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Battery Management Systems (BMS) for EV:

Electric Vehicles and the Future of Energy-Efficient Transportation

ABSTRACT

The mode of transit in the current trend is gradually shifting from internal combustion engine operated vehicle to battery operated electric vehicle. The need of electric vehicle began the revolution from tra- ditional gasoline-powered vehicles to electric vehicles (EVs). An electric vehicle uses electric traction motors for propulsion. It could also be powered through a collector system by electricity from off-vehicle sources or could also be self-contained with a battery, solar panels, or an electrical generator to convert fuel to electricity.

INTRODUCTION

Electric vehicle companies are enabling modern technologies like Artificial Intelligence and IOT to improve efficiency. Nowadays, vehicles are essential in the day to day life and for industrial use as well. Sufficient effort is being done to withdraw the combustion engines by electric motors (Liu et al., 2016).A system with IOT will definitely streamline the performance of EV charging and looks the impacts. IOT will improve the city planning and makes the city life easy. Automotive/transportation sector is under- going a phenomenal course of rapid, change. This transformation is enabled by similar factors that are driving advancements in the Internet of Things including increased computing resources and ubiquitous connectivity. They're easier on the environment. EV's don't even have an exhaust system, meaning they have zero emissions. And since gas-powered vehicles are large contributors to greenhouse-gas buildup

in the earth's atmosphere, making the switch to an electric car can help contribute to cleaner air and a healthier planet. Electric vehicles (EVs) burn no gasoline and have no tailpipe emissions, but producing the electricity used to charge them does generate global warming emissions.

Benefits of Electric Vehicles

There are a number of great benefits to electric vehicles (EVs) over conventional petrol/diesel cars.

- Cheaper to run. Owners of an EV have the advantage of much lower running costs.
- Cheaper to maintain. ...
- Other savings. ...
- Better for the environment.

ADVANTAGES

Better for the Environment

There are a ton of people who choose to purchase an electric vehicle solely because these vehicles are better for the environment than the alternatives. These cars do not contain an exhaust system at all, which means they aren't creating emissions like other cars. Vehicles that are powered by gas are major contributors to the buildup of greenhouse gases, which stay in the earth's atmosphere. As such, having an electric car helps keep air cleaner and the planet healthier.

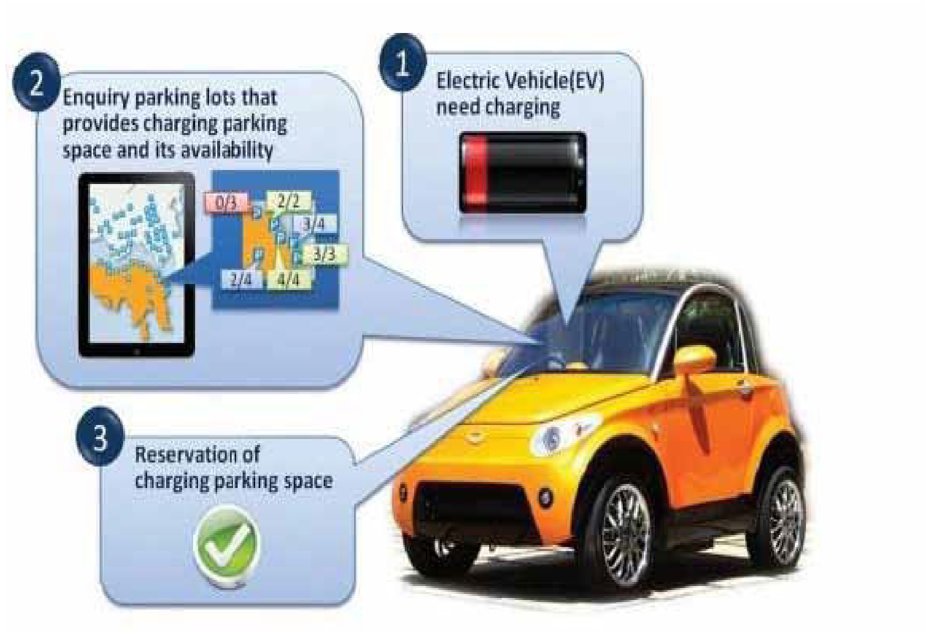
Electricity is Less Expensive than Gas

When you break everything down, the average American pays about 15 cents a mile to drive a gas- powered vehicle. This might seem negligible but that changes when you look at the cost to drive an electric car. Rather than 15 cents a mile, many electric cars run on five cents a mile due to the fact that electricity is largely less expensive than gasoline. Most people will also be charging their cars in the garage, which means installing a few solar panels can cut that price even further while offering savings on powering your entire home.

Less Maintenance at a Lower Cost

With a gasoline-powered car, there's a ton of maintenance. It starts with oil changes and only goes on from there. Electric cars don't have oil and don't require that maintenance task or others associated with a gas engine. Anything related to the combustion engine in a traditional car isn't needed with an electric car. In addition, the brakes on electric vehicles tend to last longer. That only adds to the cost savings of choosing an electric car rather than one that uses gasoline. It all starts to add up when you begin to think about it

Figure 1. Importance of Electric vehicle



BATTERY MANAGEMENT SYSTEM IN ELECTRIC VEHICLES

The mode of transit in the current trend is gradually shifting from Internal combustion engine operated vehicle to Battery operated Electric Vehicle. The need of Electric Vehicle began the revolution from traditional gasoline-powered vehicles to Electric Vehicles (EVs). An Electric Vehicle uses electric traction motors for propulsion. It could also be powered through a collector system by electricity from off-vehicle sources, or could also be self-contained with a battery, solar panels or an electrical generator to convert fuel to electricity.

Battery Management System (BMS) for Electric Vehicles

The Lithium-ion batteries have proved to be the battery of interest for Electric Vehicle manufacturers because of its high charge density and low weight. Even though these batteries pack in a lot of punch for its size they are highly unstable in nature. It is very important that these batteries should never be over charged or under discharge at any circumstance which brings in the need to monitor its voltage and current. This process gets a bit tougher since there are a lot of cells put together to form a battery pack in EV and every cell should be individually monitored for its safety and efficient operation which requires a special dedicated system called the **Battery Management System**.

LITERATURE REVIEW

Since Battery electric vehicle is involved type of battery and its importance is included. Along with bat- tery importance Types of electric vehicles and importance of battery in electric vehicle is discussed here.

LITHIUM-ION BATTERY

History

The idea of Lithium Ion battery was first coined by G.N Lewis in the 1912, but it became feasible only in the year 1970’s and the first non-rechargeable lithium battery was put into commercial markets. Later in 1980’s engineers attempted to make the first rechargeable battery using lithium as the anode material and were partially successful. They failed to notice that these types of lithium batteries were unstable during the charging process and it would create a short inside the battery increasing the temperature and causing a thermal runaway. In 1991, one such lithium battery used in mobile exploded over a man’s face in Japan.

LI-ION BATTERY

Chemistry and Working

As the name obviously indicates, the Lithium Ion batteries use the Lithium ions to get the job done. Lithium is a very light metal with high energy density, this property enables the battery to be light in weight and provide high current with a small form factor. Energy density is the amount of energy that can be stored in per unit volume of the battery, the higher the energy density the smaller the battery will be. Despite the overwhelming properties of lithium metal, it cannot be used as an electrode directly in the batteries since lithium is highly unstable because of its metallic nature. Hence we use lithium-ions which more or less has the same property of a lithium metal but it is non-metallic and is comparatively safer to use.

Nominal Voltage: The nominal voltage is the actual voltage rating of an 18650 Cell. By default, it is 3.6V and will remain the same for all 18650 cells despite of its manufactures.

Full discharge voltage: An 18650 cell should never be allowed to discharge below 3.2V, failing to do so will alter the internal resistance of the battery which will damage the battery permanently and might also lead to explosion.

Full charge Voltage: The charging voltage for lithium ion cell is 4.2V. Care should be taken that the cell voltage does not increase 4.2V at any given time.

mAh Rating: The capacity of a cell is normally given in terms of mAh (Milli Ampere hour) rating. This value will vary based on the type of cell you have purchased. For example, let's assume our cell here is 2000mAh which is nothing but 2Ah (Ampere/hour). This means that if we draw 2A from this battery it will last for 1 hour and similarly if we draw 1A from this battery it will last for 2 hours. So, if you want to know how long the battery will power you project (Run-time) then you have to calculate it using the mAh Rating.

Run Time (in hours) = Current drawn / mAh Rating
Where, current drawn should be within the C rating limit.

C Rating: The C rating of the battery again changes for each battery, let's assume that the battery we have is a 2Ah battery with 3C rating. The value 3C means that the battery can output 3 times th rated Ah rating as its maximum current. In this case it can supply upto 6A (3*2 = 6) as the maximum current. Normally 18650 cells have a 1C rating only.

Maximum current drawn from battery = C Rating * Ah Rating

Charging Current: Normally it will be 0.5C, meaning half the value of the Ah rating. For a 2Ah rating battery the charging current will be 1A (0.5*2 = 1).

Charging time: The minimum charging time required for a single 18650 cell to charge to can be calculate by using the value of charge current and Ah rating of battery.

Internal Resistance (IR): The health and capacity of a battery can be predicted by measuring the internal resistance of the battery.

State of Charge (SOC) %: The state of charge is nothing but the capacity of the battery, similar to the ones shown in our mobile phone. The capacity of a battery cannot be plainly calculated with its voltage valve, it is normally calculated using current integration to determine the change in battery capacity over time.

Depth of Discharge (DOD) %: No battery will have 100% discharges since as we know it will dam- age the battery. Normally an 80% depth of discharge is set for all batteries.

Cell dimension: Another unique and interesting feature of the 18650 cell is its dimension. Every cell will have a diameter of 18mm and a height of 650mm which makes this cell gets its name 18650.

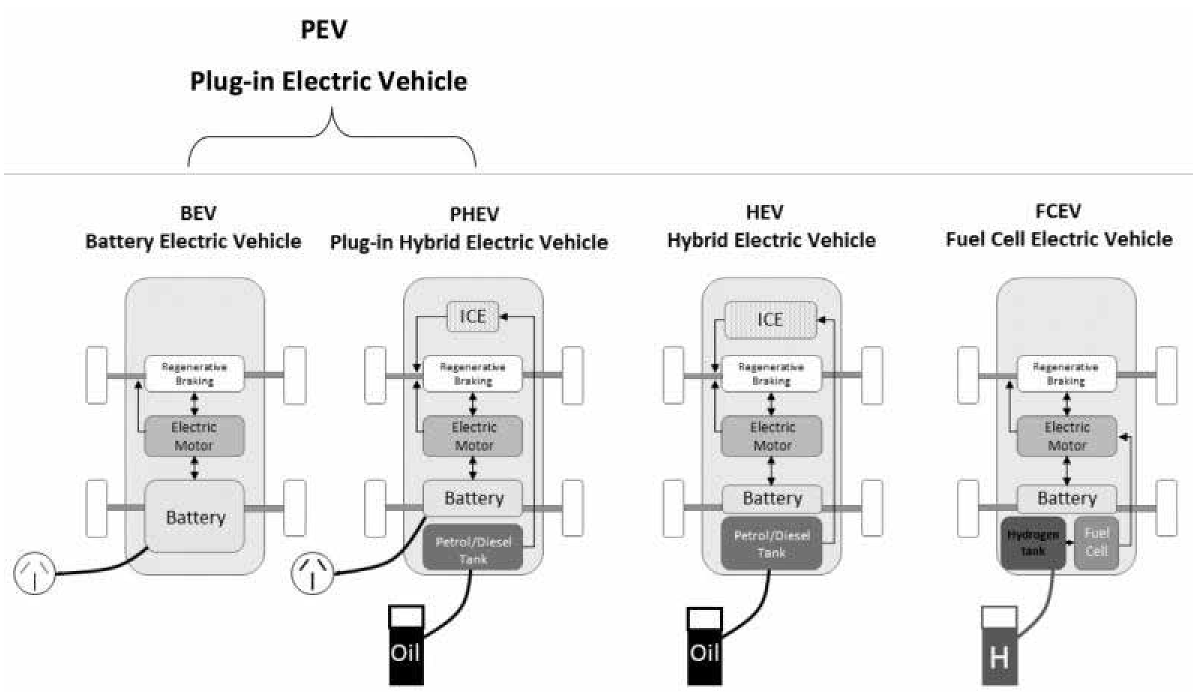
TYPES OF ELECTRIC VEHICLES:

BEV, PHEV AND HEV

There are three main types of electric vehicles (EVs), classified by the degree that electricity is used as their energy source. BEVs, or battery electric vehicles, PHEVs of plug-in hybrid electric vehicles, and HEVs, or hybrid electric vehicles.

Electric Vehicles can be categorized as follows:

Figure 2. Types of Electric Vehicles

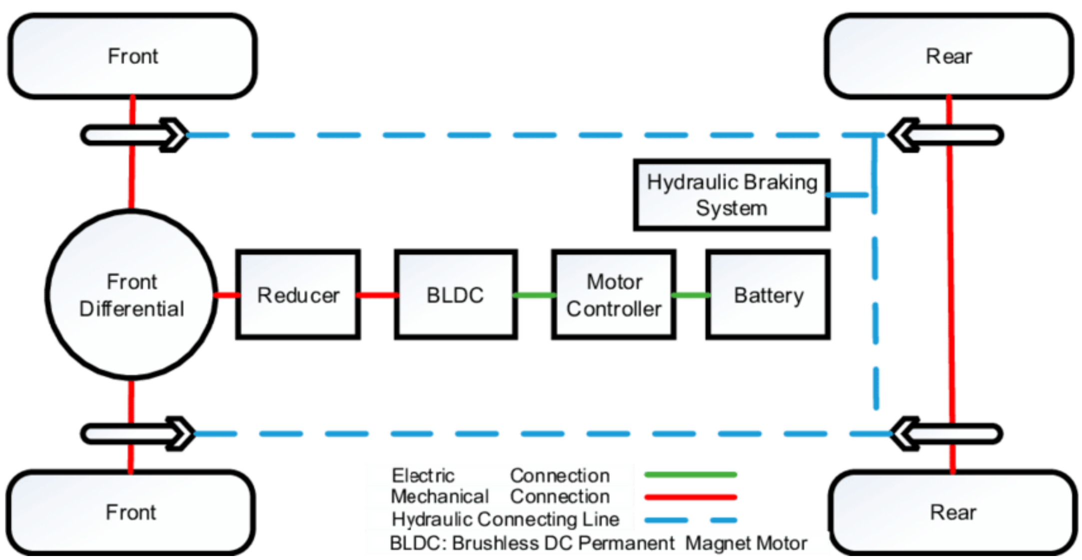


vehicles. BEVs are charged by electricity from an external source. Electric Vehicle (EV) chargers are classified according to the speed with which they recharge an EVs battery.

The classifications are Level 1, Level 2, and Level 3 or DC fast charging. Level 1 EV charging uses a standard household (120V) outlet to plug into the electric vehicle and takes over 8 hours to charge an EV for approximately 75-80 miles. Level one charging is typically done at home or at your workplace.

- Level 1 chargers have the capability to charge most EVs on the market.
- Level 2 charging requires a specialized station which provides power at 240v. Level 2 chargers are typically found at workplaces and public charging stations and will take about 4 hours to charge a battery to 75-80 miles of range.
- Level 3 charging, DC fast charging, or simply fast charging is currently the fastest charging solu- tion in the EV market. DC fast chargers are found at dedicated EV charging stations and charge a battery up to 90 miles range in approximately 30 minutes.

Figure 3. Battery Electric Vehicles (BEV)

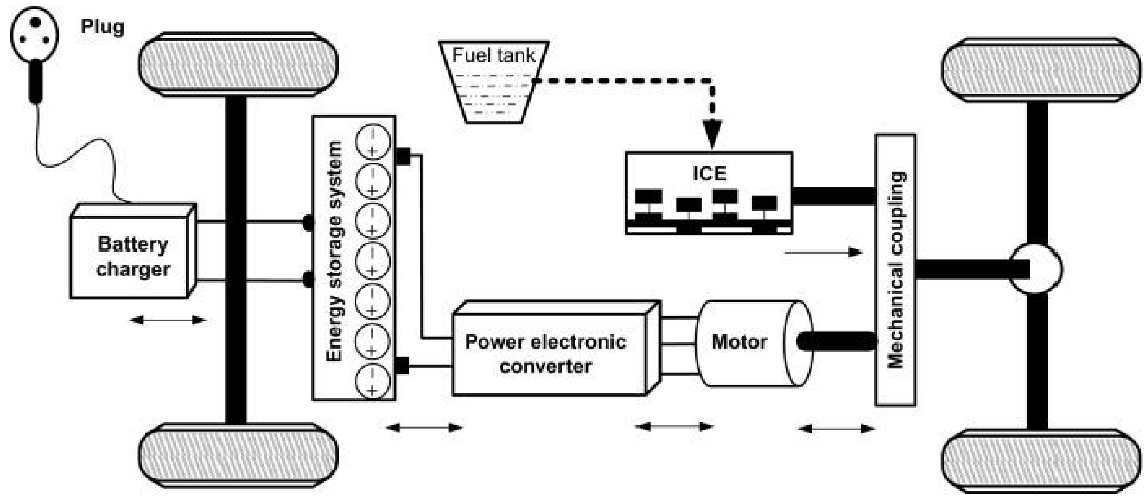


Plug-in Hybrid Electric Vehicle (PHEV): Plug in hybrid electric vehicles can recharge the battery through both regenerative braking and plugging in to an external source of electrical power. While stan- dard hybrids can go about 1-2 miles before the gasoline engine turns on, plug in hybrid electric vehicle models can go anywhere from 10-40 miles before their gas engines provide assistance. Plug-in Hybrid Electric Vehicles or PHEVs can recharge the battery through both regenerative braking and “plugging in” to an external source of electrical power.

PHEV Examples

- Chevy Volt

Figure 4. Plug-in Hybrid Electric Vehicle



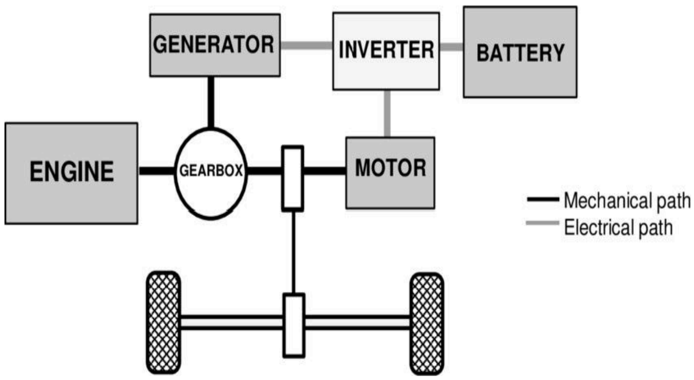
Hybrid Electric Vehicles (HEV): Hybrid Electric Vehicles are powered by both gasoline and electric- ity. The electric energy is generated by the braking system of the moving vehicle to recharge the battery. This is called “regenerative braking”, a process where the electrical motor helps to slow the vehicle and uses a number of the energy normally converted to heat by the brakes. HEVs are powered by both gasoline and electricity. The electric energy is generated by the car’s own braking system to recharge the battery. This is called ‘regenerative braking’, a process where the electric motor helps to slow the vehicle and uses some of the energy normally converted to heat by the brakes. HEVs start off using the electric motor, then the gasoline engine cuts in as load or speed rises. The two motors are controlled by an internal computer, which ensures the best economy for the driving conditions.

HEV Examples

- Toyota Prius Hybrid
- Honda Civic Hybrid
- Toyota Camry Hybrid

Fuel Cell Electric Vehicle (FCEV): A Fuel Cell Vehicle (FCV) or Cell Electric Vehicle (FCEV) may be a sort of electric vehicle which uses a cell, rather than a battery, or together with a battery or supercapacitor, to power its on-board motor

Figure 5. Hybrid Figure



6. Fuel cell Electric Vehicle

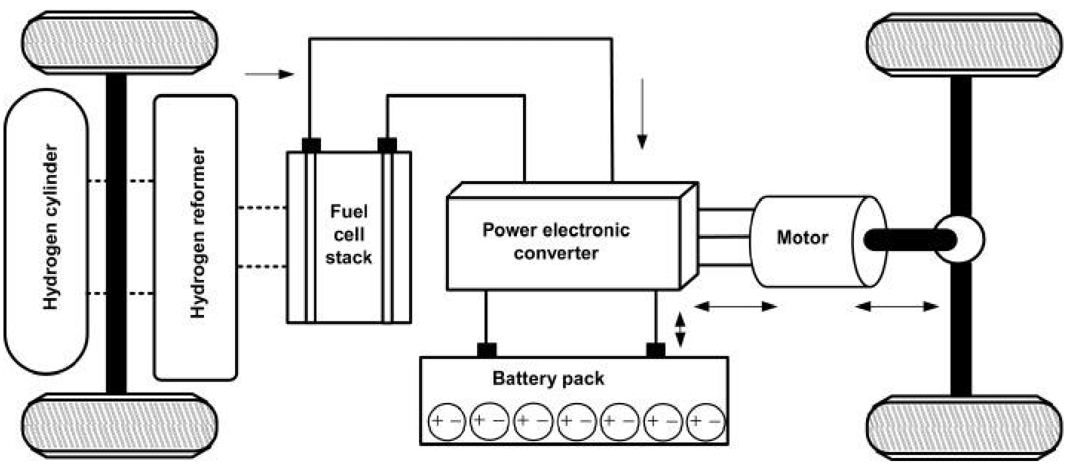


Table 1.

Types of EV	PEV	HEV	FCEV
Energy source	(i) Battery	(i) Battery/ultracapacitor (ii) Internal combustion engines	(i) Fuel cells
Propulsion technique	(i) Electric motor drives	(i) Electric motor drives (ii) Internal combustion engines	(i) Electric motor drives
Characteristics and feature	(i) Zero emission (ii) Short driving range (iii) Higher initial costs	(i) Low emission (ii) Longer range (iii) Complex	(i) Zero emission (ii) Highest initial costs (iii) Medium driving range
Major techniques	(i) Electric motor control (ii) Battery management (iii) Charging device	(i) Electric motor control (ii) Battery management (iii) Managing multiple energy sources and optimal system efficiency (iv) Components sizing	(i) Fuel processor (ii) Fueling system (iii) Fuel cell cost
Regenerative braking	(i) Yes	(i) Yes	(i) Yes

COMPARISON BETWEEN DIFFERENT TYPES OF EV

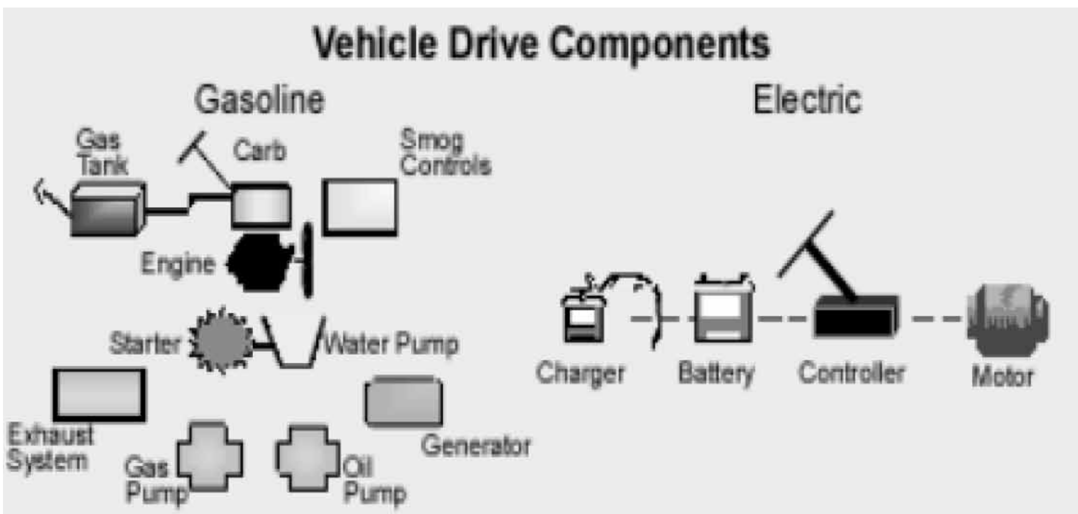
Components of the Electric Vehicle are,

EV Powertrain: power train provides power to the vehicle. Powertrain refers to the set of components that generate the power required to move the vehicle and deliver it to the wheels. An EV powertrain has 60% fewer components than the powertrain of an ICE vehicle.

Difference between Powertrains of EVs and ICE vehicles

The powertrain of an electric vehicle is a simpler system, comprising of far fewer components than a vehicle powered by an internal combustion engine.

Figure 7. Components of vehicle drive



Main Components of an ICE vehicle powertrain – An ICE vehicle has hundreds of moving parts. Main components of its powertrain are Engine, Transmission and Driveshaft. Power is generated by the engine and transmitted to the driveshaft.

Battery Pack:The battery pack is made up of multiple Lithium-ion cells and stores the energy needed to run the vehicle. Battery packs provide direct current (DC) output.

DC-DC Converter: The DC supplied by battery pack is converted to AC and supplied to the electric motor. This power transfer is managed by a sophisticated **motor control mechanism** (also referred to as Powertrain Electronic Control Unit) that controls the frequency and magnitude of the voltage supplied to the electric motor in order to manage the speed and acceleration as per driver’s instructions com- municated via acceleration/brakes.

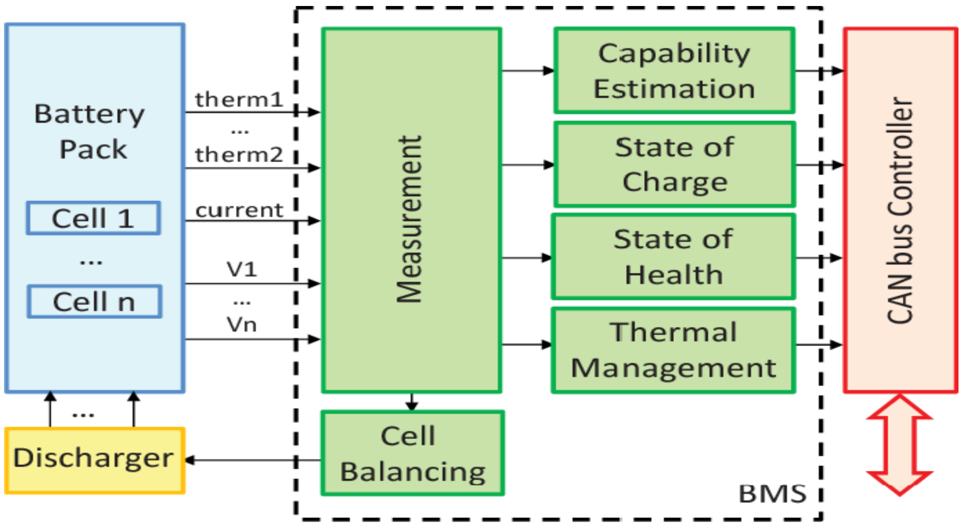
DC-AC Converter The DC supplied by battery pack is converted to AC and supplied to the electric motor. This power transfer is managed by a sophisticated motor control mechanism

Electric Motor: Converts electrical energy to mechanical energy, that is delivered to the wheels via single ratio transmission. Many EVs use motor generators that can perform regeneration as well.

On-board Charger: Converts AC received through charge port to DC and controls the amount of current flowing into the battery pack.

Body Control Module (BCM): The BCM is responsible for supervising and controlling the func- tions of electronic accessories such as power windows, mirrors, security and vehicle access control.

Figure 8. Block diagram of Battery Management System



The Primary Functions of the BMS for an EV battery consists of

١. **Safety**: Electric vehicles run on high voltage Lithium-ion battery packs. Lithium-ion batteries have higher energy density (i.e. 100-265 Wh/kg) than other battery chemistries. These batteries come with a risk of catching fire under unusual circumstances. It is imperative to operate the EV bat- teries in pre-defined safe limits to ensure the safety of the user as well as the vehicle. The Battery Management System continuously monitors parameters such as temperature, voltage and current in and out of the pack to ensure it is being operated in safe conditions the entire time. BMS is responsible for thermal management of the battery and monitors its temperature continuously. If required, BMS can adjust cooling and trigger other safety mechanisms to cease operations and minimize the risk. e.g. in Hyundai Kona Electric, if overheating of the battery pack is detected by the BMS, the vehicle's power output is automatically limited and the car is put in fail-safe mode. Overcharging of lithium-ion cells can also lead to thermal runaway and potentially an explosion. BMS continuously monitors the voltage of the pack as well as individual battery cells and controls the supply of the current to avoid overcharging. BMS can enforce the limits of maximum charge or discharge current according to temperature.

٢. **Performance Optimization:** BMS is responsible for optimizing the performance of the battery pack. Lithium-ion batteries perform best when their State of Charge (SOC) is maintained between the minimum and maximum charge limits defined in the battery profile. Overcharging as well as deep discharging degrades the capacity of the battery, thereby shortening its life. At the time of charging, BMS determines how much current can safely go in and communicates the same to the EVSE (Electric Vehicle Supply Equipment or the Charger). During discharge of the battery, BMS would communicate with the motor controller to avoid the cell voltages reaching too low. The vehicles can show a corresponding alert to the user to charge the battery pack. The BMS also controls the recharging of the battery pack by energy generated through regenerative braking.

٣. **Health Monitoring and Diagnostics:** The BMS uses the collected data points (temperature, volt- age, current etc.) to estimate the State of Charge and State of Health (SOH) of the battery pack. The SoC refers to available energy in the battery and determines how far the vehicle can go before needing to recharge. The SOH measures the current condition of the battery as compared to its original capacity and indicates the battery's suitability for the application. Both SoC and SOH are presented as percentages.BMS also checks for anomalies in the parameters and behavior of the cells and the battery pack. It stores the error codes and logs diagnostic information that helps fix any issues with the battery. The BMS can either take necessary corrective actions or trigger failsafe mechanisms to preserve the health of the pack.

٤. **Communication:** The BMS is responsible for communicating with other ECUs (Electronic Control Units) in the vehicle. It relays the necessary data about the battery parameters to the motor controller to ensure the smooth running of the vehicle. BMS also checks for anomalies in the parameters and behavior of the cells and the battery pack. It stores the error codes and logs diagnostic information that helps fix any issues with the battery. The BMS can either take necessary corrective actions or trigger failsafe mechanisms to preserve the health of the pack.

Battery Management system (BMS) Design Considerations

There are lot of factors that are to be considered while designing a BMS.

Discharging Control: The primary function of a BMS is to maintain the lithium cells within the safe operating region. For example, a typical Lithium 18650 cell will have an under-voltage rating of around 3V. It is the responsibility of the BMS to make sure that none of the cells in the pack get discharged below 3V.

Charging Control: Apart from the discharging the charging process should also be monitored by the BMS. Most batteries tend to get damaged or get reduced in lifespan when charged inappropriately. For lithium battery charger a 2-stage charger is used. The first stage is called the Constant Current (CC) during which the charger outputs a constant current to charge the battery. When the battery gets nearly full the second stage called the Constant Voltage (CV) stage is used during which a constant voltage is supplied to the battery at a very low current

State-of-Charge (SOC) Determination: SOC as the fuel indicator of the EV. It actually tells us the battery capacity of the pack in percentage. But it is not as easy as it sounds. The voltage and charge/ discharge current of the pack should always be monitored to predict the capacity of the battery. Once the voltage and current are measured there are a lot of algorithms that can be used to calculate the SOC of the Battery pack.

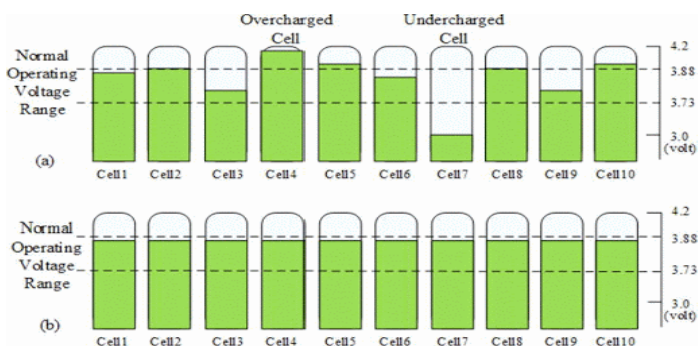
State-of-Health (SOH) Determination: The capacity of the battery not only depends on its voltage and current profile but also on its age and operating temperature. The SOH measurement tells us about the age and expected life cycle of the battery based on its usage history. This way we can know how much the mileage (distance covered after full charge) of the EV reduces as the battery ages and also, we can know when the battery pack should be replaced. The SOH should also be calculated and kept in track by the BMS.

CELL BALANCING TECHNIQUE

Cell balancing is the process of equalizing the voltages and state of charge among the cells when they are at a full charge. Most typical battery chargers detect full charge by checking whether the voltage of the entire string of cells has reached the voltage regulation point. In passive balancing, energy is drawn from the most charged cell and dissipated as heat, usually through resistors. In active balancing, energy is drawn from the most charged cell and transferred to the least charged cells, usually through capacitor- based, inductor-based or DC-DC converters.

Active cell balancing is a more complex balancing technique that redistributes charge between bat- tery cells during the charge and discharge cycles, thereby increasing system run time by increasing the total useable charge in the battery stack, decreasing charge time compared with passive balancing, and decreasing heat. Passive balancing allows the stack to look like every cell has the same capacity as the weakest cell.

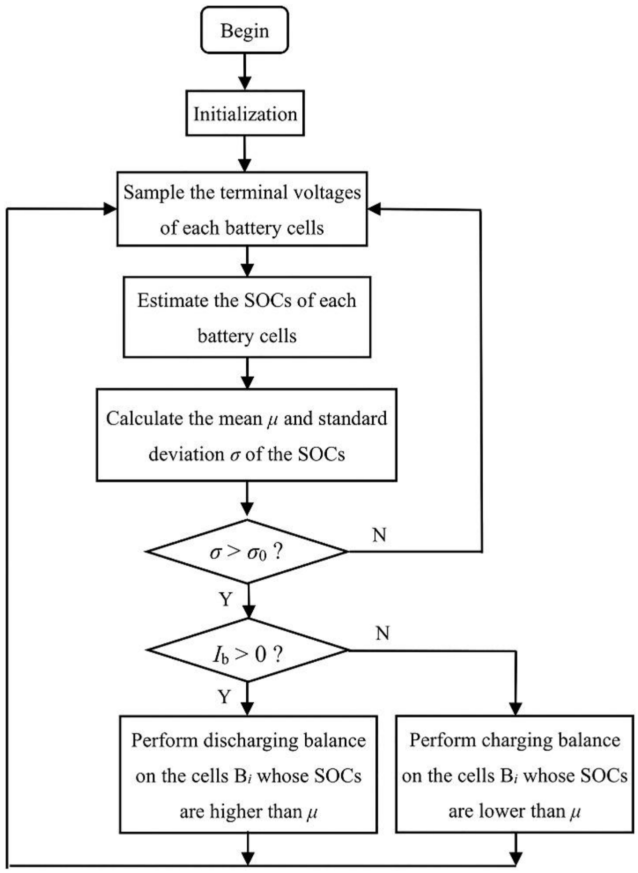
Figure 9. Cell Balancing Technique



Active Cell Balancing Technique

With passive and active cell balancing, each cell in the battery stack is monitored to maintain a healthy battery state of charge (SoC). This extends battery cycle life and provides an added layer of protection by preventing damage to a battery cell due to deep discharging over overcharging. Passive balancing results in all battery cells having a similar SoC by simply dissipating excess charge in a bleed resistor; it does not however, extend system run .Active cell balancing is a more complex balancing technique that redistributes charge between battery cells during the charge and discharge cycles, thereby increas- ing system run time by increasing the total useable charge in the battery stack, decreasing charge time compared with passive balancing, and decreasing heat generated while balancing.

Figure 10.



Flowchart of Active Cell Method

Active Cell Balancing During Discharge

The diagram below represents a typical battery stack with all cells starting at full capacity. In this ex- ample, full capacity is shown as 90% of charge because keeping a battery at or near its 100% capacity

Figure 11. Full capacity.

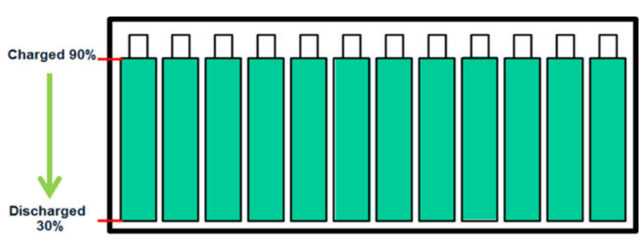


Figure 12. Mismatched discharge.

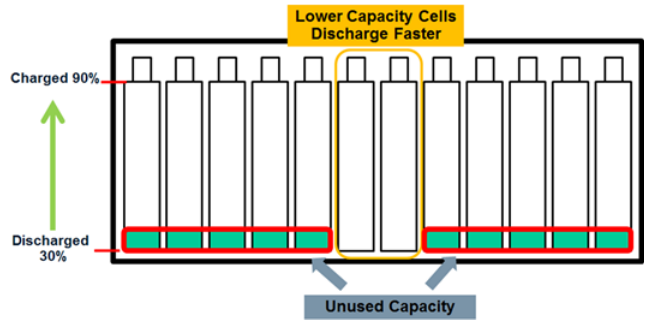
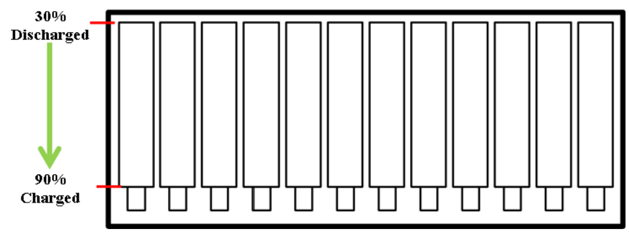


Figure 13. Full depletion with active balancing.



point for long periods of time degrades lifetime faster. 30% represents fully discharged to prevent deep discharge of the cells.

Over time, some cells will become weaker than others, resulting in a discharge profile represented by the figure below.

It can be seen that even though there may be quite a bit of capacity left in several batteries, the weak batteries limit the runtime of the system. A battery mismatch of 5% results in 5% of the capacity unused. With large batteries, this can be an excessive amount of energy left unused. This becomes critical in remote systems and systems that are difficult to access since it results in an increase in the number of battery charge and discharge cycles, which reduces the lifetime of the battery, leading to higher costs associated with more frequent battery replacement. With active balancing, charge is redistributed from the stronger cells to the weaker cells, resulting in a fully depleted battery stack profile.

Figure 14. Charging without balancing.

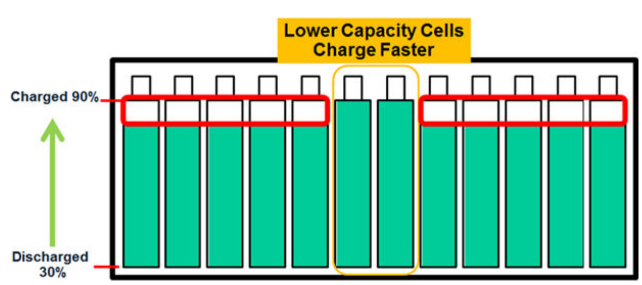
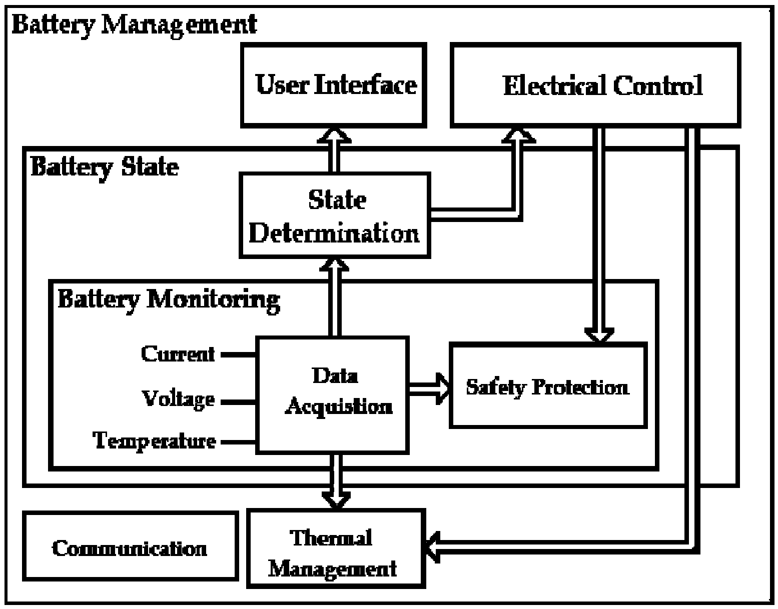


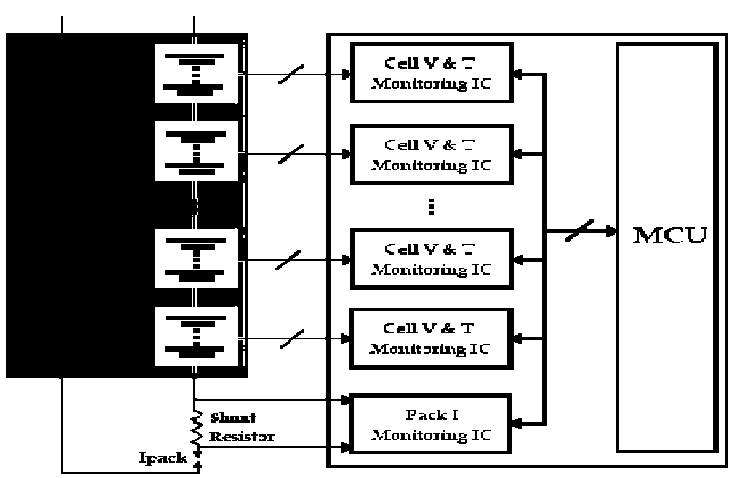
Figure 15. Block diagram of Battery Management System



Active Cell Balancing While Charging: When charging the battery stack without balancing, the weak cells reach full capacity prior to the stronger batteries. Again, it is the weak cells that are the limiting factor; in this case they limit how much total charge our system can hold. The diagram below illustrates charging with this limitation.

Building Blocks of a BMS: From a hardware structure perspective there are only three types of BMS based on its topology they are Centralized BMS, distributed BMS and Modular BMS.

Figure 16. Block diagram of cell monitoring system



BMS Data Acquisition

The primary function of the BMS is to monitor the Battery for which it needs to measure three vital parameters such as the voltage, current and temperature from every cell in the battery pack. If a set of cells are connected in series then we have to measure voltage across each cell but current for the entire set will be same since current will be same in a series circuit.

Battery state Estimation: The major computational power of a BMS is dedicated to estimate the Battery state. This includes the measurement of SOC and SOH. SOC can be calculated using the cell voltage, current, charging profile and discharging profile. SOH can be calculated by using the number of charge cycle and performance of the battery.

Basic Methods

§ Coulomb Counting method
§ Ampere-hour (Ah) method
§ Open-Circuit Voltage (OCV) method
§ Impedance / IR Measurement Method

Machine Learning Based Algorithms

§ Neural Network Fuzzy Logic
§ Support Vector Machine

Advanced Method

§ State-Space Model Estimation using Kalman Filter

Coulomb Counting Technique: Coulomb counting Technique is the most used and easy to understand algorithm. It is based on the fact that the ratio between the Total charge Input and the Maximum capacity of the battery will give us the SOC value. The formula for the same is given below.

SOC = Total Charge Input / Maximum Capacity

But this method is not very reliable because the maximum capacity of the battery will get reduced as the battery ages. Hence many other algorithms were developed.

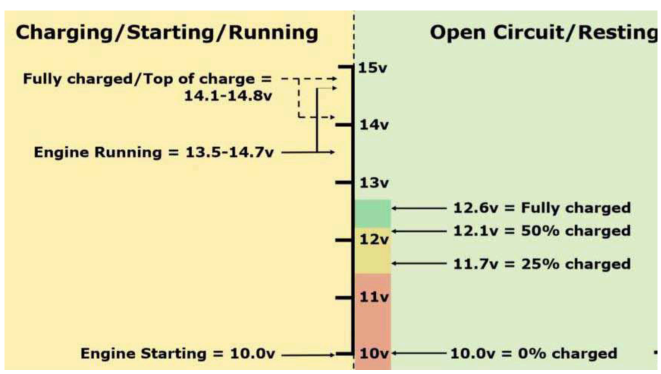
STATE OF CHARGE[SOC]:

The state of charge (SOC) of a cell denotes the capacity that is currently available as a function of the rated capacity. The value of the SOC varies between 0% and 100%. If the SOC is 100%, then the cell is said to be fully charged, whereas a SOC of 0% indicates that the cell is completely discharged. In practi- cal applications, the SOC is not allowed to go beyond 50% and therefore the cell is recharged when the SOC reaches 50%. Similarly, as a cell starts aging, the maximum SOC starts decreasing. This means that for an aged cell, a 100% SOC would be equivalent to a 75%–80% SOC of a new cell. Battery SOC estimation is key component for battery management system. It helps in describing the actual energy level available at the battery. Battery cell current, cell voltages, and cell temperature are critical parameters for the estimation of battery SOC. It is common to estimate the SOC percentage using charge transfer in and out of the battery, and in this case typical coulomb-counting methods are used. In this case, we can use the rated capacity of the battery, Q_{rated}, which is not a function of temperature or aging (since it is usually estimated at a standard laboratory condition at a controlled temperature). However, to accom- modate the SOC variation with aging, it is necessary to use a different term, $Q_{discharge}$. This is defined as the maximum total electrical charge, expressed in Ah that a battery can deliver from the fully charged state (SOC of 100%) to a fully discharged state (SOC of 0%) as indicated.

DESCRIPTION OF STATE OF CHARGE

State of Charge: State of charge (SOC) is the level of charge of an electric battery relative to its capacity as seen in fig 16. The units of SoC are percentage points (0% = empty; 100% = full). An alternative form of the same measure is the depth of discharge (DoD), the inverse of SoC (100% = empty; 0% = full).

Figure 17. State of charge calculation in an electric car

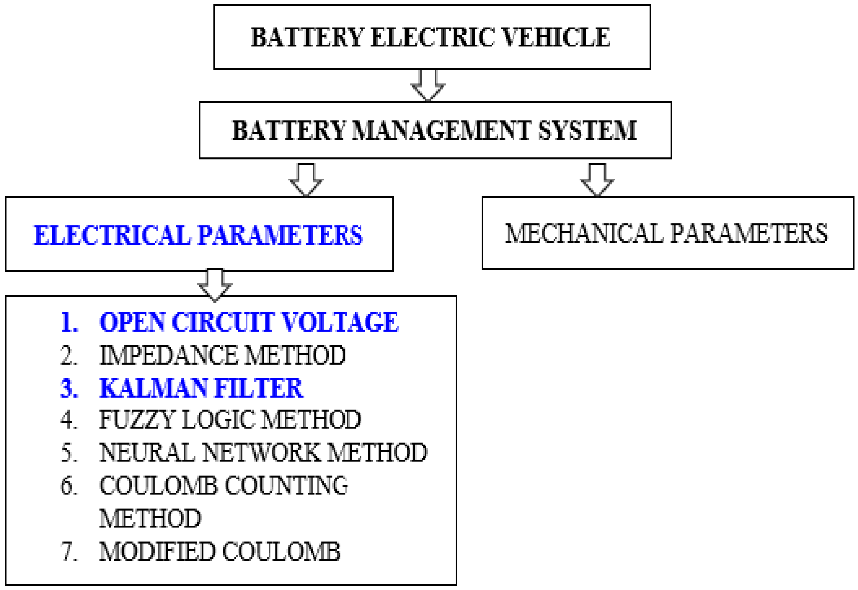


METHODOLOGY AND RESULTS

Comparative charge status analysis in a Battery Electric Vehicle using Model based Method has been carried out with suitable algorithms and simulation results. Among the various algorithms used to calculate state of charge, detail analysis of Kalman filter and Open Circuit Voltage is explained below: **Case a) Open Circuit Voltage:** In this method RC model has been built and simulated in Scilab.

Simulation Results are compared with experimental results (EU's Future Noise Policy, 2020) and it is found that it is same and it is mapped with experimental result

Figure 18. Block diagram of State of charge calculation in an electric car



Open Circuit Voltage Method

Open circuit voltage (OCV) has a considerable influence on the accuracy of battery state of charge (SOC) estimation. The OCV curve can be locally reconstructed even when the accumulated data only cover a partial range of SOC, which is suitable for electric vehicle (EV) operation conditions. From the simulation model, consider RC network in addition with voltage source. State of charge is measured at output (Wei et al., 2019). Voltage is measured at terminal 2 and total resistance is measured at terminal 1. Voltage and Resistance of the RC Circuit model has been developed using Scilab and has been indicated in fig 18 Open circuit voltage, Voc, internal resistances during discharging, Rdis, and charging, Rcha, are involved. The dependent variables considered for State of charge estimation includes:

Open circuit voltage (Voc),

Figure 19. RC Circuit model of Open Circuit Voltage

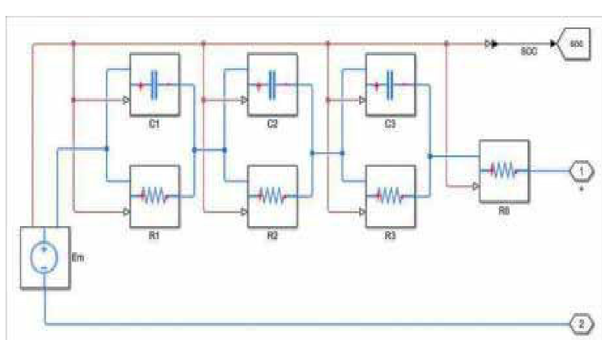
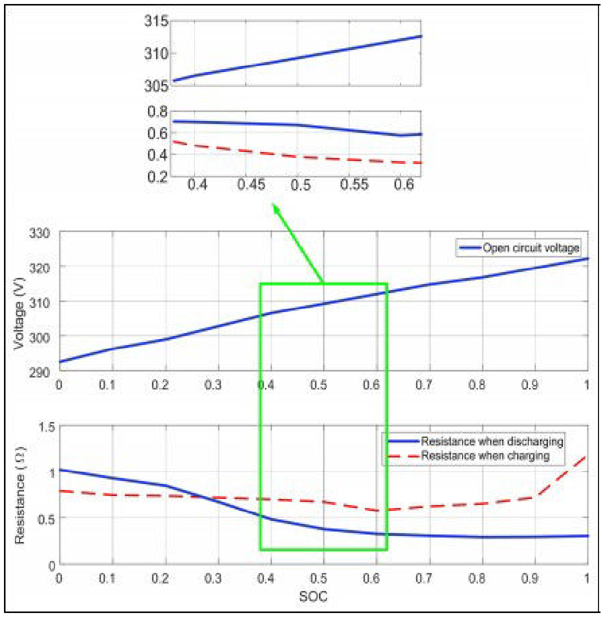


Figure 20. Battery open circuit voltage and internal resistance with respect to SOC.



Internal Resistance during discharge -Rdis

The battery current and output voltage can be calculated as follows:

$$I = \frac{V_{oc} - V_b}{R_b} \qquad V_b = \frac{P_{ele,m}}{I}$$

where Rb is the internal resistance of the battery depending on discharge and charge mode, I is the circuit current, and Vb is the battery output voltage. SOC can be obtained by integrating the current. When the current is positive, it means that the battery is discharging. On the other hand, the battery is recharging if the current has a negative value.

$$SOC = SOC_{ind} - \int_0^t \frac{I}{Q_b} dt$$

Here, SOCini is the initial value of SOC, and Qb refers to the storage capacity of the battery. From the developed RC circuit model and simulation has been carried out and results has been compared with existing paper(Pallas et al., 2018) and mapped all parameters and it is shown in fig 18 Hence method is easy to implement. However the initial value cannot be stored and hence data retrieval is found out to be difficult when state of charge has to be calculated.

Kalman Filter Method

To overcome the shortcomings of the open circuit voltage method, Kalman filter method is used. The battery can be modeled with an electrical model which the Kalman filter will use to predict the over- voltage, due to the current. This method is complex but data can be stored and data retrieval is also possible but has few errors like

Integration of current sensor error: Integration of the current obtained by an erroneous sensor causes the results to drift.

١. Degradation of battery: Degradation of the battery results in a loss of battery capacity, which causes an estimation error.
٢. Self-discharge: Self-discharge is the consumption of charge inside the battery. This cannot be observed by current measurement.

SOH: State of health (SOH) is a figure of merit of the condition of a battery (or a cell, or a battery pack), compared to its ideal conditions. The units of SOH are percent points (100% = the battery's conditions match the battery's specifications).

Coulomb Counting Method. The **Coulomb counting** method measures the discharging current of a battery and integrates the discharging current over time in order to **estimate SOC**. **Coulomb counting** method is done to **estimate** the, which is estimated from the discharging current, and previously estimated **SOC** values. In this book chapter, an efficient SOC estimation algorithm based on the Coulomb-counting algorithm which is a book-keeping approach is proposed. Using a piecewise linear relationship mapping between SOC and the Open Circuit Voltage (OCV) we try to overcome the drawbacks of this approach so as to improve its accuracy.

Motivation Behind the Proposed Work

- Electric vehicles is currently the research area where extensive research work is going on .
- If Electric Vehicle is used carbon –di-oxide emission can be reduced .
- Information regarding state of charge, state of health can be given to user with the help of IOT Based coulomb counting algorithm .
- Monitoring of an Electric Vehicle can be achieved using IOT architecture.
- Information regarding identification of charging network station can be given to user with the help of IOT.
- Hence Battery Electric vehicle is more advantageous when compared to Internal combustion engine.

Coulomb Counting

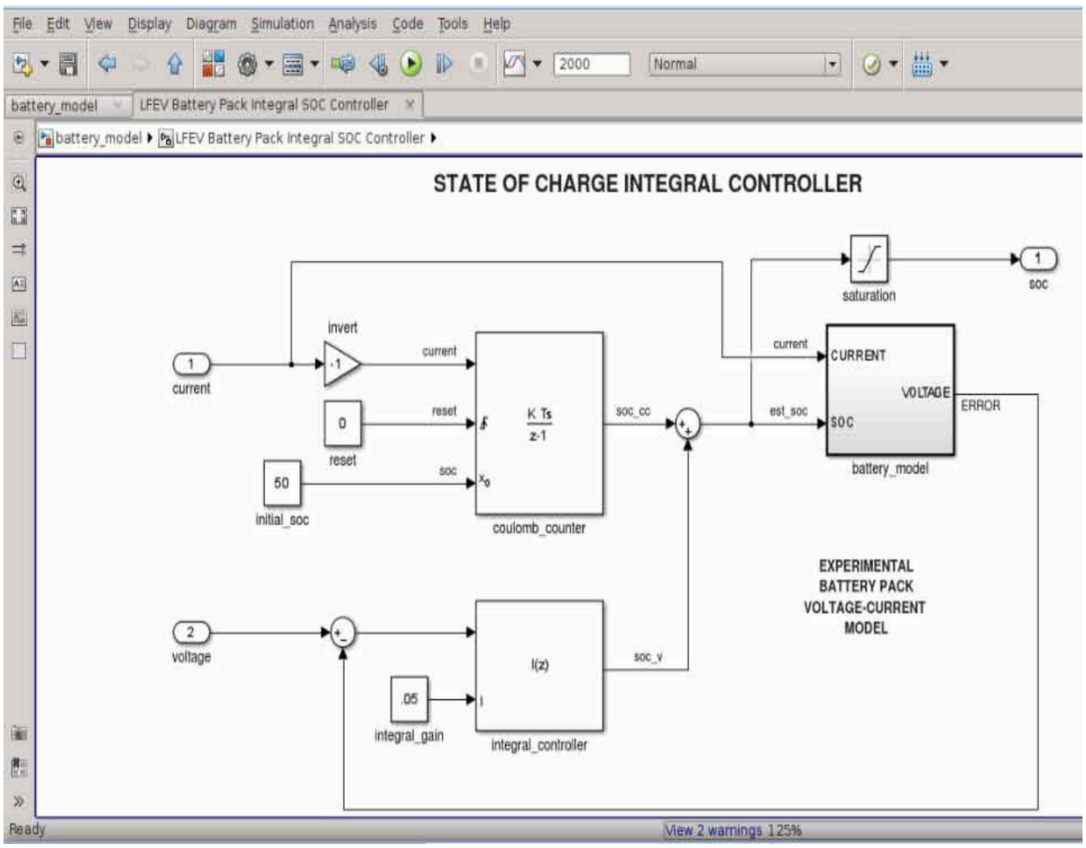
Advantages

- Linear system and nonlinear system
- Easy to implement
- Error propagation

- Battery voltages of up to 1kV.
- Charging time required is 30 MIN.
- DC CHARGING TYPE
- Error propagation: Can be reduced from 5% to 1%

Methodology of Coulomb Counting

Figure 21. State of charge controller.

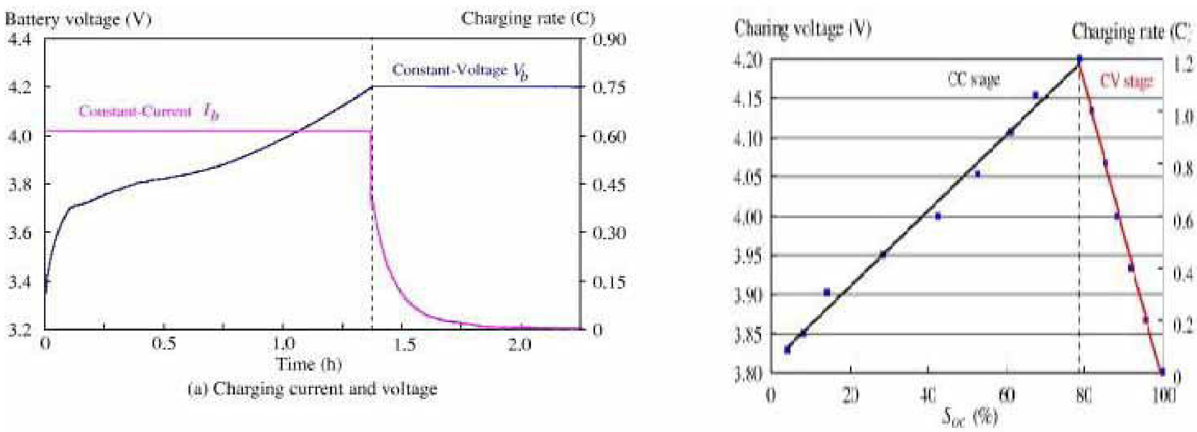


DESCRIPTION OF STATE OF CHARGE

State of Charge: State of charge (SOC) is the level of charge of an <u>electric battery</u> relative to its capacity as seen in fig 21. The units of SoC are percentage points (0% = empty; 100% = full). An alternative form of the same measure is the <u>depth of discharge (DoD)</u>, the inverse of SoC (100% = empty; 0% = full). Fig 21 indicates the block diagram representation of various algorithms used to calculate State of charge.

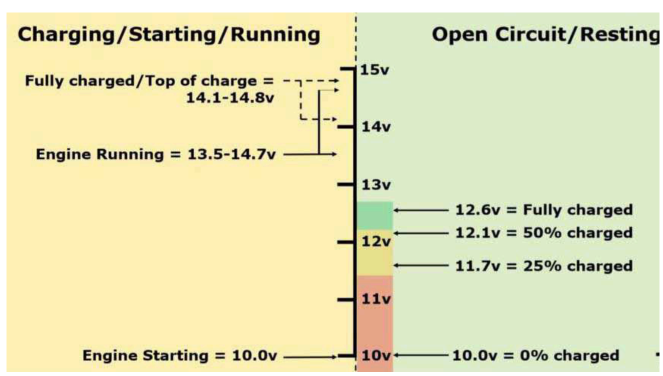
METHODOLOGY AND RESULTS

Figure 22. State of charge controller - charging profile



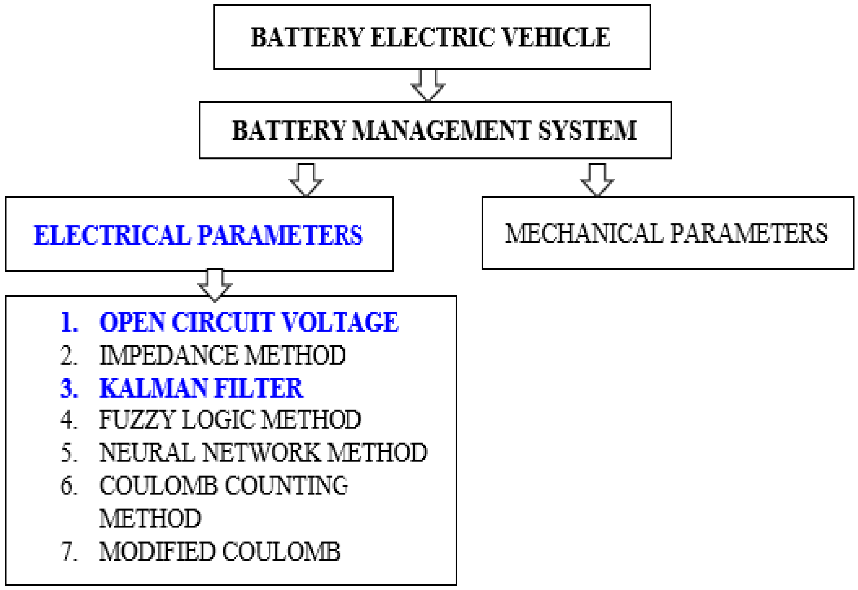
Comparative charge status analysis in a Battery Electric Vehicle using Model based Method has been carried out with suitable algorithms and simulation results. Among the various algorithms used to calculate state of charge, detail analysis of Kalman filter and Open Circuit Voltage is explained below:

Figure 23. State of charge calculation in an electric car



Case a) Open Circuit Voltage: In this method RC model has been built and simulated in Scilab. Simulation Results are compared with experimental results (EU's Future Noise Policy, 2020) and it is found that it is same and it is mapped with experimental results.

Figure 24. Block diagram of State of charge calculation in an electric car



Open Circuit Voltage Method

Open circuit voltage (OCV) has a considerable influence on the accuracy of battery state of charge (SOC) estimation. The OCV curve can be locally reconstructed even when the accumulated data only cover a partial range of SOC, which is suitable for electric vehicle (EV) operation conditions. From the simulation model, consider RC network in addition with voltage source. State of charge is measured at output (Wei et al., 2019). Voltage is measured at terminal 2 and total resistance is measured at terminal 1. Voltage and Resistance of the RC Circuit model has been developed using Scilab and has been indicated in fig 3.1. Open circuit voltage, Voc, internal resistances during discharging, Rdis, and charging, Rcha, are involved. The dependent variables considered for State of charge estimation includes:

Open circuit voltage (Voc),

Figure 25. RC Circuit model of Open Circuit Voltage

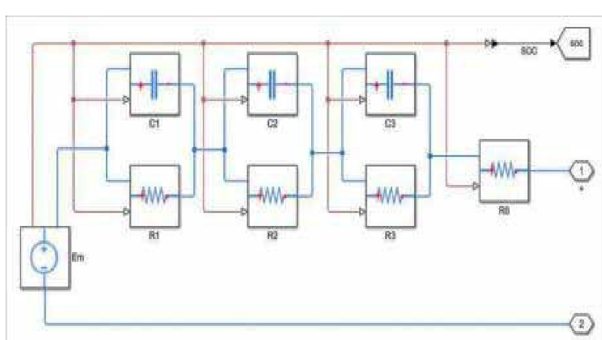


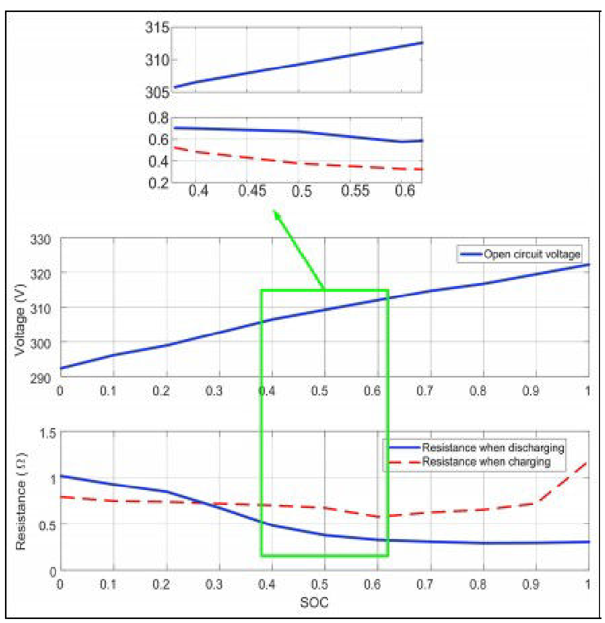
Table 2. Simulation result for a Nissan leaf electric car lithium ion battery identified RC mode

State of charge	12v battery	Voltage per cell (if comprised of separate 2v cells)	Comments
100%	12.70v+	2.12v	Cycling your battery in this zone will ensure a reasonable life expectancy
95%	12.60v	2.10v	
90%	12.50v	2.08v	
80%	12.40v	2.06v	
70%	12.30v	2.05v	
60%	12.20v	2.03v	Occasionally dropping into this zone is OK but not recommended
50%	12.05v	2.00v	
40%	11.90v	1.98v	
30%	11.75v	1.95v	
20%	11.55v	1.92v	Cycling a battery into this zone is certainly not recommended unless unavoidable. Battery life will be massively shortened.
10%	11.30v	1.88v	
Below 10% DEAD	10.5v Or less	1.75v Or less	

Internal Resistance during discharge -Rdis

The battery current and output voltage can be calculated as follows:

Figure 26. Battery open circuit voltage and internal resistance with respect to SOC



$$I = \frac{V_{oc} - V_b}{R_b} \qquad V P_{ele,m\ b}$$

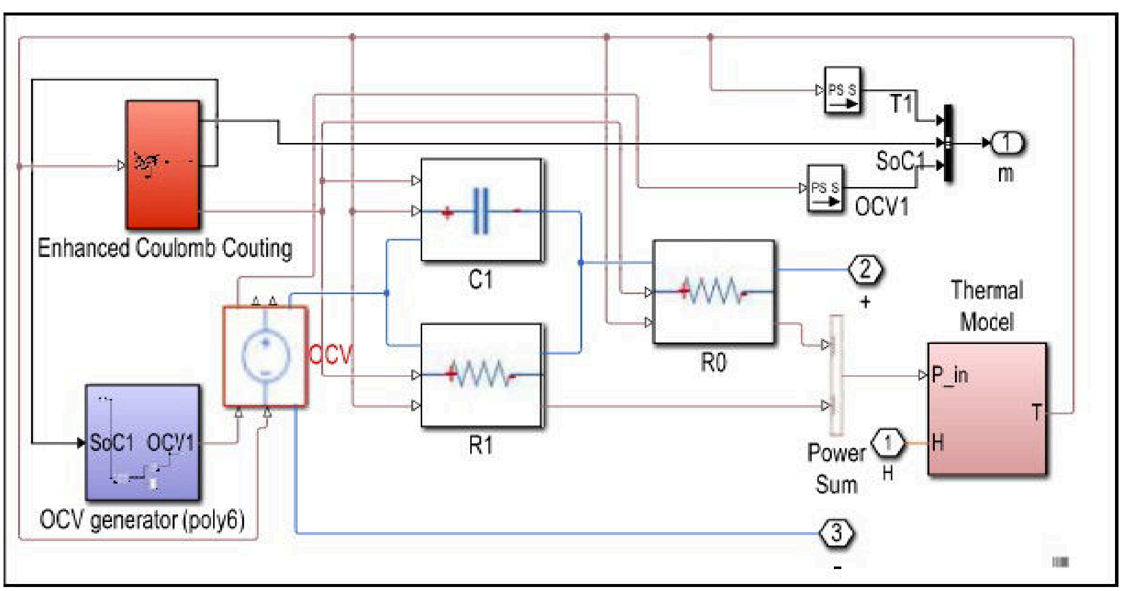
where Rb is the internal resistance of the battery depending on discharge and charge mode, I is the circuit current, and Vb is the battery output voltage. SOC can be obtained by integrating the current. When the current is positive, it means that the battery is discharging. On the other hand, the battery is recharging if the current has a negative value.

$$SOC = SOC_{ind} - \int_0^t \frac{I}{Q_b} dr$$

Here, SOCini is the initial value of SOC, and Qb refers to the storage capacity of the battery. From the developed RC circuit model and simulation has been carried out and results has been compared with existing paper(Pallas et al., 2018) and mapped all parameters and it is shown in fig 24 Hence method is easy to implement. However the initial value cannot be stored and hence data retrieval is found out to be difficult when state of charge has to be calculated.

From Table 2 Simulation result for a Nissan leaf electric car lithium ion battery identified RC model is compared for a 12V battery. It is found that Nissan leaf electric car has used Level 2 charging and experimental and simulation results is same and it is validated.

Figure 27. Enhanced Coulomb Counting



Kalman Filter Method

To overcome the shortcomings of the open circuit voltage method, Kalman filter method is used. The battery can be modeled with an electrical model which the Kalman filter will use to predict the over- voltage, due to the current. This method is complex but data can be stored and data retrieval is also possible but has few errors like

Integration of current sensor error: Integration of the current obtained by an erroneous sensor causes the results to drift.

١. Degradation of battery: Degradation of the battery results in a loss of battery capacity, which causes an estimation error.
٢. Self-discharge: Self-discharge is the consumption of charge inside the battery. This cannot be observed by current measurement.

Battery Model and Parameter Identification of Kalman Filter

While the demand on energy increases day by day, the amount of available fossil fuel reserves deplete. Relying on the fossil fuel consumption causes damages to the environment and incremented greenhouse gas emissions as well. Consequently, the renewable energy technologies have gained more attention and derived the use of more electric vehicles. Lithium-ion batteries are getting popular in both renewable energy systems and electric vehicles thanks to their high power and energy density. Therefore, accurate

Figure 28. Graph related to enhanced coulomb counting

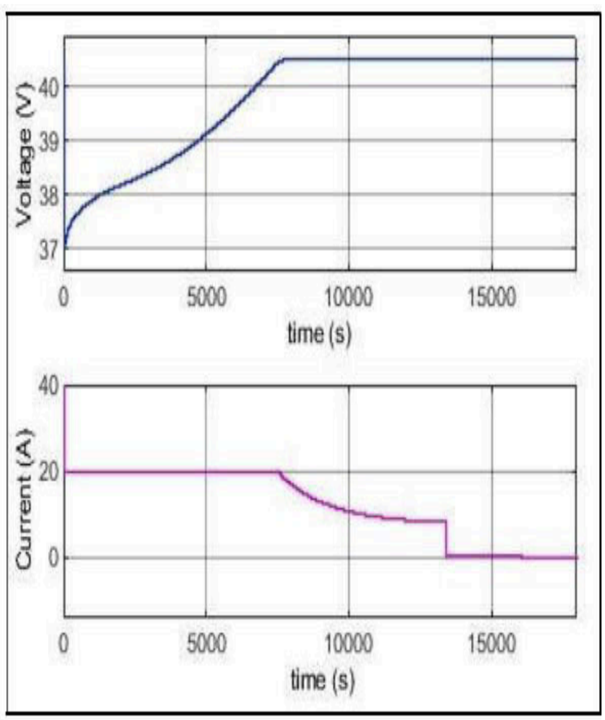


Figure 29. 2RC Li-ion battery improved physical model design and its Simscape library elements

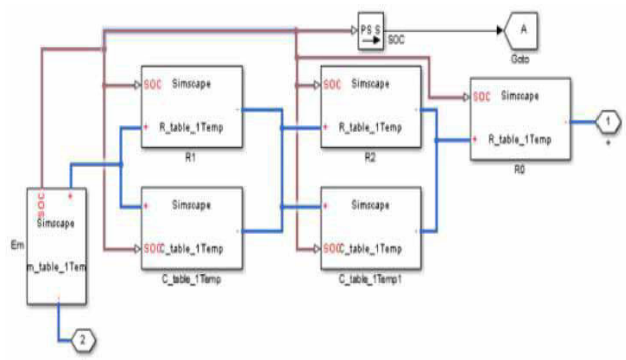
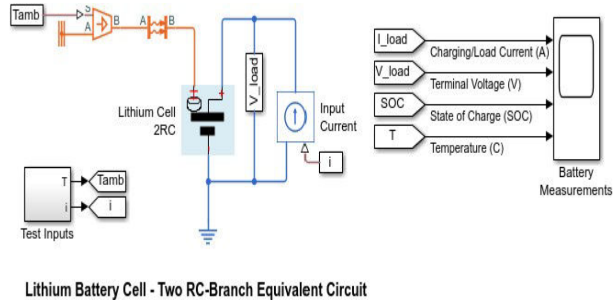
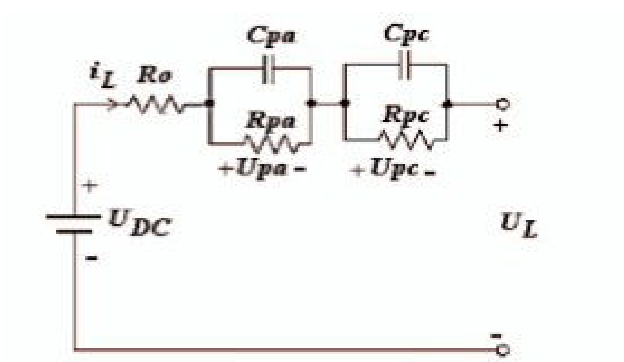


Figure 30. Two RC Branch Equivalent circuit model



battery models are vital to the design and simulation of hybrid/electric vehicle propulsion systems. Modelling and batteries are a toilsome task because of their complex electrochemical structure and nonlinear characteristics. (Liu et al., 2018) Accurate real-time SOC estimation reporting to drivers is also difficult. This work addressed these challenges using extended Kalman filter (EKF) algorithm and a two-RC-block equivalent circuit shown This battery equivalent circuit model is designed in Matlab

Figure 31. RC Thevenin Model



Simulink using the Simscape Language. Then, an algorithm with the EKF approach is developed to enhance the SOC estimation.

CONCLUSION

Electric vehicles are trending nowadays compared to internal combustion engine because of its advan- tages and less limitations. Global warming is effective with electric vehicles because of no emissions of gases. Limitations are the installed charging stations are not able to meet the increasing charging demand of Electric Vehicles. So, if that is overcome then effectively electric cars can be into effect. Among the configurations of electric vehicles battery Electric Vehicles is more advantageous because of its features. Within that Battery Management System plays a key role in Battery Electric Vehicles.

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