OPEN ACCESS
International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319–6378 (Online), Volume-13 Issue-10, September 2025

Noise-Controlled Cell Balance for Battery Electric Vehicles

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***Abstract:** Possible future battery technology which will have more or the same energy density as current gasoline fuels, and also with a significant reduction in battery weights, which will make EVs cheaper than current conditions. Some examples are listed showing the current battery capacities of various EV models. Some battery parameters are presented in the document, along with an introduction to the Battery Management System (BMS). A brief introduction is then provided on the charging of these EV batteries, including their types and variations in charging time across different types of EVs, based on their charger type and manufacturers. How DC charging is a more time-saving method than AC, and how smart charging will help the grid in case of peak or grid failure conditions.*

***Keywords-** EV Batteries, EV Energy Storage, Batteries, Electric Vehicles*

Abbreviations:
NiMH: Nickel-Metal Hydride
BEVs: Battery Electric Vehicles
UC: Ultra-Capacitors
SEI: Solid Electrolyte Interface
SOH: State Of Health
SOC: State of Charge
V2H: Vehicle-To-Home
BMS: Battery Management System
DOD: Depth Of Discharge

I. INTRODUCTION

Batteries of electric vehicles are those used to power the propulsion of battery electric vehicles (BEVs). They are also known as traction batteries. In routine cars, rechargeable batteries are used for a secondary purpose. The primary source of energy to power the propulsion in this vehicle is usually IC engines, which have around 38% efficiency and produce exhaust gases which are noxious to the environment. In the case of electric cars, traction batteries are used to power the main motor of the electric vehicle, having 90-95% efficiency. Traction batteries are primarily used in electric cars, golf carts, electric motorcycles, forklifts, and other vehicles. Electric-vehicle batteries conflict with SLI (starting, lighting, and ignition) batteries due to their nature. Providing power for sustained periods of time. For this application, Deep-cycle batteries are used, contrary to SLI batteries. Traction batteries must be drafted with a high ampere-hour capacity. Electric vehicle batteries are classified based on their relatively high power-to-weight ratio, energy-to-weight ratio, and energy density. For improved performance and reduced vehicle weight, smaller and lighter batteries are used. Rechargeable batteries used in electric vehicles are composed of lead-acid, nickel-metal hydride, NiCd, lithium-ion, lithium polymer and, less frequently, zinc-air and molten salt batteries. Electricity stored in batteries is measured in ampere-hours, and total energy is measured in watt-hours. For EVs, batteries make up a significant cost, unlike fossil-fuelled cars. The batteries can be discharged and recharged each day... Perhaps most notable, battery costs have plummeted [1], and from 2008 to 2014, the cost of electric vehicle batteries has been reduced by more than 35% [2]. In 2020, the predicted market for automobile traction batteries was over $37 billion [3]. The operating cost of an electric vehicle is a small fraction of the operating cost for IC engines, which reflects higher energy efficiency. The cost of replacing the batteries dominates the operating costs [4].

A. Energy Storage: Gasoline Vs Batteries

The main reason the electric car didn't make it before was due to the size and weight of the battery required. Back then, fuel proved to be a far more efficient way of energy storage. But as you can see in the table below, battery technologies have developed to the point where size and weight are much less of an issue.

Table I: Improvement in Battery Technologies Over the Years (for Energy)

Energy Source	Year	Energy (Wh/kg)	Compared to Gasoline
Gasoline	1900- 20??	12,000	-
Lead-acid	1900	10	1,2000 X worse
Lead-acid	2000	35	350 X worse
NiMH	2000	80	150 X worse
Lithium	2015	250	50 X worse
Lithium	2015	400	30 X worse
Lithium-air	???	12,000	Same

If you simplify this table, you can easily compare how much weight you need to bring in your car to get 500 km extra range with each type of battery.

Manuscript received on 27 July 2025 | First Revised Manuscript received on 08 August 2025 | Second Revised Manuscript received on 02 September 2025 | Manuscript Accepted on 15 September 2025 | Manuscript published on 30 September 2025.
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Table II: Improvement in Battery Technologies Over the Years (for Weight)

Energy Source	Year	Extra Weight Needed for 500 km (kg)	Equals
Lead-acid	1900	10,000	Elephant
Lead-acid	2000	3,000	Rhinoceros
NiMH	2000	800	Bison
Lithium	2015	400	Gorilla
Lithium	2025?	200	Pig

As shown in the table and these developments, the electric car will soon be lighter than ICE cars, considering the combined weight of the drivetrain and energy storage. Further, as you can see from this, battery prices are also swiftly plummeting, meaning that the electric car will soon also be cheaper [5].

II. ENERGY STORAGE IN EVS

Electromechanical storage devices used in EVs must fulfil specific requirements so that the EV can perform satisfactorily. The key requirements are as follows:

- Charge and discharge cycles should have high efficiency
- Under a wide range of conditions, the operation should be safe
- Specific power should be high to meet the driver's acceleration expectations
- High specific energy to ensure a satisfactory range
- Maintenance-free and long lifetime
- Minimum effect on the environment due to end-of-life disposal

The power and energy requirements for different types of EVs in comparison with HEV (Hybrid Electric Vehicle) and PHEV (Plug-in Hybrid Electric Vehicle) are listed below, together with standard voltage ratings. For this module, five categories of EV batteries are described, which are similar to those described by Van den Bossche [6] and Westbrook [7]. – Lead acid

- Nickel-based: NiMH, NiCad
- High temperature: Sodium-nickel-chloride (NaNiCl or Zebra)
- Lithium-based: Lithium-ion (Li-ion) and Lithium-polymer (Li-poly)
- Metal air: Aluminium air (Al-air) and Zinc-air (ZN-air)

Table III: Typical EV Battery Electrical Parameters

EV Type	Power (kW)	Energy(kWh)	Voltage(V)
HEV	20 – 50	1 - 3	200 - 350
PHEV	>40	2 – 15	200 – 500
BEV	>80	25 - 100	200 - 1000

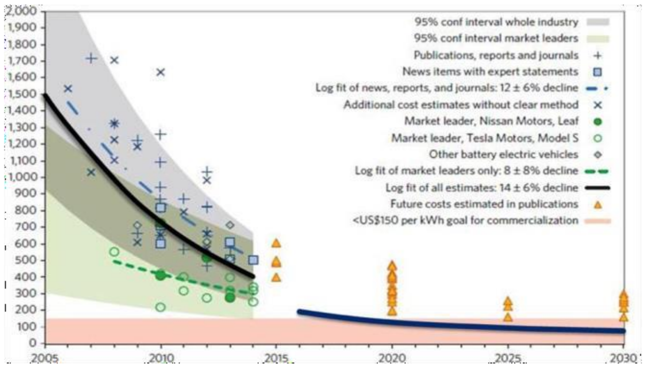
A. Types of Batteries

i. Lead Acid Batteries

This is a mature technology where limited progress has been made in terms of energy and power density. Deep-cycle batteries are available, which have reinforced electrodes to avoid separation and sludge formation [8]. Prospects for use in EVs are limited, due to low energy densities, sensitivity to temperature and life cycle [9].

ii. Nickel-Based Batteries

Nickel-metal hydride (NiMH) batteries are used extensively for traction purposes and are optimised for high energy density. Nickel-cadmium (Ni-Cd) batteries also show good potential for high specific energy and specific power, although the presence of cadmium has raised some environmental concerns [10].



[Fig.1: Rapidly Falling Cost-Effective]

iii. High Temperature Batteries

Sodium-nickel chloride (NaNiCl or Zebra) batteries have been deployed in numerous EV applications to date [11]. The high specific energy is attractive for long-range EVs. The high operating temperature (300°C) requires pre-heating before use, which can consume a significant amount of energy if the device is parked regularly for long periods. For this reason, this battery is considered more suitable for applications where the EV is being used continuously (public transport and delivery vans, etc.).

iv. Metal Air Batteries

Aluminium-air (Al-air) and zinc-air (Zn-air) batteries both use oxygen absorbed from the atmosphere on discharge and expel oxygen when being charged. The energy density of these batteries is high, but lower power densities mean that applications are limited. Al-air batteries consume the aluminium electrode, and must be removed and replaced or reprocessed. Some applications have been tested where fleets of EV delivery vehicles are operating with Zn-air batteries, which feature removable zinc cassettes that can be replaced when discharged, allowing for recharged units. The low specific power of metal air batteries may see these battery types restricted to long-distance delivery vehicles, but the advantages of regenerative braking may be sacrificed.

v. Lithium-Based Batteries

The type of active material classifies lithium-based batteries. Two main types exist: those with liquid (Li-ion-liquid) and those with polymer electrolyte (Li-ion-polymer). The Li-ion-liquid type is generally preferred for EV applications. Within the Li-ion type, there are three lithium materials: lithium cobalt (or lithium manganese oxides), lithium iron phosphate and lithium titanate.

vi. Lithium Manganese

Lithium manganese (LiMn2O4) offers a potentially lower-cost solution. It has been extensively studied for use in electric vehicle applications, especially in Japan. The drawback of this type of battery is the poor battery life due to the slight solubility of

Retrieval Number:100.1/ijese.B35560512222
DOI:10.35940/ijese.B3556.13100925
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Mn. b) Lithium Iron Phosphate. Many companies in the world manufacture lithium iron phosphate ($LiFePO_4$) batteries and have gained credibility through their use in power tools. Lithium iron phosphate cells have a much lower energy density than standard format cells, but can be charged much faster— around twenty to thirty minutes. Moreover, $LiFePO_4$ has been recently considered because it features improved stability on overcharge, which is suitable for safety, and a very high Power and has potential for lower cost because it uses iron. c) Lithium Titanate. Lithium titanate allows charging on the order of ten minutes and has been shown to have an extremely long cycle life, on the order of 5000 full depth of discharge cycles. Lithium titanate has high inherent safety because the graphite anode of the two other batteries is replaced with a titanium oxide.

Table 4: Qualitative Comparison of EV Batteries [12]

Attribute	Lead-acid	Ni-MH	ZEBRA	Metal-air	Li-ion
Specific energy (kWkg-1)	1	2	3	3	3
Specific Power (kWkg-1)	1	3	1	1	3
Capacity (kWh)	1	2	3	3	3
Discharge Power (kW)	3	2	2	1	3
Charge Power (kW)	1	2	2	1	3
Cold temperature Performance (kW & kWh)	3	2	3	2	1
Shallow cycle life	2	3	1	1	3
Deep cycle life	1	3	1	1	2
Cost (€kW−1 or €kWh−1)	3	1	1	1	1
Abuse tolerance	3	3	2	2	2
Maturity Technology	3	3	2	2	2
Maturity Manufacturing	3	1	2	2	1
Recyclability	1	1	3	2	2

*1=poor; 2=fair; 3=good

B. Different Vehicles and their Battery Capacity

i. Hybrid EV

- Chevrolet Malibu (2016): 1.5 kWh
- Ford Fusion II / Ford C-Max II: 1.4 kWh
- Hyundai loniq Hybrid: 1.56 kWh
- Kia Niro: 1.56 kWh
- Lexus CT 200h: 1.3 kWh
- Lexus NX 300h: 1.6 kWh
- Toyota Prius II: 1.3 kWh
- Toyota Prius III: 1.3 kWh
- Toyota Prius C / Toyota Yaris Hybrid: 0.9 kWh
- Toyota Camry Hybrid (2012): 1.6 kWh

ii. Plug-in Hybrid EV

- Audi A3 e-tron: 8.8 kWh
- Audi Q7 e-tron: 17 kWh
- BMW i8: 7 kWh
- BMW 2 Series Active Tourer 225xe: 6.0 kWh
- BMW 330e iPerformance: 7.6 kWh
- BMW 530e iPerformance: 9.2 kWh
- BMW X5 xDrive40e: 9.0 kWh
- Chevrolet Volt: 16–18 kWh
- Ford Fusion II / Ford C-Max II Energi: 7.6 kWh
- Fisker Karma: 20 kWh
- Honda Accord PHEV (2013): 6.7 kWh
- Honda Clarity PHEV (2018): 17 kWh
- Hyundai Ioniq Plug-in: 8.9 kWh
- Koenigsegg Regera: 4.5 kWh [18]
- Mitsubishi Outlander PHEV: 12 kWh
- Porsche 918 Spyder: 6.8 kWh
- Toyota Prius III Plug-in: 4.4 kWh
- Toyota Prius IV Plug-in: 8.8 kWh
- Volkswagen Golf GTE: 8.8 kWh
- Volkswagen Passat GTE: 9.9 kWh
- Volkswagen XL1: 5.5 kWh
- Volvo V60: 11.2 kWh

iii. Battery EV

- Addax MT: 10-15 kWh
- BMW i3: 22–33 kWh
- BYD e6: 60–82 kWh
- Chevrolet Bolt / Opel Ampera-e: 60 kWh
- Citroen C-Zero / Peugeot iOn (i.MIEV): 14 kWh (2011) / 16 kWh (2012-)
- Fiat 500e: 24 kWh
- Ford Focus Electric: 23 kWh (2012), 33.5 kWh (2018)
- Honda Clarity (2018): 25.5 kWh
- Hyundai Kona Electric: 64 kWh
- Hyundai Ioniq Electric: 28 kWh
- Kia Soul EV: 27 kWh
- Luxgen S3 EV+: 33kWh
- Nissan Leaf I: 24–30 kWh
- Nissan Leaf II: 40 kWh (60 kWh in future option)
- Mitsubishi i-MIEV: 16 kWh
- Renault Fluence Z.E.: 22 kWh
- Renault Twizy: 6 kWh
- Renault Zoe: 22 kWh (2012), 41 kWh (2016)
- Smart electric drive II: 16.5 kWh
- Smart electric drive III: 17.6 kWh
- Tesla Model S: 60–100 kWh
- Tesla Model X: 60–100 kWh
- Tesla Model 3: 50–70 kWh
- Toyota RAV4 EV: 27.4 kWh (1997), 41.8 kWh (2012)
- Volkswagen e-Golf Mk7: 24–36 kWh

C. Specific Power Limitation

The ability of a battery to deliver and accept energy at very high rates is limited by the physical processes occurring within the battery cells. When current flows into the battery, the reaction within the cell must occur at a corresponding rate [13]. This means that the dynamics of the response at the electrode. Surface and the transport of Ions (kinetic properties) must occur at the same rate as the supplied current. Because of the high currents associated with high power, the reaction rate is unable to match the rate at

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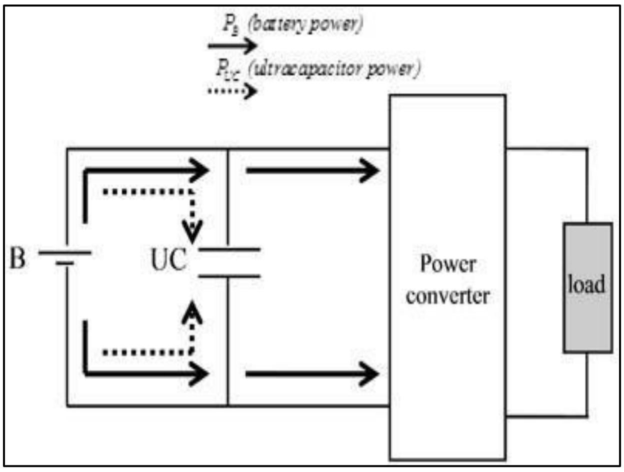
which current is being delivered. As a result, the capacity of the battery is reduced, and joule heating occurs within the cell.

D. Specific Energy Limitation

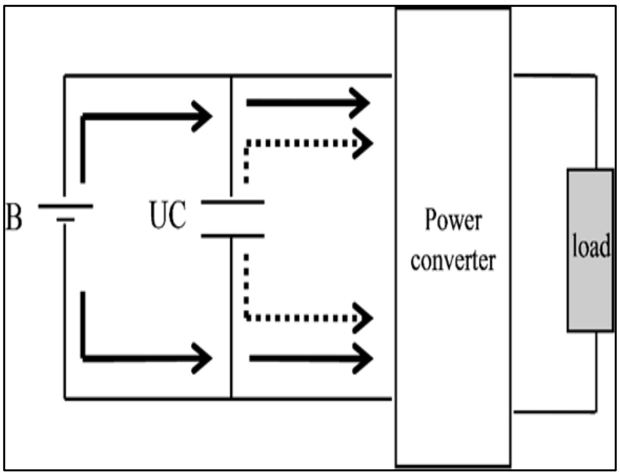
The restricted energy content of batteries is one of the significant drawbacks limiting the successful implementation of EV technology. Considering the specific energy of gasoline is 9.2 kWh kg-1, corresponding to more than 3 kWh kg-1 sound specific energy [14], the limitations of the battery-powered EV become apparent. Two emerging battery technologies addressing the specific energy limitations are lithium air (Li- air) and lithium flour (Li-flour).

E. Hybrid Energy Storage

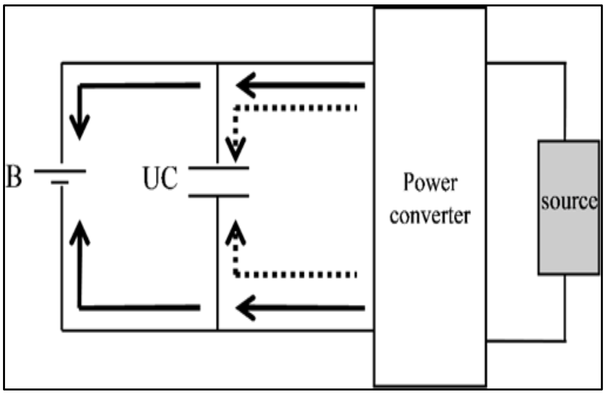
One method of achieving high specific power electrical energy storage is to utilise ultra-capacitors (UC) [15]. The use of UCs alone would not suffice, as these components display poor specific energy characteristics. The ideal solution is to use a hybrid energy storage method in a parallel configuration, as shown in the figure. This set-up combines the high specific power density of UCs with the higher specific energy of an electrochemical battery (B).



[Fig.2: The Case for a Low Power Demand, Where B Can Charge the UC]



[Fig.3: The Case Where a Higher Power is Demanded and Both B and UC Contribute to the Total Power Supply]



[Fig.4: The Case for Both Energy Storage Sources Can be Recharged Using Regenerative Braking]

This type of configuration, however, is costlier due to the additional components and the increased complexity in controlling and managing both power sources. This cost could be offset by selecting a battery technology which has high specific energy, as specific power is no longer a requirement to fulfil.

F. Battery Lifetime

Predicting the ageing effects of individual cells, and therefore battery lifetime, is a complex task, but crucial if the reliability and usability of EVs are to be improved. According to Troltsch et al [16], the primary ageing mechanism is the growth of a surface film, also known as the solid electrolyte interface (SEI), on the negative electrode. Other physical effects occur over time, which affect the conductivity of the electrolyte and hence increase the internal resistance. The net effect is a decrease in battery capacity over time. The lifetime of the battery is the time during which the battery capacity is above a minimum accepted capacity. As described in the Handbook of Batteries [17], this lifetime depends on the depth of discharge (DOD), the number of cycles and the age.

G. State of Health

The state of health (SOH) of a battery system refers to the energy content of the battery after considering the effects of ageing. In terms of EV performance, relating the State of Charge (SOC) to the SOH provides a more accurate indication of the energy remaining in the battery and thus a more precise fuel gauge to the driver. This concept is explained with reference to the Table below. Assuming an energy usage of 0.2 kWh/km and a battery with a capacity of 30 kWh, a range of 150km is achieved. However, as the battery ages and the capacity decreases, the range decreases. If the battery energy indicator does not consider these ageing effects, the EV will have a shorter range than predicted.

Table 5: Effect of Battery Age on SOH

Age	SOH (% of capacity)	Range (km)
Beginning of Life (BOL)	100	150
Middle of Life (MOL)	90	135
End of Life (EOL)	80	120

Retrieval Number:100.1/ijese.B35560512222
DOI:10.35940/ijese.B3556.13100925
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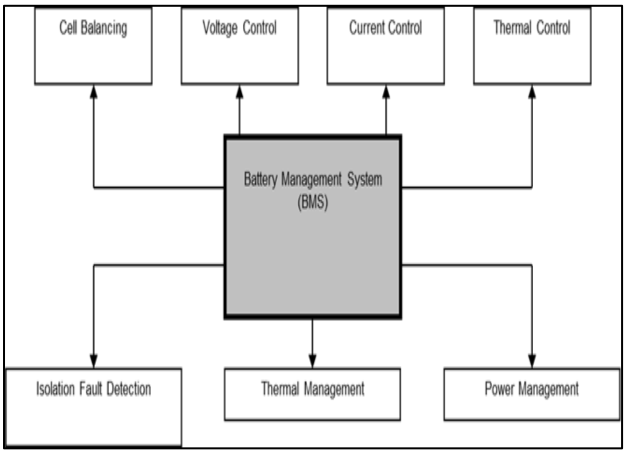
H. Battery Management System

Batteries for electric vehicles consist of many interconnected cells, combined to form a battery pack. Individual battery cells show a reduction in capacity with increasing charge and discharge cycles, as well as temperature variations. When cells are connected in a series or parallel configuration, as in a battery pack, management and control of the charge and discharge conditions become crucial to extend the lifetime and limit ageing effects of individual cells. A battery management system (BMS) is used to monitor, control and balance the pack. The main functions of a BMS are outlined in the figure below. Without balancing the battery pack, the battery not only risks unnecessary damage but also operates sub-optimally. Because the worst cell is limiting the performance of all cells in the battery pack, it is essential to prevent significant differences in the state of charge of the cells.

The cost and complexity of a BMS depend on the functionality and intelligence built into the management system. State-of-charge (SOC) estimation is an important parameter to measure accurately, especially if EVs are integrated with a smart electrical grid. Different methods of estimating SOC are detailed in Battery Management Systems: Accurate State-of-Charge Indication for Battery-Powered Applications [18].

Because the performance of battery cells varies with temperature, it is therefore crucial to include a thermal management

system in the battery pack. This ensures that all cells are both electrically and thermally balanced, thereby extending their lifetime. Thermal management systems can either use air or liquid as the transfer medium. For integrating into the vehicle, the power consumption must be low, and it must not add much additional mass. The thermal management system can realise its performance requirements using either passive or active means. A passive system using only the ambient environment may provide sufficient thermal control for some battery packs, whereas active control may be required for others.



[Fig.5: Battery Management]

To understand the importance of the battery management system, we take a closer look inside. The BMS can monitor and control (directly or indirectly) several different parameters of the battery: 1) Voltage

2) Current
3) State of Charge
4) Temperature
5) State of Health

First of all, the voltage of the total battery pack and of the individual cells is monitored by the BMS. The BMS can keep track of the difference between the minimum and the maximum cell voltages, and estimate if there is a dangerous imbalance in the battery pack. The charging and discharging current of the battery pack is essential to control, as too high a current can overheat a battery and lead to a failure. Furthermore, improper control of the charging and discharging current can lead to overvoltage and undervoltage of the battery, respectively, which can ultimately harm the battery.

The state of charge function is critical to track, because many batteries must not be discharged below a certain percentage. This is because, if the depth of the discharge becomes too high, some batteries can start to break down or lose their capacity. The state of charge can be determined from the measured values of the voltages and currents.

Another function is the temperature of the battery pack and the individual cells. Temperature is directly related to battery lifetime, as high temperatures can cause the battery to degrade faster. The particular cell temperature is essential to know as well, to see if there are local hot spots, indicating a possible failure. Using the BMS together with the battery thermal management system can cool the battery and keep it within a nominal range. When a coolant is available, the temperature of the intake and output coolant is an essential indicator of the battery pack's temperature.

The state of health is a measurement to estimate the overall condition of the battery with respect to its lifetime. Battery cell balancing is a key feature of the BMS to help increase battery lifetime. Naturally, after a while, the different cells in a battery pack will start to show differences in the state of charge and thus show localised under- or overcharging. This can have multiple causes. For example: manufacturing inconsistencies, different charging/discharging currents, heat exposure and more. This is detrimental to the lifetime of the battery pack because most cells in the battery pack are connected in series (adding voltages). This means that if one battery cell fails, the entire battery pack will appear to be defective (producing zero current). The BMS can perform balancing passively or actively. In the case of passive cell balancing, passive elements such as resistors are used. This is simple but inefficient, as it leads to power losses in the resistors. On the other hand, in the case of active balancing, DC-DC power electronic converters are used to equalise the cells and reduce the differences in the operational state of individual cells.

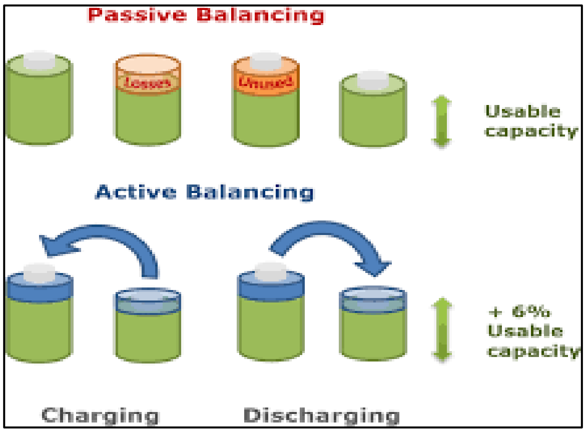
I. Li-ion and BMS

Almost all electric vehicle battery systems are made with the lithium-ion battery chemistry. Lithium-ion rechargeable batteries are more sensitive to imbalance than other battery chemistries. This is because lithium battery chemistries are more susceptible to chemical damage, like cathode fouling, molecular breakdown and unwanted chemicals from side reactions. Chemical damage in lithium-ion batteries can occur rapidly when slight overvoltages or overcurrents are applied. Heat accumulation inside the battery pack can accelerate these unwanted chemical reactions.

Lithium battery chemistries often permit flexible membrane structures, which makes it possible to use lightweight sealed bags, improving the energy density and specific energy of the battery. Some unwanted chemical reactions that occur when the battery is mistreated will result in gaseous by-products. This leads the batteries to become ‘puffy’ or ‘balloon-like’, which is a strong indicator of a failed battery. A significant danger associated with lithium-ion batteries is the accumulation of pressure, which can lead to an explosion. The organic electrolyte contains hydrocarbon chemicals, which are flammable, leading to a dangerous cocktail upon battery failure. This illustrates why a proper battery management system is crucial for lithium-ion batteries.

J. Techniques to Improve Battery Life

It is clear that the BMS, through balancing, thermal management and control of voltage and current, helps in improving the battery life. Another critical factor that can improve battery life is to reduce the number of charge-discharge cycles and the maximum depth of discharge. The battery should not be completely charged and discharged, because this is detrimental to battery life. Furthermore, some EV manufacturers let their customers set the maximum percentage until which the battery should be filled for everyday use, and they recommend a relatively low setting of around 80%, which can be increased for longer trips. Another setting in EVs, which is sometimes available, is the option to limit the car's power output. This has the downside of lower acceleration, but it limits the discharge rate of the battery, making it less detrimental to the battery.



III. CHARGING OF EVS

The most common source of charging for EVs is the power grids. Other small sources of power, like solar cells, wind power or hydro power, can also be used to charge the EV batteries. Charging time is commonly limited by the grid's capacity. A standard home outlet delivers one .5 kilowatts (in the U.S., Canada, Japan, and different countries with a 110 V supply) and three kilowatts (in countries with a 240 V supply). In 1995, some charging stations charged BEVs in one hour. In November 1997, Ford purchased a fast-charge system created by AeroVironment, known as "PosiCharge," for testing its fleet of Ranger EVs, which charged their lead-acid batteries in between six and fifteen minutes. In February 1998, General Motors declared a version of its "Magne Charge" system that may recharge NiMH batteries in approximately 10 minutes, providing a range of sixty to 1 hundred miles. In 2005, handheld device battery designs by Toshiba were claimed to be able to accept an 80% charge in as little as 60 seconds. Scaling this specific power characteristic up to a similar seven-kilowatt-hour work unit pack would require a peak of 340 kilowatts of power from some supply for those sixty seconds. It's not clear that such batteries can work directly in BEVs, as heat build-up could make them unsafe. Electric cars, such as the Tesla Model S, Renault Zoe, and BMW i3, can recharge their batteries at fast charging stations in half an hour to eighty per cent. Scientists at Stanford University in California have developed a battery that can be charged within one minute. The anode is made of aluminium and the cathode is made of graphite. The electric car Volar-e of the company Applus + IDIADA, based on the Rimac Concept One, contains lithium iron phosphate batteries that can be recharged in 15 minutes. According to the manufacturer, BYD, the lithium-iron-phosphate battery of the electric car e6 can be charged to 80% at a fast-charging station within 15 minutes and to 100% in 40 minutes.

On-board chargers are located within the vehicle, and the size and power rating are constrained by the available space within the car. Off-board chargers are located outside the vehicle, providing more flexibility in terms of the power that can be delivered. Both classes of charging devices must contain control circuits and communicate in real-time with the vehicle battery. This is to ensure that the battery is charged in an optimum way, avoiding any damage to the battery through overcharging. AC charging uses an on-board charger, while DC and battery swap use an off-board charger. In case of an inductive charger, a combination of both an on-board and off-board charger is required.

A. Conductive Charging

This is the most common charging method currently available, which falls into two categories: AC (alternating current) and DC (direct current) charging. *1) Conductive Charging – AC*

[Fig.6: AC Conductive Charging]

– Advantages

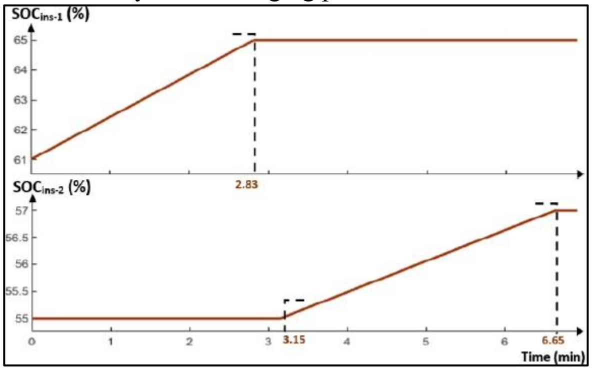
1) The battery can be recharged anywhere using the AC grid and

the on-board EV charger

2) The EV charger can easily communicate with the Battery Management System (BMS), and no additional power electronic converters are needed in the EV charger. This leads to a higher performance and lower Disadvantages

1) AC power has to be converted into DC power in the car, and there is a limitation on the power output for AC charging due to the size and weight restrictions of the on-board charger

2) AC charging needs a relatively long time due to the relatively lower charging power



[Fig.7: Conductive Charging – DC]

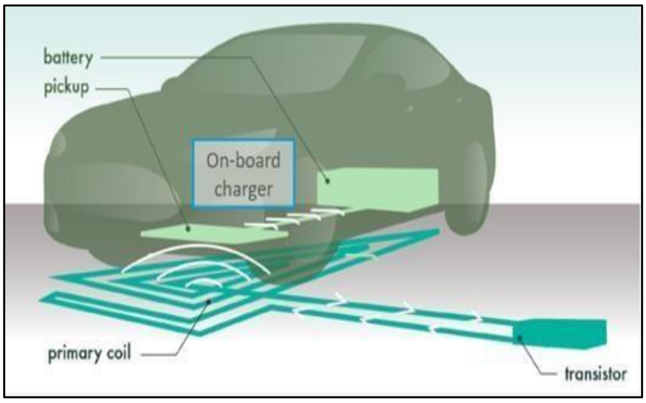
1) Adverse impact on power system: high power demand on the grid, esp. at peak hours

2) Since the off-board chargers and the BMS are physically separated, reliable communication is essential to ensure correct charging conditions.

B. Inductive Charging

Inductive charging also has two categories: Static & Dynamic

1) Static Inductive Charging



[Fig.8: Static Inductive Charging]

The main idea behind inductive charging is the use of two electromagnetically linked coils. The primary coil is placed on the road surface, in a pad-like construction related to the electricity network. The secondary coil is placed on the vehicle, ideally on the bottom or top of the car. The 50Hz AC power from the grid is rectified to DC and is then converted to a high-frequency AC power within the off-board charger station. Then this high-frequency power is transferred to the EV side by electromagnetic induction. The coils on the car convert this high-frequency AC power back to DC to charge the EV using the on-board charger.

– Advantages

1) Convenience

2) Suitable for self-driving cars

– Disadvantages

1) High investment

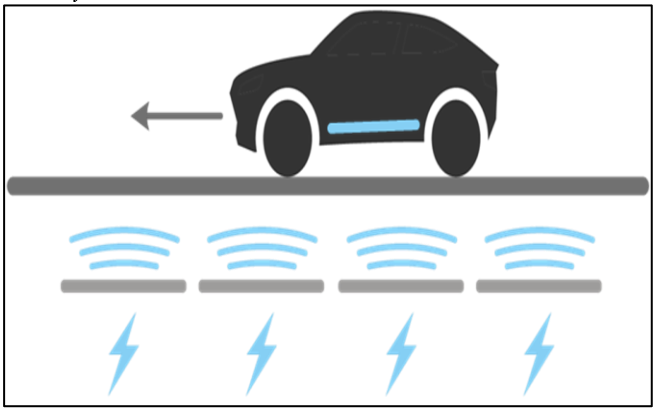
2) Limited space & weight of charge pads

3) Misalignment tolerance between the vehicle and the charge pad

4) Power losses and relatively lower efficiency than conductive charging

5) Electromagnetic radiation exposure

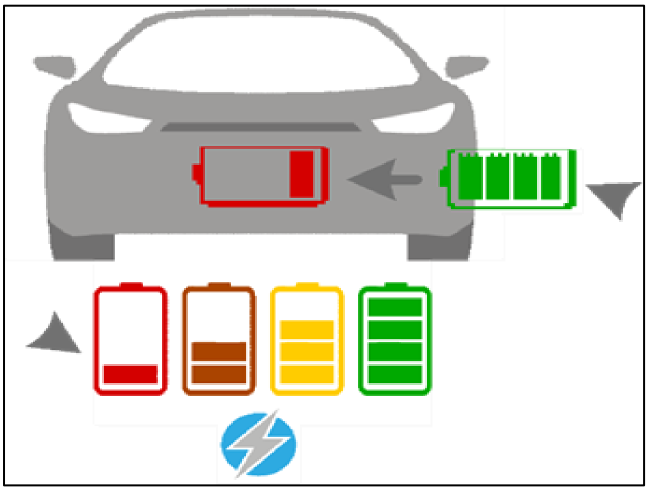
2 Dynamic Inductive



[Fig.9: Dynamic Inductive]

The other way to charge a car wirelessly is called dynamic charging. The coils connected to electric cables, which provide the power, are buried in the road. The coils emit an electromagnetic field that is picked up by vehicles driving over them and converted into electricity to charge the cars.

C. Battery Swap



[Fig.10: Battery Swap]

The third method of EV charging is battery swap. It works by switching out the depleted battery and replacing it with a fully charged one. The process involves driving into a battery switching bay, and an automated process will position the vehicle, switch out the current battery and replace it with a fully charged battery. The depleted batteries are charged in the station for later deployment. The system works on the business concept that the EV user owns the vehicle and not the battery. A battery swap

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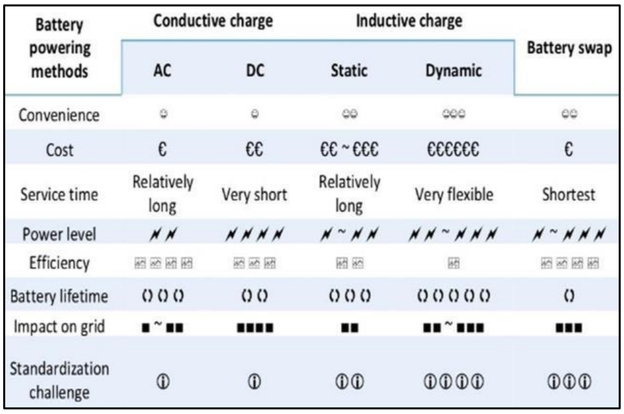
requires a foolproof method to estimate the battery's state of health, allowing for the detection of its usage pattern and ensuring that only authorised vehicles and charging stations can charge it.

Advantages

1) No range anxiety
2) Quick and easy refilling like a combustion engine car tank
3) Longer charging times available for the EV battery compared to fast DC charging – Disadvantages
1) The requirement of a standardised battery interface across multiple car manufacturers.
2) Consumer acceptance of not owning a battery and having to change the vehicle battery.

D. Comparison of EV Charging Methods



[Fig.11: EV Charging]

IV. CONCLUSION

Overall comparison of these batteries is as follows:

– It can be observed that the dynamic inductive charging is the most convenient charging method, but also the most expensive. Even if the static inductive charging is cheaper than the dynamic one, the average cost of inductive charging is higher than that of any other method. Dynamic inductive charging has the most flexibility, as the car can be charged at any time when on the way and does not need to stop by the service point.

– To power the battery, the battery swap method needs the shortest serving time. For all charging methods except battery swap, the serving time is highly related to the power level. In this case, the DC conductive charging method has the highest power capacity among all the methods.

– Finally, considering the standardisation challenge, the dynamic inductive charging and the battery swap are faced with the most difficult challenges. It is because both methods require standardisation between car types, battery size, power level and even shape. Future battery developments may alter the economic equation, making it advantageous to use newer, high-capacity, and longer-lived batteries in electric cars/plug-in hybrids (BEVs/PHEVs). These newer batteries can be used in grid load balancing and as a large energy cache for renewable grid resources. Since BEVs can have up to 50 kWh worth of battery storage, they represent more than the average home's daily energy demand. Even without a PHEV's gas generation capabilities, such a vehicle could be used for emergency power for several days (for example, lighting, home appliances, etc., with a combined load of 1 kW could be powered for 50 hours). This would be an example of Vehicle-to-home transmission (V2H). As such, they may be seen as a complementary technology for intermittent renewable power resources, such as wind or solar electricity. Hydrogen FCEVs with tanks containing up to 5.6 kg of hydrogen can deliver more than 90 kWh of electricity.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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