IJIREEICE ISSN (O) 2321-2004, ISSN (P) 2321-5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

ISO 3297:2007 Certified ⋇ Impact Factor 7.047 ⋇ Vol. 10, Issue 9, September 2022

DOI: 10.17148/IJIREEICE.2022.10908

A review of Battery Management System for EV: Estimation and Types

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Abstract: Battery management systems (BMS) are employed in electric vehicles to monitor and regulate the charging and discharging of rechargeable batteries, which increases efficiency. Battery management system maintains the battery's security, dependability, and senility without putting it in a harmful state. Various monitoring approaches are employed to maintain the battery's status, including monitoring of voltage, current, and ambient temperature. Different analog/digital sensors with microcontrollers are utilised for monitoring purposes. This paper discusses a battery's maximum capacity as well as its state of charge, health, and longevity. Future problems and potential solutions can be discovered by reviewing all of these approaches. This study proposes the computation and monitoring of three important indices for EVs BMS, namely state of charge (SOC), state of health (SOH), and state of function (SOF). The accuracy of residual capacity is questionable because the majority of SOC definitions are directly tied to nominal capacity. In order to reduce the mistake in the SOC estimation, the SOC is redefined using the current maximum capacity.

Keywords: Electric vehicle, Battery Management System (BMS), Lithium-ion Battery, Fuel Cell Electric Vehicles (FCEVs)

I. INTRODUCTION

Electric vehicles are playing a crucial role due to their zero emissions of hazardous gases and efficient energy utilisation. A powerful battery management system (BMS) is needed for electric vehicles' numerous battery cells, which are equipped to supply the necessary power. Compared to conventional gas vehicles, EVs have a number of benefits, including being environment friendly, energy efficient, economical, and comfortable. BMS is primarily made up of numerous battery modules, different sensors, and electronic control units (ECU). An array of battery strings is assembled into a battery module to produce high voltage and large currents. As a result, BMS is made to track or estimate battery conditions, such as voltage, current, predictions of remaining range, battery health, and power capability estimation. The fundamental parameters used to assess the entire BMS are state of charge (SOC), state of health (SOH), and state of function (SOF). BMS provides safety to the operator of the host application. It recognises dangerous operating circumstances and reacts to them appropriately. It shields the battery's cells from harm in abuse or failure conditions.

Rechargeable battery packs made of lithium are frequently used in electrical vehicles. To keep the overall electric vehicle system safe, effective, and reliable, battery packs must be closely watched and regulated. A battery used in an electric vehicle should deliver high power in addition to long-lasting energy. The most often used traction batteries are lithium-ion, lead-acid, and metal hydride; among these, lithium-ion is the most widely utilised due to its benefits and performance. A typical electric vehicle's battery capacity ranges from 30 to 100 KWH or more. Decisions are made by the battery management system (BMS) depending on factors such as battery charging and discharging rates, estimated SOC and SOH, cell voltage, temperature, and current, among others.

II. BATTERY MANAGEMENT SYSTEM (BMS)

A crucial component is the battery management system (BMS) of an electric car because the batteries used in these vehicles shouldn't be subjected to excessive charging or discharging. When that happens, it results in the battery being damaged and a rise in temperature, which shortens the battery's life. By efficiently employing the energy that is stored in the car, it is also used to increase the range of the vehicle. The BMS should contain accurate algorithms to measure and estimate the functional status of the battery and, at the same time, be equipped with state-of-the-art mechanisms to protect

DOI: 10.17148/IJIREEICE.2022.10908

the battery from hazardous and inefficient operating conditions [1]. Battery cycle life is measured in cycles, with an industry standard of cycles to 80% capacity often used as a benchmark [2].

The following are reasons why a battery management system is necessary:

- Maintain the battery's durability and safety
- Monitoring and assessing state of charge of the battery
- To regulate the state of charge
- To maintain cell balance and control operating temperature
- Management of renewable energy

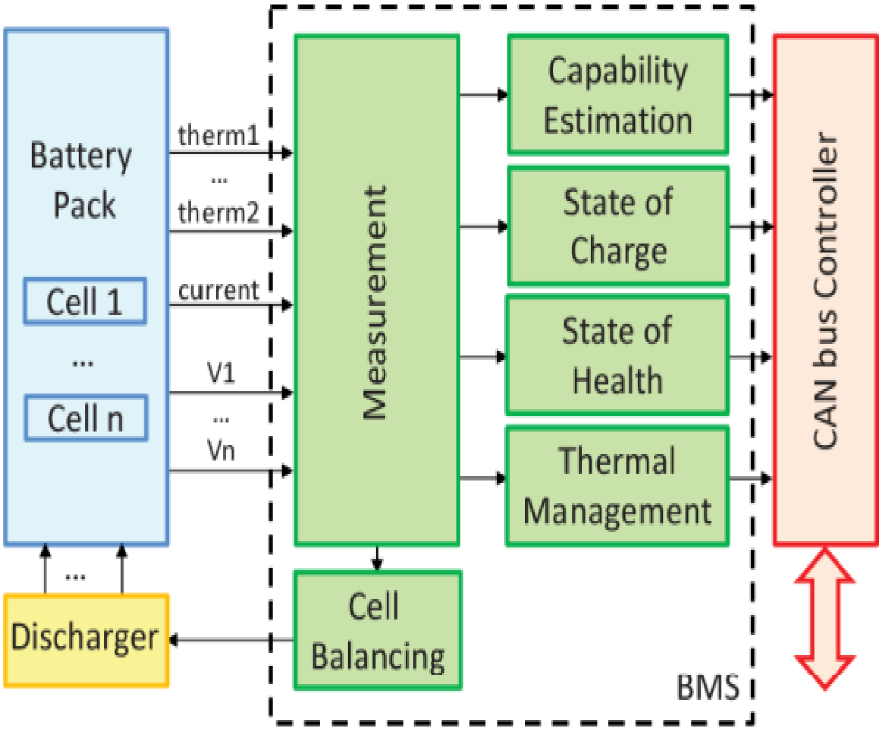

Fig 1: BMS block diagram

III. STATE OF CHARGE AND ITS ESTIMATION

The quantity of battery that is readily available as a proportion of the battery's rated capacity is known as the state of charge. By controlling charging and discharging, the battery management system may check the battery's state of charge and determine whether it is running within the safe operating range. The SOC's value ranges from 0% to 100%.the cell gets recharged when the SOC reaches 50% because the SOC is not permitted to rise above 50%. The maximum SOC starts to decline as a cell ages. SOC is measured in percentage points (0 = empty, 100 = filled). This shows that a 100% SOC for an old cell would be similar to a 75%–80% SOC for a new cell. The depth of discharge (DOD), which is the inverse of SOC (100% = empty; 0% = full), is another way to express the same measurement.

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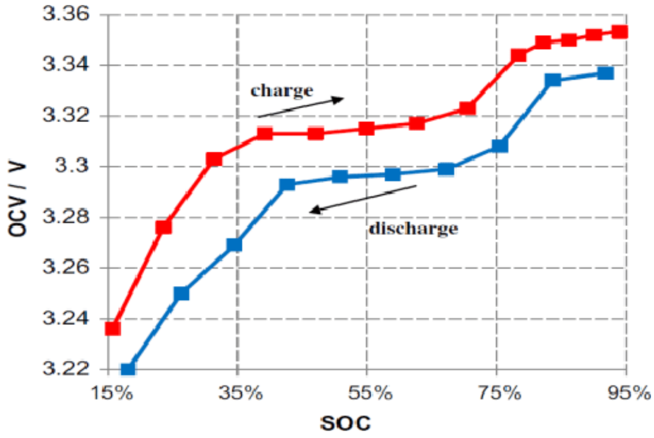

Fig 2: SOC during charging and discharging

Calculating battery SOC is an essential component of a battery management system. State of charge is difficult to estimate. The equation is used to calculate it is

$$SOC = 1 - \frac{\int idt}{C_n}$$

Where i is the current and C_n is the maximum capacity that the battery can hold.

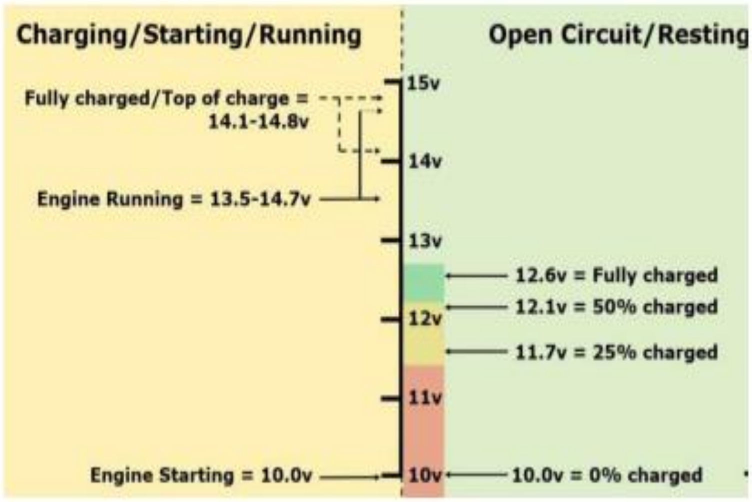

Fig 3: State of charge calculation in an electric car

The status of charge can be estimated using a variety of techniques. The methods for estimating the state of charge are listed below.

- Kalman filtering SOC estimation method
- Coulomb counting SOC estimation method
- Fuzzy logic SOC estimation method
- Open circuit voltage SOC estimation method
- Impedance spectroscopy SOC estimation method

The Kalman filtering method, among all these other approaches, has been effective in estimating SOC for EV'S.

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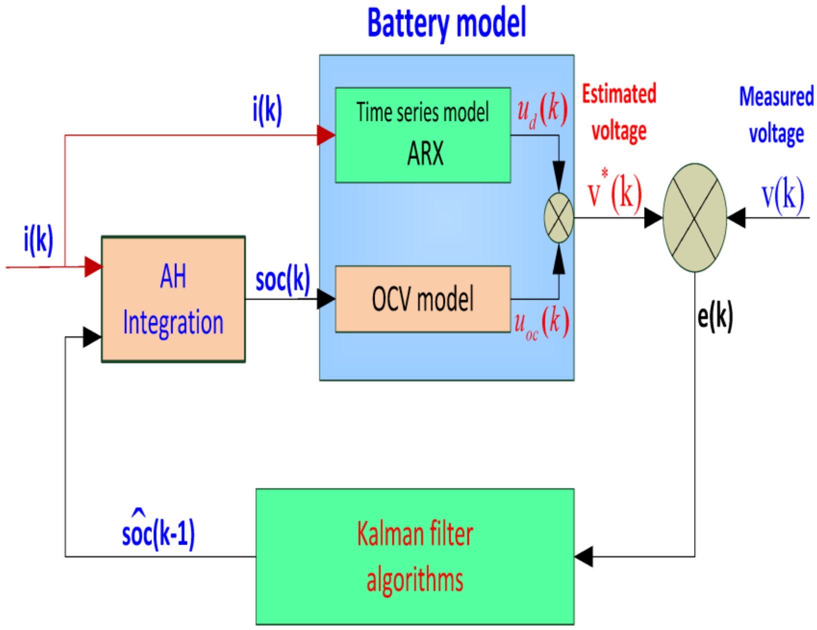

Fig 4: Kalman filtering SOC estimation model

IV. STATE OF HEALTH AND ITS ESTIMATION

The State of Health (SOH) of a battery is the ratio of its maximum instantaneous releasable capacity to the new battery's capacity. SOH is represented in percentage form; a 100% SOH means the battery is new/fresh. SOH can be derived by capacity, internal resistance, battery parameters like power density and discharge rate. With the aging and degradation, the SOH of the battery decreases. The battery's condition is described by the state of health estimation in relation to the recently produced battery. It offers information about the volume of discharges that are possible throughout its lifetime. In EV, the term "SOH" refers to a car's capacity to cover that distance.

According to Pattipati *et al* capacity fade and power fade together combined as health characteristics [3]. Capacity fading with a fully charged battery, refers to decreased driving range. Power fading refers to decline in acceleration capacity. Power fading happens when a cell's impedance rises with ageing. Total impedance is as a result ($R_{HF} + R_{tc} = R$) where R_{HF} and R_{tc} stand for frequency resistance and transfer resistance respectively.

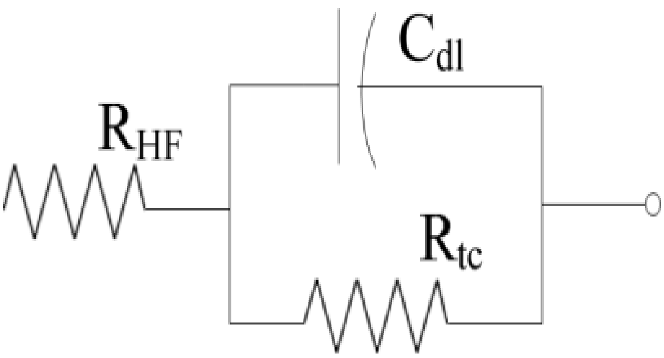

Fig 5: Circuit model for a Li-ion battery

1000 charge-discharge cycles reduce the SOH of a typical Li-ion battery to 80%. The typical approach is described by

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$$\text{SOH} = \frac{nominal\ capacity - loss\ of\ capacity}{nominal\ capacity}$$

$$P = \frac{V^2}{R}$$

$$\text{Power Fade} = 1 - \frac{power(k)}{power(0)} = 1 - \frac{R(0)}{R(0)}$$

$$\text{Capacity Fade (\%)} = 1 - \left(1 - \frac{capacity(k)}{capacity(0)}\right) * 100$$

A. STATE OF LIFE (SOL)

SOL stands for a battery's useful life that is still left. Equation gives the RUL of a battery using a for various thresholds of capacity fade C(i) and power fade P(i).

$$\text{RUL(k)} = \text{h}\left(\{P(i), C(i)\}_{i=1}^{k}\right)$$

where, roughly, k is the k^{th}week for an end-of-life condition. The RUL is a 23% power fade and a 30% capacity fade.

V. CAPACITY ESTIMATION BLOCK

BMS must use an algorithm to compute the maximum charge and discharge current at any moment after determining SOC and SOH. In order to prevent the battery from being subjected to overcharging or undercharging, the output of this block is supplied to the vehicle's electronic control unit (ECU). The capability estimates block's job is to tell the ECU of the battery's current safe amount of charging and discharging current. This knowledge is crucial for the battery's secure operation and helps prevent unintentional violations of the battery's requirements. Fig 7 and 8 below show the relationship between the allowed charge and discharge currents, stated in terms of the maximum charge/discharge current for particular battery parameter values, and the control laws for determining the maximum discharge and charge current based on the inputs. The allowable charge/discharge currents, indicated in terms of maximum charge and discharge currents, respectively, are shown in the fig 7 and 8.

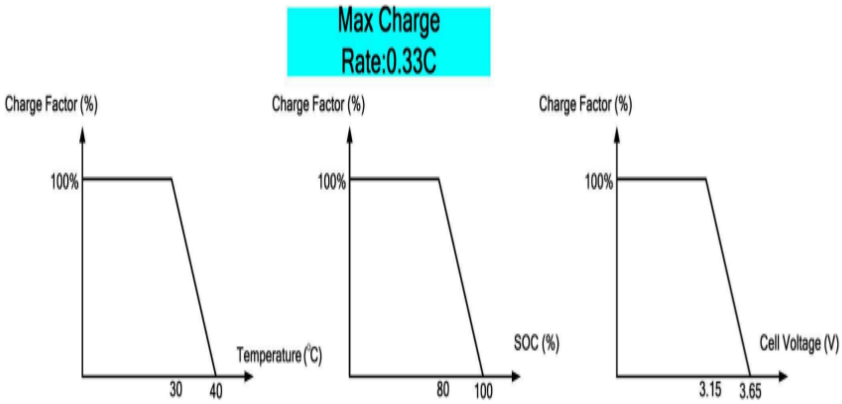

Fig 7: Effects of inputs on the maximum charge current

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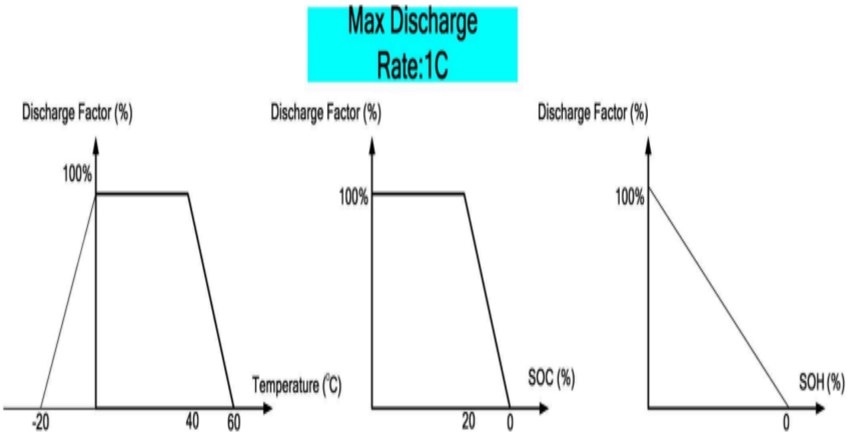

Fig 8: Effects of inputs on the maximum discharge currents

The BMS will limit the charging current in accordance with a function that depends on the temperature, SOC, and cell voltage, as shown by the charts in Fig. 7. It is not recommended to discharge the battery at the minimum temperature mentioned, which is less than -20 °C [4].

VI. THERMAL MANAGEMENT BLOCK

Fig 9 depicts the thermal management block's boundary diagram, which calculates the battery temperature. The 1-D temperature-estimation approach provides the foundation for the temperature estimation. Thermal management refers to tracking and regulating battery temperature to prevent damage from extremely high or extremely low temperatures. The thermal management block measures the ambient and battery temperatures, starts cooling or heating, and alerts the ECU in the situation of an abnormal temperature rise. Thermal management is important to keep the battery pack under optimal temperature range and within an acceptable temperature radius. It records the state of the battery and detect critical points for battery failures and transmit alarm messages. It keeps the traction motor at optimal working temperature.

When the battery is too cold: low temperature effects on the battery are

- <5 ℃ (battery cannot be fast charged)
- <0 ℃ (battery loses charge, loss in power, acceleration and driving range)

When the battery is too hot: high temperature effects on the battery

- >30 ℃ (it degrades the battery performance)
- >40 ℃ (it can lead to serious and irreversible damage)
- >150 ℃ (it leads to thermal runaway)

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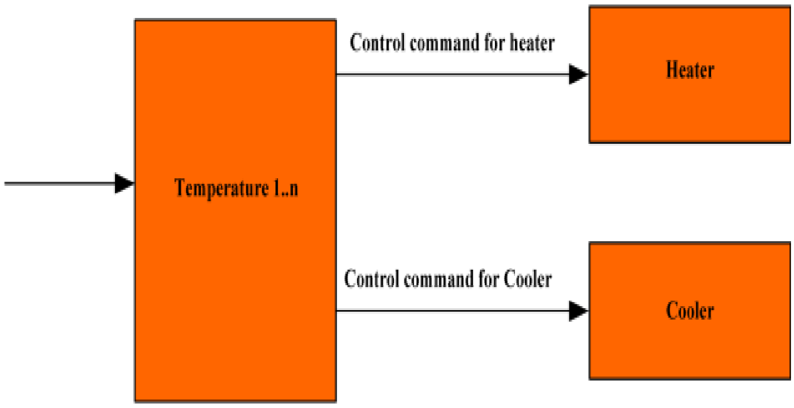

Fig 9: Thermal management block

Methods of battery cooling:

1. Air Cooling
2. Liquid Cooling
3. Refrigerant Cooling
4. Phase Change Material (PCM)

VII. LITHIUM-ION BATTERIES USED IN EVs

Vehicles powered by gasoline and diesel emit a lot of carbon dioxide, which has an adverse impact on the environment. To avoid worsening the above problems, recently, the government of the UK, France, Germany, Netherlands and other countries have announced a schedule to stop producing petrol vehicles, most of which are from 2025 to 2040 respectively [5]. EVs will largely replace gasoline-powered vehicles in the coming years. The rechargeable battery system is the essential element of an electric vehicle; hence it needs to be extremely efficient. Compared with other commonly rechargeable batteries like Ni-Cd, Ni-MH and Lead-acid battery, the lithium-ion battery is featured by high energy and power density, long service life and environmental friendliness and, thus, has been widely applied in consumer electronics [6]. The success of commercial Li-ion batteries in the 1990s was not an overnight achievement, but a result of intensive research and contribution by many great scientists and engineers [7]. The growing demands for lithium-ion (Li-ion) batteries in electric vehicles has accelerated the need for new, more efficient charging techniques to increase charging speed and dependability without compromising battery performance. Over the past ten years, numerous initiatives have been made to create the best charging methods for industrial Li-ion batteries.

Due to their better energy density and longer lifespan comparing to their lead-acid and nickel-metal hydride competitors [8]-[10], lithium-ion batteries have now been commercialised for use in plug-in hybrid (PHEV) and electrical vehicles (EVs).

However, to create a battery pack for high power applications like EVs and energy-storage systems, many batteries must be arranged in parallel and serial. Costs, stability, consistency, and safety issues result from this. The uses for lithium-ion batteries are constrained by these issues. The charge rate, temperature, and voltage range all have an impact on how safely and reliably lithium-ion batteries can be used. If these limits are exceeded, battery performance may rapidly deteriorate and even safety issues could develop. In addition, to ensure the reliable operation of lithium-ion batteries, it is important to evaluate the lithium-ion battery capacity and predict the RUL over the entire service life [11]. Battery charging is substantially more difficult in EVs than fuel-driven internal combustion engine charging due to poor charging speed and uncertain impacts of charging schemes on battery performances. The pace of lithium-ion battery charging becomes a barrier to the widespread adoption of EVs. The US Department of Energy (DOE) has set a charge goal of 10 miles of range per minute for fast charge [12]. For an EV with 100-mile range (24 kWh battery pack), the DOE goal is to charge full in 10 min (6C rate) [13].

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VIII. TYPES OF EVS

Since the beginning of the twenty-first century, several countries have been debating the concerns of climate change and global warming in depth. The detrimental effects of climate changes that are primarily caused by human activity have been documented in numerous pertinent papers. A significant amount of combustion of fossil fuels in industries has contributed to the serious issue of air pollution, which is a result of the world's growing civilization and industrialization. Likewise, it is impossible to ignore the exhaust fumes from automobiles. Vehicle emissions, which mostly consist of CO2, CO, and particulate matter, have also been identified as the primary cause of the influence of greenhouse gases, which has been linked to a rise in significant diseases such as cancer. As a result, it would appear that using appropriate energy-saving technology and substituting renewable energy sources for non-renewable ones is a necessity. India currently ranks as the world's fifth-largest auto market, but it has the capability to quickly overtake the top three. However, as per the Paris agreement, the increasing number of automobile customers shall not imply an increase in the consumption of conventional fuels [14].

In order to guarantee a good development rate toward attaining Net Zero Emissions with in subsequent decade, India needs a transportation revolution that will result in better public transport services, better infrastructure, better cars, and better trains. Electric vehicles are most certainly the answer to "better cars."

EVs can be categorized into four categories: Battery Electric Vehicle (BEV), Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), Fuel Cell Electric Vehicles (FCEVs)

- Battery Electric Vehicle (BEV)

A battery electric vehicle relies solely on rechargeable batteries for power. Compared to other EV kinds, battery electric vehicles have fewer moving parts, no internal combustion engine, and necessitate less maintenance.

Since BEVs can run entirely on electrical power rather than fossil fuels, they don't emit any emissions at the exhaust. Battery Electric Vehicles need to be charged in order to operate. This can be done via a rapid charging point or a home charger, or by regenerative braking to recover energy. In BEVs, the battery is recharged while the car is in motion using regenerative braking. That implies that if you stop or slow down, the battery recharges more quickly.

Tesla Model 3, Hyundai Kona Electric, Nissan LEAF, and Mercedes-Benz EQC are a few examples of battery electric vehicles.

- Hybrid Electric Vehicle (HEV)

In hybrid electric vehicles, an electric power system is paired with a traditional internal combustion engine. Hybrids use both internal combustion engines as well as regenerative braking systems to replenish their vehicle batteries because they lack the capability to plug in and replenish from the grid.

In more recent models, the energy produced during braking can also be used to recharge the batteries, converting kinetic into electric power. The Toyota Prius, in its hybrid model (4th generation), provided a 1.3 kWh battery that theoretically allowed it an autonomy as far as 25 km in its all-electric mode [15].

Toyota Camry Hybrid, Toyota Prius Hybrid, Honda Civic Hybrid, Honda Civic Hybrid are few examples of Hybrid Electric Vehicle.

- Plug-in Hybrid Electric Vehicle (PHEV)

Plug-in hybrid electric vehicles, or PHEVs, are powered by both an internal combustion engine and an electric motor. Similar to conventional hybrids, it can use regenerative braking to recharge its battery. They differ from standard hybrids in that they have a much larger battery and can replenish by plugging into in the grid.

Porsche Cayenne S E-Hybrid, Audi A3 E-Tron, Volvo XC90 T8, BMW i8 are few examples of **Plug-in Hybrid Electric Vehicle.**

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- Fuel Cell Electric Vehicles (FCEVs)

These vehicles are equipped with an electric motor that runs on compressed hydrogen and air-derived oxygen, with water being the only waste product. Due to their absence of roadside emissions, FCEVs are appealing. Even if we look at the whole taking on-road and emissions from chemical plants into consideration, the FCEV are still able to compete.

IX. CHALLENGES TO BMS IN ELECTRICAL VEHICLES

Hardly 2-3% of total vehicles are fully electrified as on today across the world. It is still under development technology (getting ready for mass manufacture) and therefore costly. There is lack of infrastructure (charging, raw material, human resources etc.). Also, there is limited service and maintenance support (repair shops, replacements etc.). Bigger battery packs require more financial investment which in turn boost the need for BMS. Battery packs need to be constantly monitored and managed in order to maintain the safety, efficiency and reliability of the overall electric vehicle system. There are errors that occur while estimating SOC and SOH are Initial SOC error, Current measurement error, Uncertainty in the knowledge of battery capacity, Timing oscillator error and other errors in estimation of battery capacity [16]. The measurement of the SOC demonstrates that the maximum error is 0.334 % [17]. Even 100% electric vehicles are not a zero-carbon solution.

The motors that are currently installed in EV propulsion systems mainly consists of the PMSM, IM, and SRM. Because the high-energy-density PM is affected by low yield and is non-renewable and geopolitical, its cost is at least twice than the total cost of other raw materials of electric motors [18].

ADVANTAGES OF ELECTRICAL VEHICLES:

- Environment friendly
- Electricity is less expensive than gas
- Less maintenance at a lower cost

X. CONCLUSION

In EVs, the main power source used to run the generator when the electricity fails is a lithium-ion battery. The Battery Management System keeps an eye on and manages the battery to facilitate the movement of EVs. There are many types of EVs that are being produced today. The battery algorithm is substantially more accurate in estimating SOC when the Kalman filtering approach is used. It is crucial that the BMS be properly maintained for battery reliability and security. Discussion of estimation of SOC, SOH, SOL has been done. Thermal management system is very important part of BMS.

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