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Advancement in Battery Management System of Electric Vehicle

[1]Dr. Gopal Reddy K, [2] Dr. Shakunthala C, [3]Mukhndaswamy M, [4]Chethan T K, [5] Payal R Chavan, [6]Sowmyashree N

[1]Professor, VVCE Mysuru
[2]Associate Professor, ATME College of Engineering
[3]Assistant Professor, Dr.Ambedkar Institute of Technology Bengaluru
[4] [5]Student, VVCE Mysuru
[6]Assistant professor, Department of Electrical and Electronics EngineeringSJCE JSSSTU Mysuru

Abstract: Electric vehicles (EVs) have gained significant attention as a sustainable and eco- friendly mode of transportation. Central to the efficient operation of EVs is the Battery Management System (BMS), a critical component responsible for monitoring, controlling, and optimizing the performance of the vehicle's energy storage system. As the demand for EVs continues to grow, there is a pressing need for advancements in BMS technology to address various challenges such as battery safety, range optimization, and overall system efficiency. This paper presents a comprehensive overview of the recent advancements in Battery Management Systems for Electric Vehicles. It explores cutting- edge technologies and strategies that have been developed to enhance the reliability, safety, and performance of EV batteries. Topics covered include state-of-the-art battery diagnostics, real-time monitoring, thermal management, and predictive maintenance techniques.

1. Introduction:

An electric vehicle (EV) is a mode of transportation propelled by one or more electric motors. These vehicles source their power from either an internal collector system or external electricity supply. In some cases, electricity is obtained through rechargeable means, where fuel can be converted into electricity using generators, fuel cells, or even solar panels [1]. Electric vehicles play a pivotal role in combatting carbon emissions and reducing our dependence on fossil fuels, making them a significant contributor to sustainable transportation solutions.

The concept of electric vehicles dates back to the 1830s when they first made their appearance. By the end of that century, commercially available electric vehicles had become commonplace. Notably, in 1827, Anyos Jedlik, a Hungarian priest, developed some of the earliest functional electric motors,complete with essential components like rotors, commutators, and stators. He even employed these motors to propel a small vehicle, marking a crucial milestone in EV history [2]. The early 1900s witnessed the introduction of surplus electric cars in the United States. Studebaker AutomobileCompany, for instance, entered the automotive scene in 1902 with electric vehicles before expanding into the gasoline-powered vehicle market in 1904. However, with the advent of Ford Motor Company's assembly line production of gasoline cars, electric vehicles saw a significant decline in popularity [3]. Fast forward to the present, and electric vehicles have experienced a resurgence, with demand reaching unprecedented levels. As of December 2020, India had registered 14,978 electric vehicles, and inNovember of the same year, this number surged to 42,055, indicating the rapid growth of EV adoption [4]. Technological advancements have been a driving force behind this resurgence, influencing not only technical documentation [5]-[7] but also trade publications [8].

Electric cars come in various forms, such as all-electric vehicles, hybrid EVs, fuel-cell EVs, and plug-in hybrid vehicles, each operating on distinct principles. While some components and features are common across all electric vehicles, others are unique to each type. One fundamental aspect of electric vehicles is power electronics and battery management. Power electronics is founded on the principles of power conversion and control operations [9]. Recent years have seen significant progress in power electronics, driven by the demand for more efficient motor control in industrial applications and the creation of lightweight, reliable switching power supplies for complex computer and communication equipment [10].

Electric vehicles offer numerous advantages over internal combustion engines, including zero exhaust emissions in their immediate surroundings and minimal noise pollution. This makes electric vehicles particularly suitable for environments where pollution and noise restrictions are stringent, such as golf courses, warehouses, and indoor settings. The evolution of electric vehicles continues to shape the future of transportation, driving us towards a more sustainable and environmentally friendly mobility landscape.

A battery consists of multiple interconnected electric cells, typically two or more, that work together to convert chemical energy into electrical energy. These cells are bridged by an electrolyte, connecting the negative and positive electrodes. Through a hydrophobic interaction between the electrodes and the electrolyte, direct current (DC) electricity is generated. In the case of secondary or rechargeable batteries, the direction of current flow can be altered, allowing the battery to be charged repeatedly. While there are various types of rechargeable batteries, the most well-known is the 'lead-acid' battery, although other variants exist.

Electric vehicles incorporating rechargeable batteries have been around for several decades, even before the introduction of rechargeable lead-acid batteries. There is a wide range of substances and electrolytes that can be used to create batteries, including lead-acid, nickel-iron, nickel-cadmium, nickel-metal hydride, lithium-polymer, lithium-iron, sodium-sulfur, and sodium-metal chloride batteries, among others. However, lithium-ion batteries have emerged as the dominant force in the battery industry, not only in electric vehicles but also in all battery-reliant applications, from TV remotes to industrial equipment.

Lithium-ion batteries were first introduced in the early 1990s and are composed of a positive electrode made of transition metal oxide with lithium ions and a negative electrode made of lithiated carbon. The electrolyte can be an organic mixture of liquid or crystalline polymer [11]. These batteries have revolutionized portable devices and play a pivotal role in the technology of electric vehicles. They are crucial for enhancing the integration of distributed generation into power systems, contributing to a more sustainable future.

Modern lithium-ion batteries consist of two electrodes separated by a porous separator and immersed in a non-aqueous electrolyte, typically composed of ethylene carbonate (EC) and at least one linear carbonate like dimethyl carbonate (DMC), diethyl carbonate (DEC), or ethyl methyl carbonate (EMC), along with various additives. During charging, lithium ions migrate through the crystalline lattice of $LiCoO2$ to the anode side, forming lithiated graphite ($LiC6$). During discharging, the ions return to the cobalt oxide framework host, while electrons are released to the external circuit. This process, often referred to as "rocking-chair chemistry," results in the generation of carbon and lithium metal oxide, producing electrical energy. The final chemical reaction in the battery can be represented as:

$$C6Lix + MyOz \longleftarrow\!\!-\!\!-\!\!\longrightarrow 6C + LixMyOz$$

This study focuses on innovations in battery technology aimed at overcoming current challenges. While batteries are a crucial component of electric vehicles, their design and management are of paramount importance. There is a growing demand for batteries that offer increased efficiency, reduced cost, improved durability, compact size, and easier handling of components, both now and in the future.

Lithium-ion batteries, including their molecular counterpart lithium polymer batteries, have a well-established history of successful utilization in laptop computers and consumer electronics. They have emerged as the preferred battery technology for electric vehicles due to their exceptional energy density and extended cycle life. In 1979, significant advancements in this field were made by pioneers like N. Godshall, who introduced a graphite anode paired with lithium cobalt oxide, a breakthrough that was further developed by John Goodenough and Akira Yoshino shortly thereafter [13] [14] [15] [16].

2. LI – ION BATTERY AND ITS WORKING:

A lithium-ion battery is fundamentally composed of multiple individual cells interconnected together. Each cell consists of three essential components: a positive electrode known as the cathode, a negative electrode referred to as the anode, and a liquid electrolyte.

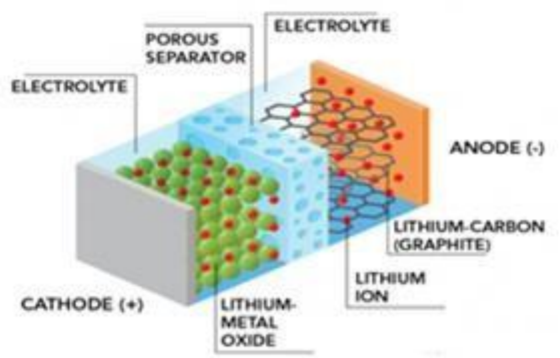


Fig-1: Parts of Lithium ion Battery

Lithium, in its elemental form, is highly reactive and is not directly employed in lithium-ion (Li-ion) batteries. Instead, Li-ion batteries typically utilize lithium-metal oxides, such as lithium-cobalt oxide (LiCoO2), as the source of lithium ions. These lithium-metal oxides are employed in the cathode, while lithium-carbon compounds are often used in the anode due to their capacity for intercalation—a process that allows molecules to incorporate other substances into their structure.

Within a lithium-ion battery, electrochemical processes involving oxidation and reduction occur. Reduction takes place at the cathode, where lithium-cobalt oxide (LiCoO2) is formed as cobalt oxide reacts with lithium ions. This reduction process can be represented as follows:

$CoO_2 + Li^+ + e \quad > LiCoO_2$

Conversely, at the anode, oxidation occurs, leading to the formation of graphite (C6) and lithium ions through the graphite intercalation complex LiC6. The oxidation half-reaction is depicted as:

$LiC_6 \quad > C_6 + Li^+ + e^-$

The overall reaction, which occurs during both discharging (left to right) and charging (right to left) of the battery, can be represented as:

$$LiC_6 + CoO_2 \rightleftarrows C_6 + LiCoO_2$$

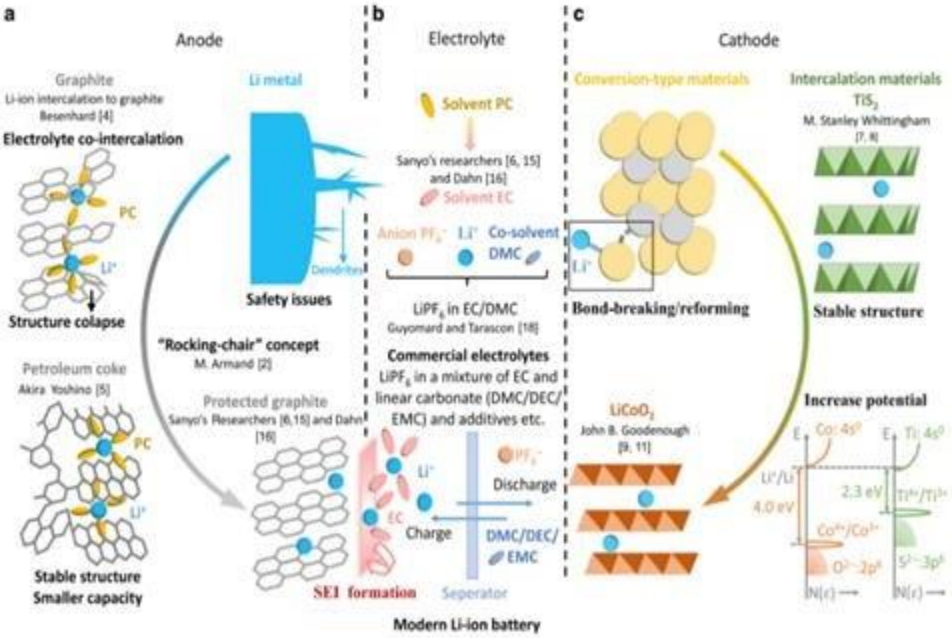


Fig-2: Lithium ion Battery

Several key discoveries have significantly contributed to the development of conventional lithium-ion batteries. These include advancements in anode materials like graphite, petroleum coke, and lithium metal; the formulation of electrolytes containing a mixture of Ethylene Carbonate (EC), solvent Propylene Carbonate (PC), and at least one linear carbonate chosen from DiEthyl Carbonate (DEC), DiMethyl Carbonate (DMC), Ethyl Methyl Carbonate (EMC), along with various additives; and the utilization of cathode materials, particularly conversion-type materials like LiCoO2 [18].

Discharging:

During the initial discharge phase, lithium atoms undergo oxidation, leading to the generation of Li+ ions and electrons. Simultaneously, Li+ ions move through the electrolyte and separator towards the positive electrode via a diffusion process. Electrons, on the other hand, travel through the external circuitry, flowing from the negative electrode to the positive electrode. This resulting electron flow can be harnessed for various applications. Electrons eventually recombine with Li+ ions at the positive electrode and become stored within the molecular structure of the active material [19].

Charging:

When an external voltage of the same polarity is applied across the current collectors, the charging process is initiated. Lithium atoms within the metal oxide framework then exit this structure and ionize into Li+ ions, simultaneously releasing electrons. Much like the discharge process, Li+ ions proceed to diffuse towards the negative electrode. At the surface of graphite particles, a recombination of Li+ ions and electrons occurs, forming neutral lithium atoms. These neutral atoms are subsequently re- intercalated into the chemical structure of the graphite particles [19].

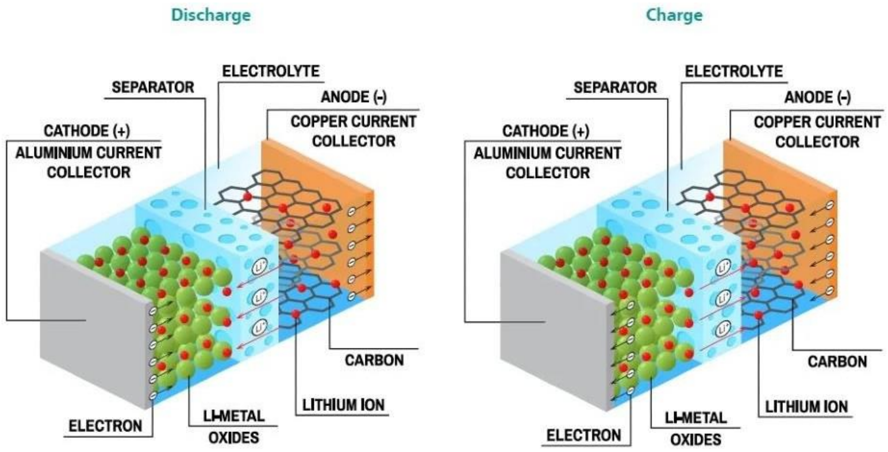


Fig-3: Lithium ion Charging and Discharging process

3. Innovations In Lithium Ion Batteries:

For the development of next-generation rechargeable batteries, lithium metal is considered a promising candidate as an anode. However, a significant challenge in utilizing lithium metal stems from its tendency to form non-uniform electrode deposits, often referred to as "lithium dendrites." These dendrites, which exhibit varying morphologies, typically emerge during the charging process on the negative electrode. The presence of these dendrites can lead to a decline in the electrochemical performance of the battery. Moreover, at extreme temperatures, the interaction between electrolytes and lithium dendrites can result in the generation of gases, causing a continual increase in internal battery pressure and raising safety concerns such as battery explosions and electrolyte leakage. Notably, solid electrolyte interphase (SEI) films lack thermal stability when lithium dendrites are present, making them prone to short circuits or even explosions over time.

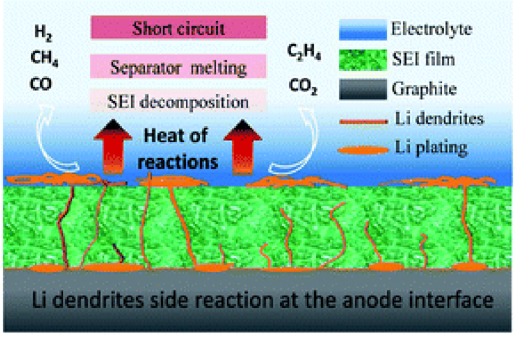


Fig-4: Lithium ion battery reaction process

The formation of dendrites is believed to be driven by mass transfer and competition in the reduction rate of Li ions closer to the cathode surface. When the rate of ion reduction significantly outpaces the rate of mass transfer, it creates an electro-neutral region near the cathode referred to as the "space- charged layer," which is devoid of ions. Dendrite growth is thought to be initiated by the instability of this layer. Consequently, minimizing or eliminating this layer could effectively limit dendrite formation, thus extending the battery's lifespan. To address this challenge, the objective was to re-establish charge balance and mitigate the gap by facilitating ion movement past the cathode using a microfluidic channel. It has been discovered that increasing the ion flow into the cathode can be an effective strategy for suppressing dendritic growth, reducing it by up to 99 percent, as demonstrated in a study conducted by Wan [20].

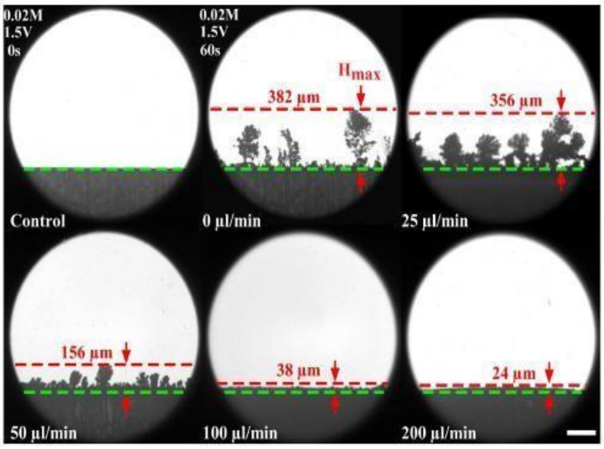
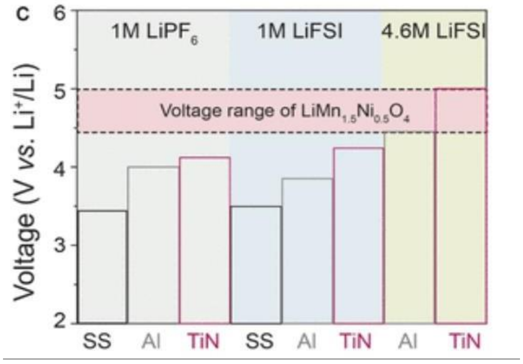


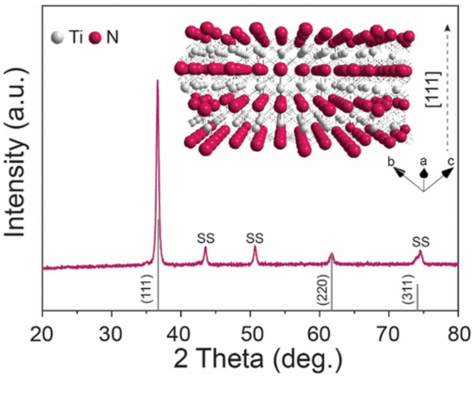
Fig-5: Process of Evolution

Batteries represent a critical component of electric vehicles, and their ability to be rapidly charged at high voltages is paramount. Understanding battery behaviour at high voltage is essential for comprehending battery characteristics during charging. Lithium-ion batteries should be capable of withstanding high voltage for cost-effective operation. These batteries typically have a nominal voltage of 3.7 volts per cell, and by connecting cells in series, battery packs can be configured with varying voltages in 3.7-volt increments. For instance, an 11.1-volt battery may consist of three cells, a 14.8-volt battery may comprise four cells, and a 37-volt battery could include ten cells. Lithium-ion batteries are renowned for their high energy density, ranging from 250 to 670 Wh/L or 100 to 265 Wh/kg, surpassing many other battery technologies. Additionally, they are capable of delivering up to 3.6 volts, which is three times higher than Ni-Cd or Ni-MH batteries. Consequently, they can supply substantial current, making them well-suited for high-power applications. Moreover, Li-ion batteries require less frequent recharging due to their reduced maintenance requirements [22].

High voltage in batteries can significantly enhance their energy capacity. Various sources of high voltage can be effectively utilized in battery systems. The energy density of a battery refers to the amount of energy it can store per unit volume, and this is where LiHv (high-voltage lithium) batteries excel compared to conventional LiPo batteries. LiHv batteries can be charged to a maximum voltage of 4.35V, which represents an increase from the traditional 3.7V nominal voltage. This innovation is readily producible and has the potential to boost battery capacity by 15 percent. A key challenge in commercializing high-voltage Li-ion batteries lies in the availability of economically viable and oxidation-resistant current collectors capable of operating at potentials up to 5 V vs. Li+/Li. High cathode overcharging can lead to oxidation and corrosion of current collectors, which remains a challenge to address. Common cathode current collectors, such as aluminum (Al) and stainless steel (SS), are not suitable for high-voltage applications as they oxidize at relatively low voltages around 3.9 volts. Titanium nitride (TiN), characterized by its excellent electrical conductivity and oxidative stability in LiPF6- and LiFSI-based electrolytes, presents a promising alternative for high-voltage commercial battery applications. Experimental results indicate that TiN can function effectively at high voltage levels, with electrochemical oxidation initiating at 3.44 V/3.49 V, 4.0 V/3.85 V, and 4.12 V/4.24 V against Li+/Li for Al, SS, and TiN current collectors, respectively [24][25][26].



X- ray diffraction analyses have confirmed the formation of highly crystalline cubic TiN coatings on stainless steel, exhibiting a preferred (111) orientation. This exceptional oxidative stability of TiN current collectors is attributed to the (111) orientation of the TiN film [27].



In conclusion, this research and survey suggest that titanium nitride can be effectively utilized in lithium-ion batteries for commercial high-voltage applications. Rapid charging, made possible by high voltage, offers numerous advantages, including reduced weight and bulk, as well as enhanced power delivery. Higher-voltage systems can significantly reduce the amount of copper required, resulting in lighter and simpler electric motors. Charging time can also be drastically reduced with fast chargers, enabling shorter refuelling periods for electric vehicles. Additionally, high-voltage systems improve power retention during charging, contributing to extended driving ranges.

4. Flow Batteries:

Type of battery that uses vanadium to store energy are called as vanadium redox battery (VRB), also known as the vanadium flow battery (VFB) or vanadium redox flow battery (VRFB). It's a form of rechargeable battery in which the charge carriers are vanadium ions.[28] Vanadium Because Redox flow battery (VRFB) systems are the most developed among flow batteries due to their active species being in solution at all times during charge/discharge cycling, their amazing reversibility, and their fairly high power production.

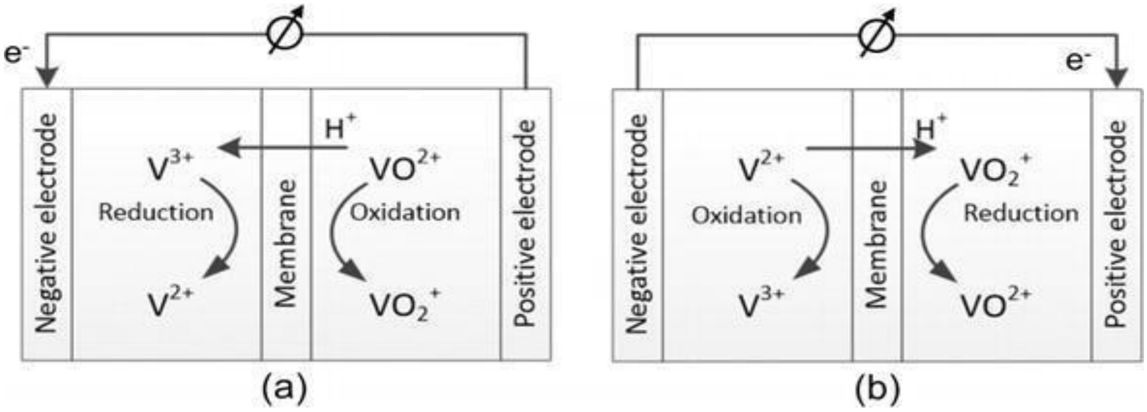


Fig 6: Schematic diagram of a vanadium redox flow battery: (a) charging reaction and (b)discharging reaction.

The cathode undergoes reduction whereas the anode undergoes oxidation during discharge. Protons spread across the membrane and electrons move through the external circuit when these redox reactions take place.

At Negative electrode: $V_2+ < ------------ > V_3+ + e^-$
At Positive electrode: $VO_2+ + 2H+ + e^- <----------------> VO_2+ + H_2O$
The Overall reaction: $V_2+ + VO_2+ + 2H+ < ----------------> VO_2+ + V_3+ + H_2O$
The all-vanadium redox flow batteries type standard cell voltage is 1.26 V. The cell voltagemay be computed using the Nernst equation for a particular temperature, pH value, and vanadium species concentrations:
$E= 1.26\ V - RT/F \ln([VO\ ^{+}]\cdot[V\ ^{+}])/([VO\ ^{+}]\cdot[H^{+}]2\cdot[V_2^{+}])$ 3 2 2
Vanadium ions may permeate the membrane, yielding in self-discharge and undesirable combination of vanadium species on both the sides of the cell, as shown in the diagram. [29]:At the negative electrode:

$$V_2^{+} + VO_2^{+} + 2H^{+} ---> V_3^{+} + H_2O\ 2V_2+ + VO_2+ + 4H+ ---> 3\ V_3^{+} + 2H_2O_2$$

$$V_3+ + VO_2+ ---> 2VO_2^{+}$$

At the positive electrode:

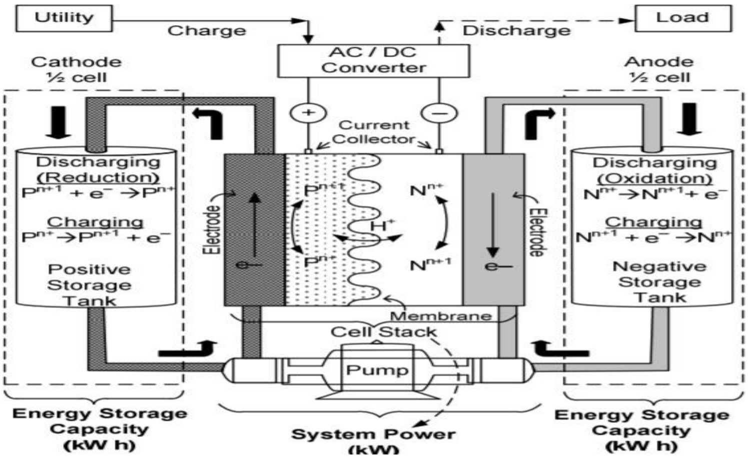
$$V_2^{+} + 2VO_2^{+} + 2H^{+} ---> 3VO_2^{+} + H_2OV_3^{+} + VO_2^{+} ---> 2VO_2^{+}$$

$$V_2^{+} + VO_2^{+} + 2H^{+} ---> 2V_3^{+} + H_2O$$

Various types of vanadium-based flow batteries have been developed over time, including vanadium-vanadium, bromine-polysulfide, iron-chromium, vanadium-bromine, zinc-cerium, zinc-bromine, and soluble lead RFBs. However, as previously mentioned, all flow batteries operate on the same fundamental principles. These flow batteries have a wide range of applications, including their use in electric vehicles, owing to their numerous advantages.

Flow batteries significantly enhance battery management for electric vehicles, offering several benefits such as cost-effectiveness, efficiency, mobility, versatility, and user-friendliness. They are characterized by modularity, portability, and operational flexibility. Moreover, flow batteries maintain the reactants and electrolyte separate (except for the flooded soluble lead RFB, which employs a homogeneous electrolyte). This separation minimizes self-discharge, extends the battery's lifespan, and reduces maintenance and operational costs. In the context of hybrid electric vehicle (HEV) applications, flow batteries offer rapid response from idle and high-rate output performance over a short duration.

A flow battery is an electrochemical energy storage device that enables a significant decoupling of system power and storage capacity. The former is determined by the design and size of the cell stack, while the latter depends on factors such as the size of the storage tanks, the electrolyte's proportion, and the reactant concentration. An ion exchange membrane separates the two electrochemical half-cells, namely the negative and positive half-cells, within the battery. The electrolyte is circulated through the cell stack via a pump. In the case of soluble lead-acid Redox Flow Batteries, a single electrolyte is employed without the need for a membrane.



Generally, RFBs share more similarities with FCs, albeit with a notable distinction. In FC systems, the electrolyte remains confined within the cell stack, whereas in RFB systems, the electrolyte flows across the cell stack to facilitate redox reactions. Recharging an RFB is a swift process involving the replacement of depleted electrolyte solutions with fully charged ones, a procedure that can be carried out at rapid refuelling or recharging stations, akin to traditional gas stations. Moreover, the power output of the system is contingent on the acceleration capabilities of the target vehicle, while the energy storage capacity is contingent on the distance the vehicle can travel.

The capability to decouple the energy and power components of an RFB provides vehicle designers with increased flexibility. Unlike the fixed nature of storage tanks and cell stack physical architecture, designers have the liberty to customize the dimensions of the power and energy components to align with the vehicle's design and fulfil specific performance criteria. For a comparative overview of various battery types, please refer to the table below (taken from [7]).

Types of Batteries	**Equipment's**	**Condition ofElectrolyte**	**Storage of Energy**
Static batteries(Secondary batteries)	Materials of Active Electrode	Held within the cellin static condition	Electrode within the structure could be reversible
Redox FlowBatteries	Aqueous electrolyte withinreservoir	Electrolyte whichflow through the cell	Reversible electrode reactions and Within redox species that re-circulate through the cell
Fuel Cells	Sum of air and liquid or gaseousfuel	Within the cellpolymers of solid andceramic acts as solid electrolyte	non-reversible and Withinreactants externally to the cell

Another crucial aspect to consider is the refuelling or recharging process. Flow battery systems offer an intriguing refuelling method that eliminates the limited range of current batteries and their high costs. This allows electric vehicles (EVs) to compete favourably in terms of pricing. Additionally, they provide a seamless connection to zero-carbon renewable energy sources and make the most efficient use of off- peak base-load grid electricity. With all these positive attributes, if the power density of aqueous electrolytes can be increased, flow batteries could be an excellent solution for addressing EV energy storage requirements, potentially opening up much larger global markets in the future. Flow batteries rely on electrolytes to function, and the introduction of nanofluids in these batteries has been a significant advancement.

Researchers from Argonne National Laboratory and the Illinois Institute of Technology (IIT) collaborated to develop an innovative electrical energy storage system that utilizes nanofluid technology and flow batteries to create a liquid rechargeable battery equivalent in convenience to gasoline. They employed Nano electro fuel, a special liquid containing Nano-scale battery-active particles that can be charged and discharged multiple times within a specialized flow battery cell. This rechargeable Nano electro fuel technology harnesses the unique physical properties of these rechargeable nanoparticles suspended in fluids, resulting in rapid response times, excellent charge/discharge efficiency, and a longer fuel life cycle. Nano electro fuels offer a significantly higher volumetric energy density than traditional redox electrolytes, with a large solid/liquid interface at the Nano scale. These properties enable energy to be stored and distributed using a recoverable nanoparticle material through electrochemical processes, similar to solid-state batteries. Moreover, Nano-sized battery materials have demonstrated much faster discharge/charge rates compared to micron-sized cathode and anode materials. Nano electro fuel technology, with its high-energy-density properties, provides an excellent solution for flow battery systems.

Regarding high-voltage applications, rechargeable semi-flow batteries composed of vanadium-metal hydride have been developed. These batteries use a graphite felt positive electrode and a metal hydride negative electrode, operating in specific electrolytes. These systems offer higher voltage efficiency and energy density compared to traditional all-vanadium redox flow batteries. They eliminate the issues associated with V2+ oxidation, making them more efficient for high-voltage applications.

Now, comparing Li-ion batteries to redox flow batteries:

1. **Cost:** Lithium-ion batteries are relatively expensive to manufacture, making them less cost-effective, especially for mass-produced consumer goods.
2. **Safety Requirements:** Lithium-ion batteries require safety circuitry to prevent overcharging, deep discharge, and excessive current, increasing their complexity.
3. **Aging:** Li-ion batteries degrade over time and with the number of charge-discharge cycles, typically lasting only 500 to 1000 cycles before capacity degradation occurs.
4. **Fragility:** Lithium-ion batteries are not suitable for heavy-duty applications due to their vulnerability to damage.

In contrast, redox flow batteries offer several advantages, including the decoupling of power and energy capacity, longer duration, increased safety, longer asset life, versatility in various temperature conditions, a lower levelized cost of storage, easier monitoring and control, and near-zero time- dependent deterioration.

These characteristics make redox flow batteries a compelling alternative, especially for applications requiring long-duration energy storage.

Type of Battery	$\%\eta_{V}$	$\%\eta_{C}$	$\%\eta_{E}$	WhL^{-1*}	WL^{-1**}	$j/mA\ cm^{2}$
Bromine Polysulphide	75	-	77	20-35	60	60
Vanadium-vanadium	81	90	73	20-35	60-100	60-100
Iron- Chromium	82	-	66	20-35	6	10
Vanadium- Bromine	80	83	-	20-35	50	50
Zinc-/bromine	-	-	80	20-35	40	40
Zinc-cerium	-	83	-	20-35	50	50
Soluble lead acid	-	79	60	20-35	25	25
Conventional lead acid	-	-	68	60-80	230	-
Lithium ion	-	100	80	150-200	275	-
Nickel Metal Hydride	-	-	75	100-150	330	-

The table provided above [taken] offers a comparison between vanadium flow batteries and other conventional flow batteries in terms of voltage, capacity, energy, weight, and power.[40] This comparative analysis clearly demonstrates that flow batteries outperform lithium-ion batteries in terms of performance and various other factors. It's important to note that lithium-ion batteries pose significant environmental hazards. The process of disposing of lithium batteries can be challenging, and not everyone is fully aware of the associated dangers. In light of these considerations, flow batteries emergeas a superior alternative for replacing lithium-ion batteries in a wide range of applications.

5. Conclusion:

The advancements in Battery Management Systems (BMS) for Electric Vehicles represent a significant leap forward in the development of sustainable and efficient electric mobility. The evolution of BMS technology has addressed critical challenges and paved the way for a brighter future in the electric vehicle industry.

The integration of state-of-the-art battery diagnostics, real-time monitoring, thermal management, and predictive maintenance techniques has improved the overall safety, reliability, and performance of electric vehicle batteries. These advancements ensure that EV owners can enjoy longer battery life, greater driving range, and peace of mind regarding their vehicle's safety.

References

[1] Asif Faiz; Christopher S. Weaver; Michael P. Walsh (1996). Air Pollution from Motor Vehicles: Standards and Technologies for Controlling Emissions. World Bank Publications. p. 227, December 2017.

[2] Guarnieri, M. (2012). "Looking back to electric cars". 2012 Third IEEE history of electro-technology conference (HISTELCON). Proc. HISTELCON 2012 – 3rd Region-8 IEEE history of Electro – Technology conference: The Origins of Electro technologies. pp. 1–6

[3] Hendry, Maurice M. Studebaker: One can do a lot of remembering in South Bend. NewAlbany, Indiana: Automobile Quarterly. pp. 228–275. Vol X, 3rd Q, 1972. p231

[4] Electric vehicle sales in India grow 240% in December 2021: Report. By HT Auto Desk.

[5] C. C. Chan and K. T. Chau, "Electric vehicle technology—An overview of present status and future trends in Asia and Pacific areas," in Proc. Int. Electric Vehicle Symp.,1992, no. 1.02.

[6] M. J. Riezenman, "Electric vehicles," IEEE Spectrum, vol. 29, no. 11, pp. 18–21, 1992.

[7] C. C. Chan, "An overview of electric vehicle technology," Proc. IEEE, vol. 81, pp. 1202–1213, Sept. 1993

[8] D. Woodruff, L. Armstrong, and J. Carey, "Electric cars," Int. Bus. Week, pp. 36–40, May 30, 1994.

[9] W. W. Burns, III, "Power electronics—Keeping pace with society," IEEE Trans. PowerElectron., vol. PE-1, pp. 1–2, 1986

[10] M. Nishihara, "Power electronics diversity," in Proc. Int. Power Electronics Conf., 1990, pp. 21–28

[11] "Front Matter". In: Electric Vehicle Technology Explained by James Larminie Oxford Brookes University, Oxford, UK John Lowry Acenti Designs Ltd., UK. 2.6.3 The lithium ion battery page 45

[12] A retrospective on lithium-ion batteries: Jing Xie1 & Yi-Chun Lu. NatureCommunications volume 11, 2020.

[13] Godshall, N.A.; Raistrick, I.D.; Huggins, R.A. (1980). "Thermodynamic investigations of ternary lithium-transition metal-oxygen cathode materials". Materials Research Bulletin.

[14] Godshall, Ned A. (18 May 1980) Electrochemical and Thermodynamic Investigation of Ternary Lithium-Transition Metal-Oxygen Cathode Materials for Lithium Batteries.
Ph.D. Dissertation, Stanford University

[15] "goodenough"&Refine=Refine+Search&Refine=Refine+Search&Query=in%2F"good enough,+john" "USPTO search for inventions by "Goodenough, John"". Patft.uspto.gov. Retrieved 8 October 2011.

[16] Mizushima, K.; Jones, P. C.; Wiseman, P. J.; Goodenough, J. B. (1980). "LixCoO 2(0<x<-1): A new cathode material for batteries of high energy density". Materials Research Bulletin.

[17] Lets talk science :Becky Chapman September 23, 2019.https://letstalkscience.ca/educational-resources/stem-in-context/how-does-a-lithium- ion-battery-work

[18] A retrospective on lithium-ion batteries Jing Xie1 & Yi-Chun Lu. NatureCommunications volume 11.

[19] Institute for Electrical Energy Storage Technology ,TUM Department of Electrical and Computer Engineering, Technical University of Munich.

[20] Suppression of dendrite growth by cross-flow in microfluidics :MEGHANN

C. MA, GAOJIN LI, XINYE CHENLYNDEN A. ARCHER AND JIANDI WAN. SCIENCE ADVANCES • 19 Feb 2021 • Vol 7, Issue 8.

[21] SOUTH WEST ELECTRONICS ENERGY CORP.

[22] CLEAN ENERGY INSTITUTE . UNIVERSITY OF WASHINGTON ;

[23] GRE POW RECHARGABLE BATTERY : High Voltage Lithium Battery Cell - Highest Energy Density (grepow.com)

[24] Zhang, X. Y.; Winget, B.; Doeff, M.; Evans, J. W.; Devine, T. M. Corrosion of Aluminum Current Collectors in Lithium-Ion Batteries with Electrolytes Containing LiPF6. J. Electrochem. Soc. 2005, 152, B448– B454,

[25] Ma, T. Y.; Xu, G. L.; Li, Y.; Wang, L.; He, X. M.; Zheng, J. M.; Liu, J.; Engelhard, M.H.; Zapol, P.; Curtiss, L. A.; Jorne, J.; Amine, K.; Chen, Z. H. Revisiting the Corrosion of the Aluminum Current Collector in Lithium-Ion Batteries. J. Phys. Chem. Lett. 2017, 8, 1072– 1077,

[26] Overcoming the High-Voltage Limitations of Li-Ion Batteries Using a Titanium Nitride Current Collector :Shutao Wang, Kostiantyn V. Kravchyk, Alejandro N. Filippin ,Roland Widmer ,Ayodhya N. Tiwari, Stephan Buecheler ,Maryna I. Bodnarchuk and Maksym V. Kovalenko

[27] Shifting to 800-volt systems: Why boosting motor power could be the key to better electric cars. 15 February 2021 by David Jolley. Shifting to 800-volt systems: Why boosting motor power could be the key to better electric cars (youris.com)

[28] Laurence Knight (14 June 2014). "Vanadium: The metal that may soon be powering your neighbourhood". BBC. Retrieved 2 March 2015

[29] Tang A, Bao J, Skyllas-Kazacos M. Thermal modelling of battery configuration and self-discharge reactions in vanadium redox flow battery. Journal of Power Sources. 2012;216:489–501.

[30] C. Ponce-de-León, A. Frías-Ferrer, J. González-García, D. A.Szánto, and F. C. Walsh, "Redox flow cells for energy conversion," Journal of Power Sources, vol. 160, pp. 716-732, 2006.

[31] M. Skyllas-Kazacos, "Novel vanadium chloride/polyhalide redox flow battery," Journal of Power Sources, vol. 124, pp. 299-302, 2003.

[32] T. Shigematsu, T. Kumamoto, H. Deguchi, and T. Hara, "Applications of a vanadium redox-flow battery to maintain power quality " Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES, vol. 2, pp. 1065- 1070.

[33] N. Tokuda, T. Kanno, T. Hara, T. Shigematsu, Y Tsutsui, A. Ikeuchi, T Itou, and T. Kumamoto., "Development of redox flow battery system," SEI Technical Review June2000, vol. No. 50, pp. 88-94, 2000.

[34] Integration of flow batteries into electric vehicles: Feasibility and the future : Carlo U Segre , John Katsoudas and Elena V. Timofeeva . Conference: TechConnect World 2014, NSTI Innovation Conference and Expo At: Washington, DC, June 15-18, 2014 Volume: Nanotech 2014: Electronics, Manufacturing, Environment, Energy & Water,
Vol.3, pp. 435-437

[35] N. Meethong, H. Huang, et.al., Electrochem. Solid State Lett.,10, A134 (2007).

[36] C. Menictas, M. Skyllas-Kazacos, J. Appl. Electrochem. 41 (2011) 1223-1232

[37] M. Skyllas-Kazacos, F. Grossmith, J. Electrochem. Soc. 134 (1987) 2950-2953.

[38] M. Skyllas-Kazacos, M. Rychick, R.G. Robins, US Patent 4,786,567 (1988).

[39] Weng, G. M., Li, C. Y. V., & Chan, K. Y. (2013). High voltage vanadium-metal hydride rechargeable semi-flow battery. Journal of The Electrochemical Society, 160(9), A1384-A1389.

[40] Redox Flow Batteries for Hybrid Electric Vehicles: Progress and Challenges Mohd R. Mohamed1,2, Graduate Member, IEEE, Suleiman M. Sharkh3 and Frank C. Walsh4 Energy Technologies Research Group, School of Engineering Sciences, University of Southampton, High field, Southampton SO17 1BJ, UK.