A REVIEW ON BATTERY MANAGEMENT SYSTEM IN ELECTRIC VEHICLE

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Abstract:Batteries are mostly using as power source in portable electric devices in low power application, such as calculators, mobile phones, as well as in high power applications, such as electric vehicles (EVs), hybrid electric vehicles (HEVs), where a suitable battery management system is paramount in ensuring safety and reliable working operations of batteries. The purpose of this paper is to present a review on battery management system in electric vehicle, including types of batteries, operation of batteries, BMS technology and related paper studies on this technologies. Initially, in the introduction battery types are studied then operation of battery then BMS technology which is using in battery. At last final proposed model has been discussed.

Keywords:Types of battery, battery management system, SoC (state of charge), SoH (state of Health), electrical model. Thermal model, battery charging**.**

I. Introduction

The environment is polluted by the conventional internal combustion (IC) engine-based vehicles which are using fossil fuel, to replace it the most promising solution is electric vehicles (EVs) and hybrid electric vehicles (HEVs). The challenge of energy shortage and environment pollution calls for the development of new energy vehicle is considered as future transportation tool, so in recent years have seen drastic development of EV and HEV technologies. Batteries are using in wide area of application as the power supply source in EVs and HEVs with the advantages such as high energy density, low environmental pollution and long life cycle. In another stand battery requires proper care in the EV applications. Over-current, over-voltage, over-charging, over-discharging, high temperature or low temperature will cause significant safety issue to the batteries which cause damage or fire or explosion of battery because of irregular operations. Hence, by monitoring and controlling battery, the battery management system (BMS) plays important role in ensuring safety and performance of battery.

The objective of this paper is to give an overview on battery management system in electric vehicle mainly for BMS. This paper is prepared as following structure; I. Introduction, II. Classification of battery, III. Operation of battery, IV. BMS technology, V. Literature survey including different research paper studied related topics, VI. Proposed model explained in detail for battery management system in EV.

II. CLASSIFICATION OF BATTERY

According to charging/discharging operation of batteries, are classified as shown in figure-1. Here, described the operation of batteries in two different kind condition of charging and discharging. Some popular types of batteries which are mainly using in EV applications are analysed and summarized of their key technologies in table-1.

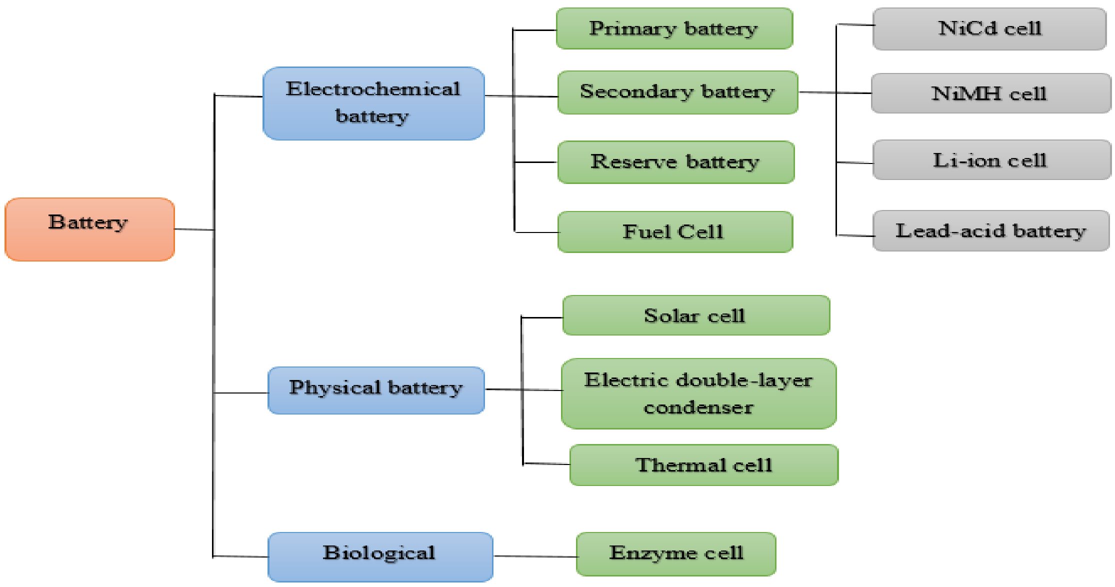


Figure-1:classification of battery

A. Primary batteries are not capable of being easily or effectively recharged electrically so that they are discharged once and discarded. Many primary cells in which the electrolyte is contained by an absorbent or separator material in which there is no free or liquid electrolyte are termed ‘dry cells’.

B. Secondary batteries can be recharged electrically after discharged to their original condition bypassing current through the in the opposite direction to that of the discharge current. They are storage device for electric energy and, also known as ‘storage batteries’ or accumulators. The applications of secondary batteries fall into two main categories:

   i. Those applications in which the secondary battery is used as an energy-storage device, generally being electrically connected to and charged by a prime energy source and delivering its energy to the load on demand. Examples are automotive and aircraft systems, emergency no-fail and uninterruptible power sources (UPS), hybrid electric vehicles and stationary energy storage (SES) system for electric utility load levelling.

   ii. Those applications in which the secondary battery is used or discharged essentially as a primary battery, but recharged after use rather than being discarded. Secondary batteries are used in this manner as, for example, in portable consumer electronics, power tools, electric vehicles, etc., for cost savings (as they can recharge rather than replaced), and in applications requiring power drains beyond the capability of primary batteries.

C. Reverse batteries, a key component is separated from the rest of the battery prior to activation. In this condition, chemical deterioration or self-discharge is essentially eliminated, and the battery is capable of long-term storage. Usually the electrolyte is the component that is isolated. In other systems, such as the thermal battery, the battery is inactive until it is heated; melting a solid electrolyte, which then becomes conductive

D. Fuel cells, like batteries, are electrochemical galvanic cells that convert chemical energy directly into electrical energy and are not subject to the Carnot cycle limitations of heat engines. Fuel cells are similar to batteries except that the active materials are not an integral part of device (as in battery), but are fed into the fuel cell from an external source when power is desired. The fuel cell differs from a battery in that it has the capability of producing electrical energy as long as the active materials are fed to the electrodes.

Battery type	Service life (cycle)	Nominal voltage (V)	Energy density (h)	Power density ( )	Charging efficiency (%)	Self-discharge rate (%)	Charging temperature ( )	Discharge temperature ( )
Li-ion battery	**600 – 3000**	**3.2 – 3.7**	**100 - 270**	**250 - 680**	**80 – 90**	**3 – 10**	**0 to 45**	**-20 to 60**
Lead acid battery	**200 – 300**	**2.0**	**180**	**180**	**50 – 95**	**5**	**-20 to 50**	**-20 to 50**
NiCd battery	**1000**	**1.2**	**150**	**150**	**70 – 90**	**20**	**0 to 45**	**-20 to 65**
NiMH battery	**300 - 600**	**1.2**	**250 - 1000**	**250 - 1000**	**65**	**30**	**0 to 45**	**-20 to 65**

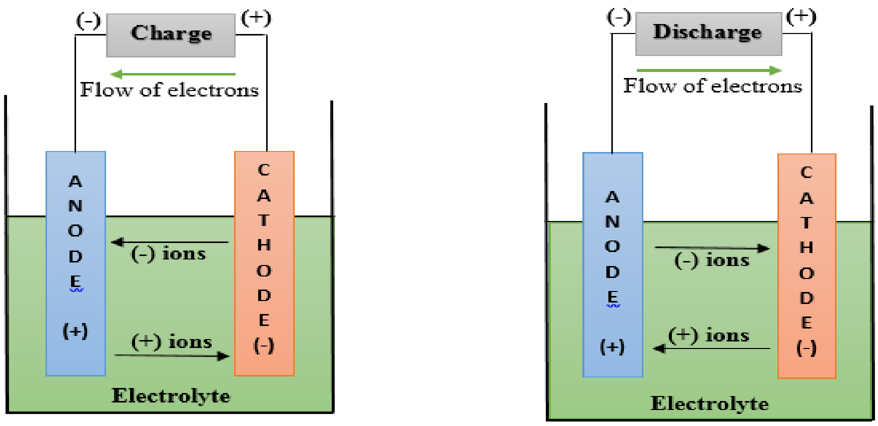
Table-1: popular types of batteries in EV application with different specifications

III. OPERATION OF BATTERY

There are two mainly working operations in the battery;charging anddischarging.

A. Charging:

During the recharge of a rechargeable / storage battery, the current flow from anode to cathode, oxidation takes place at the positive (+) electrode and reduction at the negative (-) electrode as shown in figure-2. As the anode is, by definition, the electrode at which oxidation occurs and the cathode the one where reduction takes place, the positive electrode is now the anode and the negative the cathode.



Charging **Discharging**

Figure-2: charging and discharging operation of battery

B. Discharging:

The operation of cell during discharge is also shown schematically in figure-2. When the cell is connected to an external load, electrons flow from the anode, which is oxidized, through the external load to the cathode, where the electrons are accepted and the cathode material is reduced. The electric circuit is completed in the electrolyte by the anions (negative ions) and cations (positive ions).

IV. BMS TECHNOLOGY

Compared with motor and motor control, battery measurement system is not very mature yet. It can improve the security, protection and stability of the entire battery system that online detects each state of battery cell voltage, current, battery temperature, etc. in real time. To use as power supply source in electric application, batter need special care because battery may be damaged by incorrect operation such as, too high/low temperature, over charging/discharging will increase/decrease degradation process of battery. For a high power and voltage requirement in battery bank, there is hundreds of battery connected in series and parallel configured, so this complicated structure needs special care by operating, monitoring and controlling battery modules/bank. Hence, well designed BMS is very important to protect batteries.

Battery management system, the system performs a lot of functions from gathering data to analysing it to implementing suitable pre-loaded algorithms to ensure safer functionality of the vehicle at an optimum operating point. Some of the important functions of BMS are:

- Charging and Discharging Control: The life period of a battery depends on the handling of it during the charging and the discharging periods. In most cases batteries get damaged due to improper charging than any other reasons. For Li-ion battery a constant current constant voltage charging method is used for charging. In the constant current phase the charging device or the charger provides a constant current to the battery, because of which, the voltage of the battery increases till it reaches a constant voltage. After that the charger maintains this voltage as the battery current decreases in an exponential manner until the charging of the batteries is finished. While discharging, the discharge current should be controlled to ensure that the level of charge should not drop beyond a certain limit.
- State of charge calculation: State of the charge of a battery, calculated by the BMS, is used as a feedback signal in a control system or as a reference for the user to control the charging and discharging of the batteries. Primarily three methods are used to determine the state of charge of battery:
  - Direct measurement by using voltmeter
  - Coulomb counting
  - A combination of the above two techniques
- Coulomb counting method: battery current is integrated with respect to time to get the relative value its charge. In combination method when the actual charge approaches zero charge or full charge, the voltmeter is used to measure the battery voltage and calibrate state of charge.
- State of Health (SOH) determination: SOH gives a clear scenario of the battery performance compared to a fresh battery. Generally, cell inductance or cell capacitance are used to designate the health of the battery, as these parameters change with the age of the battery.
- Cell balancing: Cell balancing is a method, in which the charge of each cell in a series chain is equalized by compensating charge in the weaker cells to have an enhanced battery life. In a battery chain small difference in charge carrying capacity between two cells, present because of variable manufacturing or operating conditions, get magnified with subsequent charging discharging cycles. During these cycles weaker cells get overstressed and become weaker and weaker. In general, three cell balancing schemes are adopted. Each of those schemes has been discussed briefly below:
  - Active cell balancing: In this scheme, charge from a stronger cell is derived and supplied to a weaker cell.

- Passive cell balancing: In this method, first the cells with the highest charge are identified by dissipative techniques and then the extra energy in that cell is removed through a bypass resistor till the charge or the voltage of that cell matches with other weaker cells.
- Charge shunting: In the charge shunting method all the cell are first charged to the rated voltage of a good cell, then the current of the stronger cells are bypassed to the weaker cell till their voltages become equal.

- Log book function: The battery management system not only monitors and gathers the data to analyze them, but also holds data (both experimentally acquired and standard values of different parameters at normal working condition). The SOH of a battery is measured and compared to that of a fresh battery, because of which the BMS must have some reference data within it.
- Communication: Like many micro-processor based controlling system, the battery management system uses bi directional data links to get different parameter data from the sensors, to store this information and to deliver diagnosis based upon these parameters by offering central signals through communication. The selection of communication protocols depends on the battery applications. To ensure smoother operation of the vehicle, the BMSs, used in the electrical vehicles or in the hybrid vehicles, interconnect with upper vehicle controller as well as with a motor controller. The two main communication etiquettes are:
  - Data buses (for instance RS232, RS485 etc.)
  - Controller Area Network (CAN) bus (industry standard for on-board vehicle communication

V. LITERATURE SURVEY

In the paper [1]; Sarang R. Soni[1], have taken the issue of the analysis of battery-super capacitor based storage for electrical vehicle with target to make battery life enhancement on the behalf of time for the purposes of charge management. They have done ten numbers of batteries being connected in series and connected with charger circuit and taken out the readings of 100 Ah and 65 Ah batteries charging process the reading for 100 Ah lead acid battery have been noted about between 13 V to 14 V and for 65 Ah Pb-acid battery it was average between 12V to 13.5 V. According to reading they showed graphical representation between the qualities V-I, V-Wh, I-R and V-T by scatter graph by correlating qualities they make equation $I = a \times V + b$; $V = c \times Wh + d$. They worked on electric double layer capacitor principle according to Helmholtz model and showed power energy relationship for various electrical energy storage devices. The challenges during this work, they faced capacitor loss (70%) for fast charging times. They could achieve; battery cannot supply that energy rapidly, higher charge/discharge rate of super capacitor increase life of battery, SC is most effective device.

In the paper [2]; Ken Darcovich [1] have investigated the effects of disturbances originating in the electric grid as well as residential appliance inrush current on the integrity of battery packs in electric vehicle that are connected to the grid or a residence for the purpose of V2H/V2G service. The analysis of electrical disturbances to automotive batteries in vehicle to grid context; they used methodology of disturbance event, i/p data was 10-65 resolution which characterized the currents transmitted through a charging unit (6.6 kW, level 2) to a battery. In the disturbance overlay; i/p provided for both charging & discharging modes for longer long term simulated time step, and to super improve the effects of disturbance onto calculation which update the battery state and its extent of capacity loss. In the last methodology of battery life simulation, they have taken the scenario for taking the measurement of parameters for driving vehicle. And they found the effect of the disturbances on the battery in terms of change of electrochemical state and extent of associated capacity loss were added on as overlays, timed as per their frequency of occurrence. In numerical model they worked on charger unit model and battery model according to GAO model. And applying current over time step caused voltage drop and advanced DOD. They implemented modelling of disturbance propagation to battery pack with taken specific parameters of battery capacity, voltage, current, time, and disturbance. They showed four types of disturbances originated in the power grid. As well as, incorporating disturbance of V2H simulation has been done by them. They achieved electrical efficiency of 89%; battery life 8.5178 years and difference between disturbance and without disturbance system was 0.03%. The challenges of their work are effects of disturbance with battery cells of lesser capacity, battery capacity loss in transport states and disturbance caused flow of current in both direction. Thus, power grid disturbances as they exist, need not be considered a reason to refrain from employing an EV for V2G or V2H service.

In the paper [3]; Chao Gong [1]; have taken the issue of the analysis on uncontrolled generation in electric vehicles and battery protection method, with target to achieve better life and health of battery. They analyzed relation between the o/p DC V/I quality of TPUR in EV drive system and the mutative EMF of IPMSM and unfixed battery parameters, and battery protection during UCG proposed. They have taken Thevenin battery model as electrical circuit model. The challenges they faced during their work are; decreasing motor speed offer achieving maximum speed No = 1500 rpm, battery packs might burn/damage/explode because of huge current impulse, high current harmonics accelerate positive plate corrosion and degrade battery life in long run.

In the paper [4]; Boyune song [1] have taken the issue of power transfer pickup for online EV, with target to achieve high power and high efficiency, a large airgap and lightweight. They developed proposed inductive power pickup by using series capacitor with ferrite cores and multiwindings. And they could achieve o/p power and efficiency of pickup o/p power of 20 kW and efficiency of 86.7% at 20 kHz and 250 mm airgap.

In the paper [5]; Mohamed YAICH [1], have done the modelling and simulation of electric and hybrid vehicles for recreational vehicles. For this they have taken different vehicle topologies (EV, SHEV, PHEV) with using ADVISOR simulation environment and MATLAB modelling. They have followed two steps; in first step, vehicle components are sized, using a power of a typical 'recreational vehicle'; and in second step, simulation results are presented and discussed to evaluate complexity, emission and consumption. By the simulation from the mentioned tables and the comparison between the three configurations (EV, SHEV, PHEV), found the results for light vehicle drive train show a slight difference between the SHEV (11.13) and PHEV (12.09) but the EV takes the lead with a ark of 14.92 which makes the pure electric vehicle solution more adequate for a low power application. As for the All-Terrain application, the parallel hybrid vehicle is considered to be the best solution comparing to the EV (10.05) and the SHEV (10.47) since it strikes the highest ark on the scale (15.32).Accordingly, the PHEV for All-Terrain application, can be a good solution nowadays, for both low emissions and excellent fuel economy, by combining the merits of both ICE vehicle and pure EV.

In the paper [6]; Gerfried Jungmeier [1] has been analyzed the key issues for applying LCA methodology to vehicles with an electric drivetrain are identified and described. Based on the proper description of the methodology, the modelling approach and the available data sources, the main influences of the environmental effects of vehicles with an electric drivetrain in the life cycle are; production and life time of the battery, electricity consumption of the vehicle in the operation phase incl. energy demand for heating and cooling,production and source of the electricity, where only additional generated renewable electricity might maximize the environmental benefits, end of life treatment of the vehicle and its battery. The IEA Task 19 will continue to establish an international expert platform on LCA of electric vehicles. Beside the scientific review and discussion on the practical application and further development of LCA to EVs, the task organizes and documents further workshops e.g.LCA aspects of battery and vehicle production, end of life management of electric vehicles, LCA aspects of electricity production and infrastructure.
In short, the below table-2 mentioned with method and algorithm which is used in literature paper including their advantages and limitations.

No	Title	Method	Algorithm	Advantage	Limitation
1	Analysis of Battery-Super Capacitor based storage for Electrical Vehicle	charge management by using super-capacitor	Helmholtz model	Super-capacitor have high cycle rate of up to 1,000,000 cycles of operations and can readily handle charge/discharge cycle in HEV	Ultra-capacitor removes 20% of battery pack and having 80% of battery pack
2	Propagation of Electrical Disturbances to Automotive Batteries in Vehicle-to-Grid Context	disturbance event, disturbance overlay and battery life simulationcharger topologies	GAO model	Large power consumption device to electrical efficiency of 89%	Smaller the battery, higher the relative capacity loss will be
3	Analysis on Uncontrolled Generation in Electrical Vehicles and a Battery Protection Method	Uncontrolled generation energy consumption		the vast amount of energy generated by IPMSM which reducing energy recycling efficiency during UCG, it can effective avoid battery damage	Faults occurs when is 1500 rpm
4	Design of High Power Transfer Pickup for On-Line Electric Vehicle (OLEV)	inductive power transfer pickup		high efficiency & power, a large air gap, light weight total power transfer efficiency of pickup module and rectifier was above 86.7% at the over 20kW rated power	core loss in secondary winding increases due to bigger magnetic flux increased core loss leads to decreased transfer efficiency
5	Modelling and simulation of Electric and Hybrid Vehicle for Recreational Vehicle	ADVISOR vehicle simulation for different vehicle topologies		efficient for low boundary area	time limitation
6	Key Issues in Life Cycle Assessment of Electric Vehicles -Findings in the International Energy Agency			Battery cell management, eco-friendly system	Less robust

(IEA) on Hybrid and Electric Vehicles (HEV)	

Table-2: list literature review with used method & algorithm with their advantages &limitations

VI. PROPOSED MODEL

Establishing a battery model is difficult due to complicated electrochemical mechanism of batteries. Even though, building an efficient model is the initial key for battery management design, monitor, control and optimization. In last two decades, various battery models have been developed with different level of accuracy and complexity. But, as shown in figure-3, this model is developed for the further implementation work, which includes battery cell, electric model, thermal model, BMS model, battery charging methods.

Figure-3 shows the technologies used in the battery management system (BMS), using this system in the electric vehicles (EVs) from the on board circuit which has current sensor, temperature sensor, voltage sensor which will measure electric parameter of battery such as, current, voltage, temperature and give a data of state of charge (SoC), state of health (SoH), state of life (SoL) by measuring of current, voltage, internal/surface temperature. By monitoring all this parameters charging process can be optimized by proper optimization algorithm will charge battery from initial stage to final stage with balancing of various charging purpose such as, fast charging, low temperature rise and high efficiency of energy conversion. Battery status in detail discussed below:

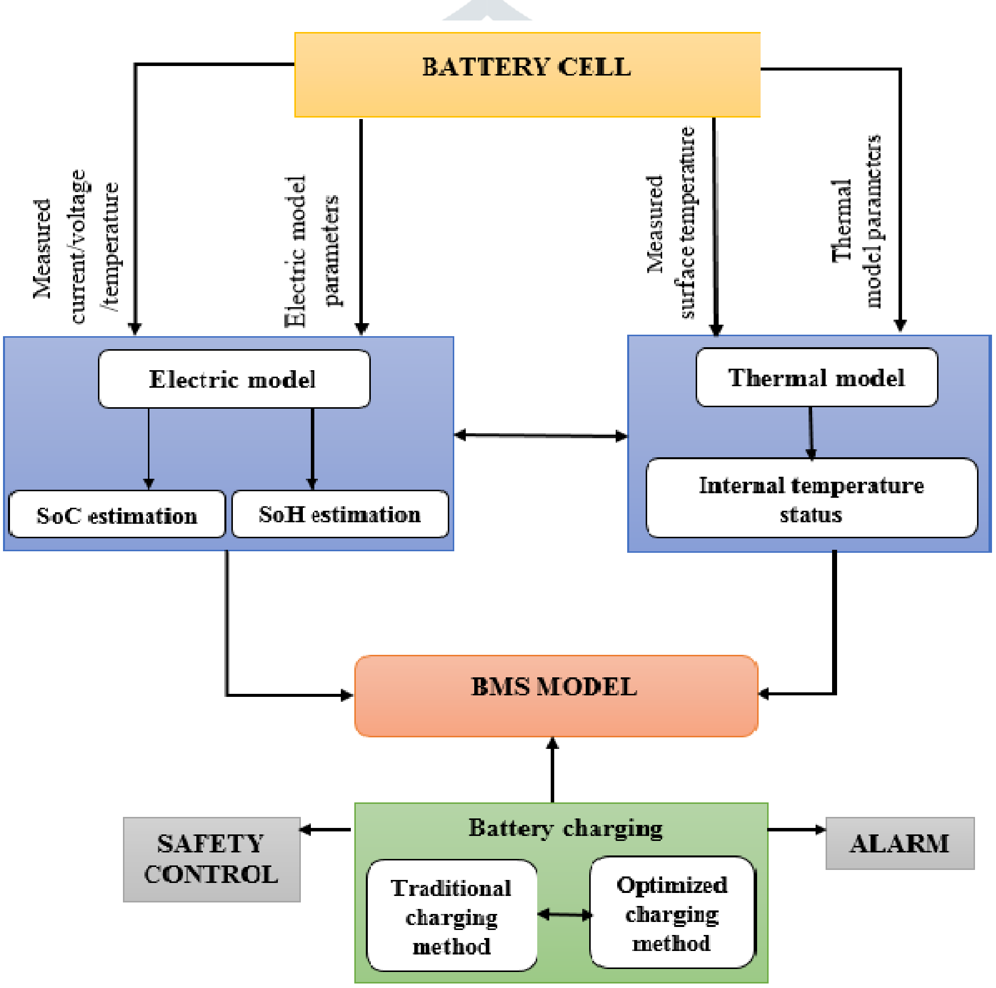


Figure-3: proposed model of battery management system in EV

- State of charge (SOC): State of charge means the amount of energy which is stored in the Battery. It is measured by the open circuit voltage of the battery. As this is a virtual voltage which cannot be measured it must be calculated back out of the terminal voltage. The state of charge is relatively represented by the values between 0 to 1. Simultaneously it can be said 0% to 100%. Where 1 or 100% respectively stands for the maximum open circuit voltage and 0 or 0% for the minimum allowed open circuit voltage. There is not necessarily a direct relation between the charge and the voltage as most of the batteries have a low voltage drop till 10% Ssoc (S for State) which is quickly increased afterwards. The SoC must be calculated in relation to the charge (Q).
  $S_{soc} \sim Q$
- Depth of discharge (DOD): The depth of discharge S includes the same information like the state of charge, but it shows the analogue amount of discharge. According to this the relation is given by,

$$S_{dod} = 1 - S_{soc}$$

According to this calculation the depth of discharge varies between 0 to 1 or 0% to 100% respectively. In contrast to the state of charge 0 stands for a fully charged battery and 1 for an empty battery.

- State of health (SOH): Depending on the age of the battery the state of health must be calculated. The state of health represents the remaining capacity Usually there is no direct influence on the maximum and minimum open voltage but the voltage rise or drop for a fixed amount of charge or discharge. The output is also given by the representative numbers 0 to 1 or 0% to 100%. In most cases of application a reduction of more than 20% of capacity leads to inconvenient operation, as the frequency of recharge increases to an unacceptable amount, the process stability is weakened, or the process cannot be completed.Figure-4 shows capacity correlation with state of health and state of function.
- State of function (SOF): The state of function states the functionality of a full minimal process that should be supplied by the battery. An example can be the start of a combustion engine in a vehicle. The state of function must state that the combustion engine is able to be started as long as the battery can afford this according to the SoC, SoH and of course the temperature. Depending on the definition, the SoF can state a current that needs to be switched of, to allow a full process, or just the general definition of a number between 0 and 1 Where 0 stands for malfunction and everything above for a successfully process finalizing.

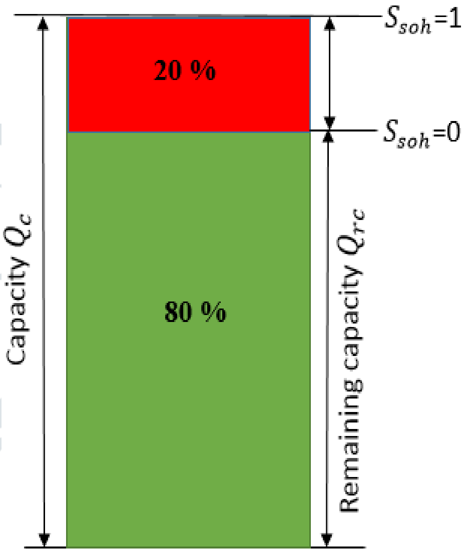


Figure-4: correlation of capacity – state of health

When any unusual situation happen in operation of battery which will detect by alarm module and safety control module and these modules will take action to eliminate these situation or give message via alarming.
Thus, in battery management system important technologies are battery modelling estimation of battery status and battery controlling and monitoring. These technologies become the growing areas of research in the battery management system especially for electric vehicles (EVs).

VII. CONCLUSION

Battery management system in electric vehicle has been reviewed in this paper by introducing about types of battery and operation of battery, as well as BMS system for EV application with charging and discharging, coulomb counting method, cell balancing including active and passive balancing, and communication types. At last shown the proposed model for further implementation in this field with describing about state of charge (SOC), depth of discharge (DOD), state of health (SOH), state of function (SOF); for better performance of battery in EV applications with monitoring status of battery and controlling battery charging.

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