurniadi, and B.Yuliarto, 'Battery Module Performance Improvement Using Active Cell Balancing System Based on Switched- Capacitor Boost Converter (S-CBC)', 2017 4th Int. Conf. Electr. Veh. Technol., pp. 93–99, 2017.
[84] "Active balancing charging module with continuous and controllable isolation for battery management system", Jian Ouyang, Shiyong Wang , Ping Zhang and Huiqi Li, IEEE – 2017.
[85] Li-Ren Yu, Yao-Ching Hsieh, Wei-Chen Liu, Chin-Sien Moo, 'Balanced Discharging for Serial Battery Power Modules with Boost Converters', National Sun Yat-sen University/Department of Electrical Engineering, Kaohsiung City, Taiwan.
[86] "Online estimation of capacity fade and power fade of lithium-ion batteries based on input–output response technique", Z Yang and D Patil , IEEE-2018.
[87] "Lithium-Ion Battery Cell-Balancing Algorithm for Battery Management System Based on Real-Time Outlier Detection", Changhao Piao, Zhaoguang Wang, Ju Cao,Wei Zhang, and Sheng Lu, Mathematical Problems in Engineering, 2015.
[88] SIMULATIVE COMPARISON OF BALANCING ALGORITHM FOR ACTIVE AND PASSIVE CELL BALANCING SYSTEMS FOR LITHIUM-ION BATTERIES, Christian Fleischer, Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University, Advanced Automotive Battery Conference (AABC), 04.-08.02.2013, Pasadena, California.
[89] "Model Based design of balancing Systems for electric vehicle battery packs". Thomas Bruen, James marco, Miguel Gama. IFAC-2015.
[90] Xiong , Wanzhou Sun , Quanqing Yu and Fengchun Sun, Elseiver-2020.
[91] "Characterization of external short circuit faults in electric vehicle Li-ion battery packs and prediction using artificial neural networks", Ruixin Yang, Rui Xionga, Suxiao Maa and Xinfan Lin, IEEE- 2019.
[92] "Range Maximisation of Electric Vehicles through Active Cell Balancing using Reachability Analysis", Changhao Piao, Zhaoguang Wang, Ju Cao, Wei Zhang, and Sheng Lu, Mathematical Problems in Engineering -2015.
[93] "Temperature-dependence in Battery Management Systems for electric vehicles: challenges, criteria, and solutions" , Haakon Karlsen, Tao Dong, and Zhaochu Yang, and Rui Carvalho , IEEE-2019.
[94] "Cloud-Based Battery Condition Monitoring Platform for Large-Scale Lithium-Ion Battery Energy Storage Systems Using Internet-of-Things (IoT)", Amit Adhikaree, Taesic Kim, Jitendra Vagdoda, Ason Ochoa, Patrick J. Hernandez, and Young Lee, IEEE-2017.
[95] Measurement sensors in an electric vehicles , International Symposium on Power Electronics Power Electronics, Electrical Drives, Automation and Motion, Philip Dost, Power Systems Technology and Power Mechatronics, Ruhr University of Bochum, Bochum, Germany, Abdoulkarim Bouabana, Power Systems Technology and Power Mechatronics, Ruhr University of Bochum, Bochum, Germany, June 2012.
[96] Overview of Electric Vehicles(EVs) and EV Sensors Aviru Kumar Basu, Shreyansh Tatiya and Shantanu Bhattacharya, S. Bhattacharya et al. (eds.),Sensors for Automotive and AerospaceApplications, Energy, Environment, and Sustainability, Chapter 7, 2019.
[97] "A Critical Approach Towards a Smarter Battery Management System for Electric Vehicle", Jeevak S. Lokhande, Dr. P. M. Daigavhane, and Mithu Sarkar, IEEE – 2017.
[98] "A Real-time Android-based Monitoring System for the Power Lithium-ion Battery Used on Evs", Wang Menghua and Xiao Bing IEEE – 2017.
[99] Y. Saber and G. K. Venayagamoorthy, "Plug-in Vehicles and Renewable Energy Sources for Cost and Emission Reductions," IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 58, NO. 4, April 2011.

[100]K. Sovacool and R. F. Hirsh, “Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles and a vehicle-to-grid transition,” Energy Policy, vol. 37, no. 3, pp. 1095- 1103, 2009.
[101]J. C. Vasquez, J. M. Guerrero et al., “Hierarchical Control of Intelligent Microgrids,” IEEE Ind. Electron. Mag., vol. 4, no. 4, pp. 23–29, Dec. 2010.
[102]. Tholkapiyan, A.Mohan, Vijayan.D.S , “A survey of recent studieson chlorophyll variation in Indian coastal waters”, IOP Conf. Series: Materials Science and Engineering 993 (2020) 012041, doi:10.1088/1757-899X/993/1/012041.